PALEOVEGETATION RECONSTRUCTION FROM SOIL PHYTOLITHS OF A CEREMONIAL SITE COMPLEX AT *MAOK-SKOISTCH* ON THE RED DEER RIVER, ALBERTA, CANADA

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ABSTRACT

Maok-skoistch (Nitsitapii for Sacred Red Rock Place) is in the dry mixed grasslands of southwestern Alberta. It sits on a horseshoe bend of the Red Deer River approximately 40 kilometers from its confluence with the South Saskatchewan River. This area contains numerous stone constructions associated with First Nations groups and their ancestors. The purpose of this study is to investigate the paleovegetation of this area to understand local and regional environmental changes. A secondary purpose is to try to detect human influence on paleovegetation.

I used phytoliths extracted from two sediment columns and the modern surface as a vegetational and environmental proxy. A sediment column extracted from a depression, or slough, on the upland prairie begins circa 5700 cal BP and provides data on the regional paleovegetation. A second column from a wooded riparian coulee in the river valley (a micro-environment) begins circa 3440 cal BP and records local vegetational changes. There is little available literature on phytoliths of the Canadian Prairies, to say nothing of the micro-environments within the region such as riparian coulees. I created a morphotype reference collection from the available relevant literature on grassland and forest phytolith assemblages. I detail how I developed a phytolith extraction protocol tailored to the sampled sediments, including the pitfalls I encountered. This section may be of use to those who have not extracted phytoliths before. I used environmental index formulae to investigate paleovegetational dynamics. I used Principal Components Analysis to find similar assemblages and to compare them to modern surface assemblages.

The paleovegetation at the upland slough conforms to the synoptic record of environmental changes. I found the river valley coulee paleovegetation responds most strongly to local conditions. Soil moisture appears to be the strongest factor in paleovegetational changes. Interestingly, the coulee record may be responsive to precipitation and glacial meltwater changes in the Rockies where the Red Deer River begins. The phytolith knowledge base in the Canadian Prairies is not robust enough yet to achieve the resolution necessary to detect human influences on paleovegetation. I outline some ideas and avenues for future research to remedy this situation.

ACKNOWLEDGEMENTS

I would like to thank my thesis supervisor, Glenn Stuart, for all his kind help and guidance in shepherding this thesis to completion. Thanks to my committee members, Margaret Kennedy for helping create this project as an adjunct to her own and expanding my theoretical horizons, and Ernie Walker for his feedback, experience, and, of course, the Texas connection. Thanks to Barney Reeves, who first broached the idea of human modifications to the local vegetation and suggested a plant microfossil analysis. Thanks to Cathy Linowski for sharing her botanical knowledge. Thank you to Katie Burdeyney for sharing her knowledge and experience extracting phytoliths. A big thanks to the Saskatchewan Association of Professional Archaeologists and the Anthropology Research Trust Fund for their financial support. Last but not least, thanks to Gabe LaMarche for being a friend and giving me an excuse to get out of the lab for Friday Afternoon Knap Time.

DEDICATION

I would like to dedicate this thesis first and foremost to my wife, Christina Kubenka; to my parents, Roy Larsen and Victoria Mason; and to Reggie, Lucy, Emmet, and Dudley. Without your love and support I would never have completed this endeavor.

I would also like to dedicate this thesis to all the nations, human and non-human, past, present, and future, that inhabit and continuously create *maok-skoistch* and all places. A desire to understand them motivates our research. Respect for and responsibility to them guide our actions. The one leads to the other.

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Introduction

1.1 The phenomenology of a prairie bluff

Standing on the prairie bluff, a wild pink flower near your feet betrays the small barrel cactus nestled snugly among the low tufts of green and blue grasses that spread to the horizon. The prairie extends out behind you and to your sides in low rolling hummocks interspersed with the occasional darker green bowl of a slough. The deeper sloughs are lined with snowberry and the occasional head-high silver buffaloberry. Short silvery green scraggles of salt sage and winterfat and cheerful clusters of small yellow and white flowers dot the low rolling earth or nestle in the spaces between stones.

The stones are scattered everywhere. The stones are fists, are heads, are hibernating bears without a den, are great bison in repose. They are ice-smooth and lizard-rough. The stones have a lithic cambium of pink or white or black, glimpsed through gaps in the thin, peeling bark of olive gray, mint green and rusty orange lichens. Patterns emerge in the stones, long lines of small boulders, low cobbled rectangles, tight empty circles, U-arcs, sinewy granitic serpentines. At the crest of a hill a pronghorn and her fawn bounce away from behind a low, round eruption of boulders, a cairn surrounded by a wide dance circle of cobbles, half-hidden in the grass, pierced by long spokes pointing in directions known only by their creators. Out of the corner of your eye you can almost see the ancestors (maybe your ancestors, maybe not) working together, singing, sometimes solemn and other times laughing, guided by Elders or Bundle keepers, guided by dreams, moving the stones into place.

Standing on the prairie bluff, the river bends wildly through the wide valley far below your feet. Creases in the prairie begin just before the bluffs drop away, their slopes marked by low, gray-green, woody shoots of wolf willow and the bright yellow eyes tucked into the pink and white frills of prairie rose flowers, their stems the thorny woe of the unwary shin. The creases expand quickly into deep angular coulees, their sides terraced by criss-cross trails carved by pronghorn and mule deer. The coulees tumble down the bluffs, shaggy and green with willow, cottonwood, and maple, snowberry, buffaloberry and saskatoon, before diving into the long, bright, silver horseshoe of the river below. In the coulees, water seeps out from the prairie, flows under the earth, and feeds grasses, sedges, cattails, timothy, mint, licorice, berries, and trees. Where the water slows, gathers, and dallies, fens develop, wobbly under the traveler's foot. Approaching the river, the time-worn folds and barrows of the bluffs settle into long, gentle slopes of alluvial plains and low, river-incised terraces. Outcrops of sandstone poke out from the colluvium of the bluffs, the blood red of iron causing them to glow sanguine in the dawn sunlight.

Down in the valley, sprawling herds of bison graze or rest or roll in the dust. Calves prance, see-sawing around their mothers, and yearlings playfully butt heads. Occasionally, a low bass grunt or the grassy-earthy scent of manure is carried up to you on the breeze. A great mass of woolly black specks, milling slowly, experienced solely by the senses of the mind.

Standing on the prairie bluff, above you is only blue sky, an unending space. You feel naked, unprotected, exposed to the universe, completely subject to its forces and its wildness. The sun warms your skin, fills your body, infuses you until you feel that you have also become a small sun. A child of the sun. Filled with an internal energy, a warmth that shines out of your body. The wind whips at your clothes, your hair. It snatches at your hat, the paper you are writing on, empty sandwich wrappers, anything it can snap up and play with. A long-billed curlew standing on a pink glacial erratic laughs as you run and scramble to retrieve your suddenly animated, errant items. Almost without you noticing, the sky turns a deep pelagic blue and dark slate clouds gather on the horizon. The clouds approach slowly, dallying in the distance for what seems like hours. The rain drapes lazily down from the clouds, silver curtains hanging in the air. The smells of grass and wet earth move with the wind and you turn your face to meet them.

And then, in a flash, you're cold to your bones.

A few drops of rain fall, moving slower than they should. The drops are fat, heavy, and cold as ice. In an instant, the air becomes water.

But before you can move, before you race for shelter, the deluge abates. The silver curtain has moved past you, as quickly as it arrived. In its wake you are wrapped in a gentle mist, just floating in the air around you, dancing in golden sunbeams, soft as rabbit fur, warm as your mother's embrace. And the rain is gone, grumbling into the distance. And the sky is prairie flax flowers and cottonwood fluff again.

To stand on the prairie bluff – alive, humble, open to the world, open to the past – is to feel your relationships to the earth and the sky, the wind and the river, the grass and the bison, the shrubs and the pronghorn, the trees and the birds, the rocks and the lizards. To feel your place in the living world, always unfolding, expressing itself in ways novel and familiar. To feel your responsibility to give the world life as it gives you life. As it gave life to the ancestors, gone but still present, who gave the world to you. And if you watch and listen and smell and taste and feel, if you understand the relationships among the ancestors, the beings, and the forces in the world, you can learn how to fulfill your responsibilities and to give again the gift that is given to you.

Figure 1.1: View from the upland prairie bluff looking south onto the Red Deer River Valley at maok-skoistch, the Sacred Red Rock Place.

1.2 Introduction

The place the Nitsitapii (the Blackfoot confederacy) call *maok-skoistch*, the Sacred Red Rock Place (Reeves and Kennedy 2017:2), is an amazing location where water, earth, and sky come together (Figure 1.1). In such a place it is easy to become romantic and feel there is a power living there. To imagine the past and to dream it while awake. The preceding section, in the spirit of feminist archaeology (Spector 1993) and phenomenology (Tilley 2008; Tilley and Bennett 2001), is an account of what it feels like for me, as a human, to stand on the bluffs above the Red Deer River Valley. To stand surrounded by grass and stones and to try to imagine how a person in the past may have experienced the location. Though slightly poeticized, everything in this account is based on my personal experiences and observations of the location, and my research into the ecology, archaeology, and ethnobotany of the location, as well as the ethnographies and anthropology of Indigenous ontologies, epistemologies, and ecological practices of regional First Nations. All of which I address in the following chapters. I did not insert the cultural traditions and understanding of any First Nation but tried to capture the ontological view of a human as part of the living world, one being among many, subject to forces as alive as any physical being. Certainly, a person standing there 1,000 or 5,000, or 8,000 years ago would not have seen, felt, and understood the location in exactly the same way as me or even each other but there may be some underlying thread of human connection between all of us. The presence of so many stone constructions certainly suggest this is so. Perhaps it is the expansiveness in all directions, the connection of water, earth, and sky and the feeling of being both under the sky and above the earth, the feeling of being in the middle.

There is another word, a shorter name, for the confluence of water, earth, and sky and that word is *plant*. It is through plant remains that I hope to learn about the past. Leaving behind the phenomenological and turning to the realm of the empirical, the purpose of this thesis is to reconstruct the paleovegetation in the study area by analysing phytoliths extracted from sediment columns. The primary goal of this project is to gain insight, through an understanding of vegetation changes, into the past environment of this area and changes to that environment. As vegetation is the foundation for animal life, understanding the vegetation in a time and place also allows us to make inferences about the animal component. As archaeologists, understanding the environment, the floral and faunal world which humans both inhabit and help create, helps us comprehend past human behaviours and make inferences from the cultural materials we study.

The secondary goal of this study is to examine whether there is any evidence of potential human impact on the vegetation, and hence the ecosystem, specifically an increased abundance, relative to other flora, of plant species and communities beneficial to human lifeways.

The significance of this project lies in the fact that most paleoenvironmental research in the area has used pollen from lacustrine settings as a proxy rather than phytoliths (Strong and Hills 2005; Yansa 2007). Pollen is a well-established paleoenvironmental proxy that provides a strong signal of regional vegetation and preserves in the anaerobic conditions of lake sediments (Pearsall 2015). Phytoliths preserve better under a wider array of conditions (Karkanas 2010) and have the potential to provide better data on local and even hyperlocal vegetation than pollen (Piperno 1988). Phytolith research is well-established in many locations, especially the tropics, but phytoliths have only been used in a few studies in the Prairie Provinces of Canada (Strömberg 2004).

The decision to investigate vegetation within a river valley coulee, a micro-environment within the prairie region, is another significant aspect of this project. Micro-environments and marginal environments (on the edges of the dominant environment) may be more sensitive to – and thus provide better signals of – environmental changes than the surrounding dominant vegetation regime. To my knowledge, this is the first study of phytoliths in a riparian coulee environment in a prairie grassland region, although a fellow graduate student recently completed a study of phytoliths in archaeological sediments from a similar environment on the outskirts of Saskatoon, Saskatchewan in the aspen-parkland (Burdeyney 2019).

1.3 Location

The study area (Figure 1.2) is in southeastern Alberta, Canada, and straddles Municipal District of Acadia No. 34 and Special Area No. 3 where they come together and border Special Area No. 2 across the Red Deer River. The location is on the left bank of the Red Deer River Valley, 30km west of the Saskatchewan border and 220km north of the United States border. The study area sits in the Grassland Natural Region (Downing and Pettapiece 2006) and is 140km north of the Cypress Hills and 320km east of the Front Range of the Rocky Mountains, near Calgary.

Much of the area remains Crown lands and unplowed native prairie or rangelands. Because of this, many archaeological sites and stone constructions created by First Nations peoples prior to European settlement remain intact on these lands. The extensive stone features at the study area constitute a number of archaeological sites, which collectively form the Minor Medicine Wheel Ceremonial Site Complex.

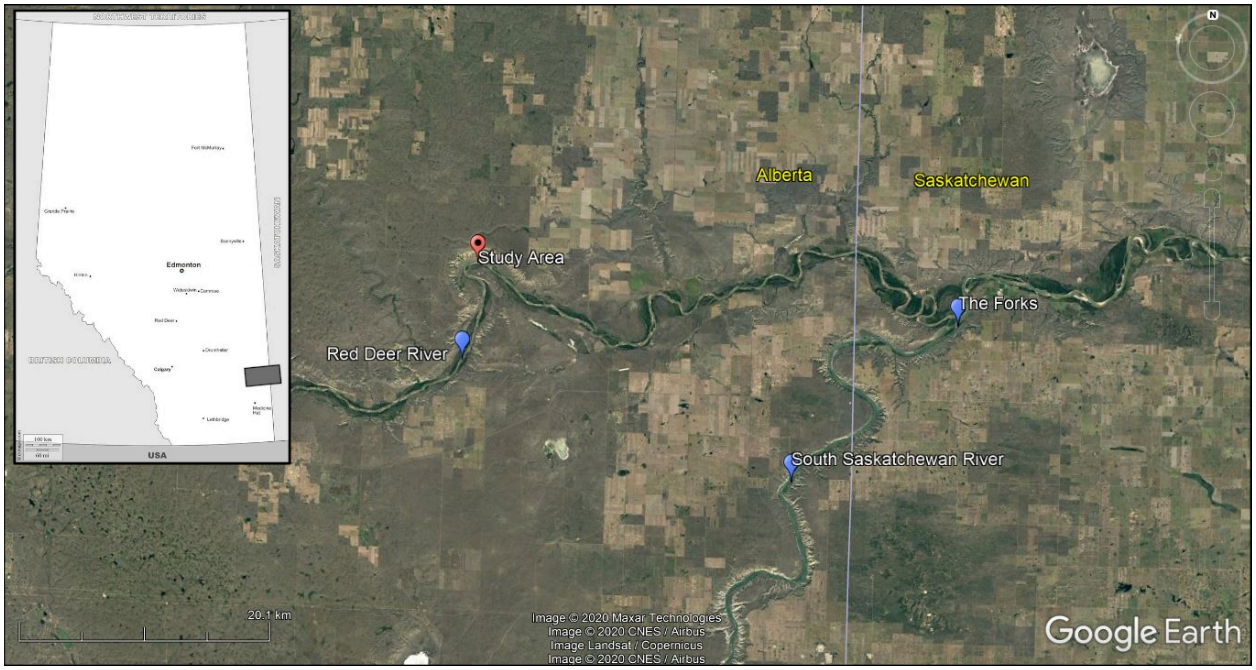


Figure 1.2: Location and aerial view of study area.

1.4 Project origin

The Minor Medicine Wheel Ceremonial Site Complex sits on prairie level bluffs overlooking a large horseshoe bend in the Red Deer River, approximately 40km upstream from its confluence with the South Saskatchewan River, known as the Forks. The site complex is named for the three medicine wheels, two of which are only 120 m apart, located on land ranched by the Minor family in the twentieth century. This site appears to have been ceremonially significant to the people who lived in the area, as evidenced by the over 2000 stone features (Figure 1.3) present, such as medicine wheels, cairns, lines, and rings (Reeves and Kennedy 2017).

The Nitsitapii name for the location is *maok-skoistch*, Sacred Red Rock Place, due to the red color imparted by iron oxide to the sideritic sandstone (Figure 1.4) which glows red in the dawn sunshine and can be seen from as far away as the Forks (Reeves and Kennedy 2017:2). To foreground First Nations as much as possible in this thesis, I will refer to the study area as *maok-skoistch* rather than as the Minor Medicine Wheel Ceremonial Site Complex. Besides being much shorter, *maok-skoistch* accords better with the fact I am investigating the environment of the area rather than the archaeological sites.

Figure 1.3: Stone constructions; left, Minor medicine wheel no. 3 central cairn; right, erratic cairn.

Figure 1.4 Sideritic sandstone; left, red iron oxide in a weathered sandstone outcrop; right, three sandstone outcrops.

There are a number of springs, seeps (Figure 1.5), and slope fens in the coulees at this location. Slope fens are areas on slopes where local topography and non-permeable subsoils or bedrock conspire to collect and retain water. The lower coulees and fens support small riparian zones of trees and shrubs (Adams 1976) and may have attracted people to this area. Furthermore, consulting botanist, Dr. Cathy Linowski (personal communication 2017), noted the presence or species composition of some vegetation in this part of the river valley appears atypical, potentially signalling an anthropogenic influence.

Figure 1.5: Seep line in valley wall.

Maok-skoistch is in the known historical territories of the Gros Ventre and Blackfoot First Nations and potentially occupied for a time by a Shoshoni group (Brink 1986). The area was first intensively surveyed in 1975 and 1976 by a team headed by Gary Adams for the Archaeological Survey of Alberta. Adams' (1976) report is currently the only substantive work dealing with the survey area. This survey focuses on classifying sites based on features, landforms, and environmental zones. It has a heavy emphasis on attempting to discover resource maximization in settlement patterns.

Site descriptions are spare, and the stone features are examined in isolation rather than seeking relationships between them or to the landscape. While Adams observed materials dating as far back as the Late Paleoindian Cody complex of the Early Precontact Period, the majority of material was identified as being from the Old Women's phase of the Late Precontact and Protohistoric Periods, and which has been associated with the Nitsitapii (Nicholson et al. 2011).

Two more reports, one by Quigg and one by Adams, both published in 1978, are likewise preliminary reports of ring sites and confine themselves to relatively basic descriptions and analysis. The previously referenced publication by Brink (1986) investigates the geographic ranges of several First Nations at the time of contact with Europeans (ca. 1700 CE) on the Plains. Brumley (1988) creates a medicine wheel typology and classifies Minor medicine wheels 2 and 3 as subgroup 1 and Minor medicine wheel 1 as subgroup 7.

After visiting the area in 2012, Dr. Margaret Kennedy, of the University of Saskatchewan, and Dr. Brian Reeves, of the University of Calgary, conducted an intensive, ongoing, multi-year, inventory survey (Reeves and Kennedy 2017). This survey takes a holistic landscape archaeology approach, using GPS and GIS to investigate connections among and between the individual stone constructions and notable features in the landscape.

1.5 Research design

This thesis is an outgrowth of the landscape archaeology project of Kennedy and Reeves. Originally, I was hoping to investigate phytoliths extracted from small sediment samples collected from various stone features but the First Nations we consulted did not want us to disturb the stones here. Instead, we decided to investigate the local paleoenvironment using phytoliths as proxies.

1.5.1 Phytoliths

Phytoliths (Figure 1.6) are opal silica bodies formed in the cells of plants. The silica enters through groundwater and accumulates in specific silica accreting structures or between cells. Plants use silica for various functions, such as increasing structural rigidity. When a plant dies and the organic tissues have decomposed, the inorganic opal silica phytoliths remain and can retain the shapes of plant cells, enabling plant identification. Phytoliths are often superior to pollen when identifying plants in a grassland setting because grass phytoliths can be identified to the sub-family level and occasionally even down to the species level, whereas grass pollen can often only be identified to the family (Fredlund and Tieszen 1994, Pearsall 2015).

When a plant decays or burns, phytoliths are released into the sediment. Phytolith movement depends on the sediment and sediment transport mechanisms. If the sediments move, through wind, water, or gravity, then phytoliths move with them. In dynamic environments, phytoliths can move kilometers away from their source (Fredlund and Tieszen 1994) or in a static environment they can stay within 20 m of their source (Piperno 1988). If the sediment source can be located, then the phytolith source can be located too.

Phytoliths, due to their inorganic nature, preserve well under a variety of conditions. Phytolith dissolution is related to soil alkalinity and water flow. Phytoliths break down rapidly when there is an alkaline environment with a pH higher than 9 (the pH of baking soda) but can dissolve in a pH between 4 and 8 when there is high water flow in the sediments (Karkanas 2010). Therefore, except under these specific circumstances, phytoliths have a high probability of preserving for long periods of time. Strömberg (2002), for example, was able to extract phytoliths from sediments of the North American Great Plains dating to the Oligocene, ca. 25 million years BP.

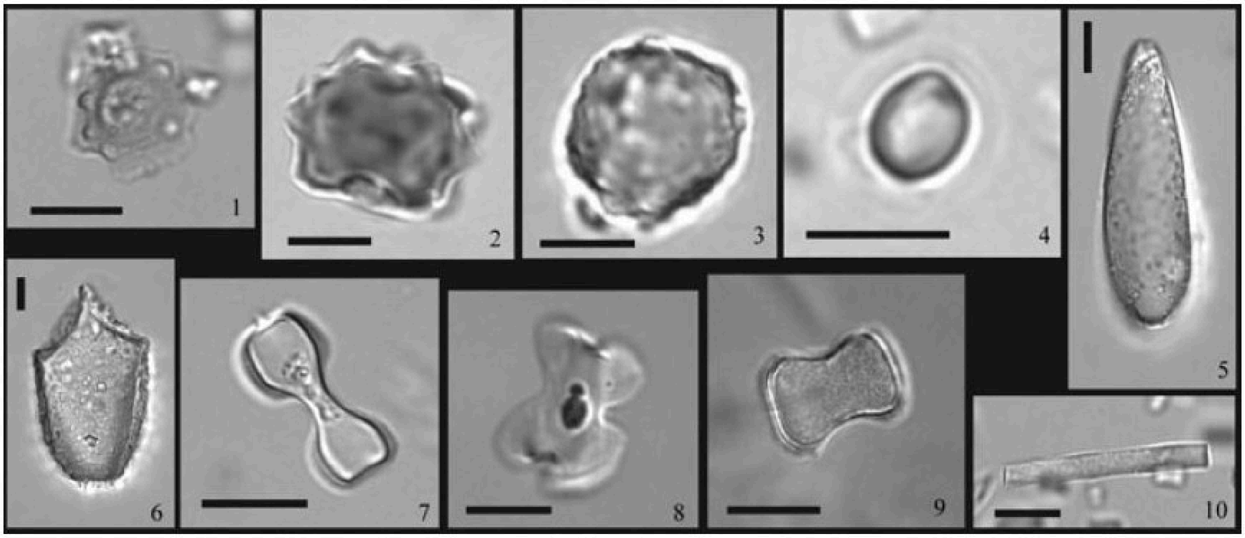


Figure 1.6: A variety of phytoliths; scale bar = 10µm (adapted from Bremond, Alexandre, Peyron, and Guiot 2005:317, Figure 2).

1.5.2 Slope fens

Reeves and Kennedy (personal communication 2017) noted the presence of slope fens, which they thought might make good sampling sites. We decided to investigate them as potential sampling sites. If they contained consolidated sediments, then they would be good candidates. If they were too water-logged, then we might encounter preservation issues (if the sediments are too alkaline) and collection and contamination issues, as our sampling device was not suited for loose, unconsolidated sediments.

1.5.3 Steps in the process

The project had three phases, field, laboratory, and analysis. The field phase consisted of finding suitable locations to sample and collecting the samples, as well as a consultation in the field with Dr. Cathy Linowski, a biologist at Medicine Hat College, to identify plant species and communities. In the laboratory phase, I created a sub-sampling system, prepared the sub-samples for phytolith extraction, collected material for radiocarbon dating, extracted phytoliths, and analysed the samples under a microscope. In the analysis phase, I used various formulae and statistical analyses to interpret the data. All steps of the research are described in detail in chapter 4.

1.6 Theoretical position

In this study, I take the theoretical position of the "New Ecology", as described by Oetelaar and Oetelaar (2007). I explore the New Ecological position in more detail in chapter 3, but, in brief, the New Ecology states that humans, like all organisms, are important and integral members of their ecosystem, without whom the ecosystem would be wholly different in more or less subtle ways. "New" is something of a misnomer, as this ecology incorporates into the scientific framework a very old worldview held by many, if not most, Indigenous cultures (Hernandez 1999).

The "Old Ecology", i.e., the traditional scientific ecology as described by Oetelaar and Oetelaar, often begins from the position that nature exists separated from humans. And humans, specifically humans of non-agricultural societies, move through nature without any measurable effect. In some ways, this is the position taken by most paleoenvironmental studies. These studies examine a proxy or proxies, such as pollen, phytoliths, or diatoms, to infer past climates, moisture regimes, water levels, or vegetation types. Humans are usually assumed to have no effect, even when they are known to have inhabited the area. In fact, animal-plant interactions of all sorts are generally ignored.

What the New Ecology points out to the Old Ecology, is that, in places and times in which humans have lived, humans are present in the ecological or environmental studies, but their presence is just not recognized. The reasons anthropogenic effects were not previously recognized are, first and foremost, they were not looked for, and secondly, the methods or the data may not supply the necessary resolution.

In this study, I try to explore the articulation of human behaviours in the environment whenever I can. What I found, for the most part, is the methods need refinement specific to the Canadian Prairies and research needs to be designed specifically to identify the human element.

1.7 Organization of the thesis

In the following chapters, I present the environmental and cultural background of the study area, describe how I performed this study, present and interpret the results of my research, discuss how this study articulates with previous research and what it indicates for future research.

In chapter 2, Environmental Context, I describe the modern environmental context of the study area. The environmental context includes the geology, topography, and soils of the area, as well as the geomorphology of the Red Deer River Valley. It also includes the climate, precipitation, and hydrology, and the floral and faunal populations.

In chapter 3, Paleoenvironments and Cultural Ecosystems, I compare different ecological theoretical frameworks of how humans interact with their environment, including traditional scientific ecology, new scientific ecology, and indigenous ecology. I describe how indigenous peoples have implemented knowledge of their environment to increase abundance and diversity in the environment, with some examples from Canadian First Nations. I move through time, beginning in the Pleistocene, integrating paleoenvironmental data from research conducted near the study area and the material cultures of the region during each environmental regime. I then combine environmental, archaeological, and ethnographic information to speculate on how humans may have been utilizing their ecological knowledge in the past.

In chapter 4, Methods and Methodologies, I discuss the methodologies for each step of the research from sampling in the field, to extracting phytoliths from the sediments, to recording phytolith observations under the microscope and analysing the data. I found, as a phytolith neophyte, that following published methodologies was helpful as a broad guide but creating a successful protocol particular to the region and sediments I studied was a process of trial and error. I believe it is important to communicate this to other beginning researchers, which is why I provide a rather detailed account of the experimentation, adaptation, missteps, and learning opportunities I experienced during the research process.

In chapter 5, Results, I present the results of the analyses. I describe the sediments we collected and present the radiocarbon dates I obtained from them. I report the morphotypes I observed as well as other biogenic silica bodies present in the samples. I state whether I observed any indicator morphotypes and the results of the environmental index formulae I used. I describe how morphotypes, indicator types, and environmental indices trend over time. I present the results of the principal components analyses and draw some conclusions at the end of the chapter.

In chapter 6, Discussion, I integrate my paleoenvironmental results into the regional framework comprising the research I surveyed in chapter 4. I interpret the results of this study based on that regional framework, as well as the particularities of the local environment in the study area. I found that the two sampling column locations may measure different environmental factors. I also detail issues and difficulties I experienced during the course of my research and describe directions for future research to grapple with the issues and create better environmental interpretations using phytoliths as a proxy.

In Chapter 7, Conclusion, I provide a brief summary of the project and the results, and I assess how well I met the goals I set out for this project.

Chapter 2
Environmental Context

Maok-skoistch is situated in southeastern Alberta in a horseshoe bend of the Red Deer River approximately 39km west, as the crow flies, or 56km upstream, following the river channel, from its confluence with the South Saskatchewan River (Figure 1.2). The area I investigated for environmental data (Figure 2.1) is an 8km stretch along the left bank with an average width of 1.3km, bounded by the riverbank on one side and, on the other, by the gravel road on the upland prairie which parallels the curve of the river.

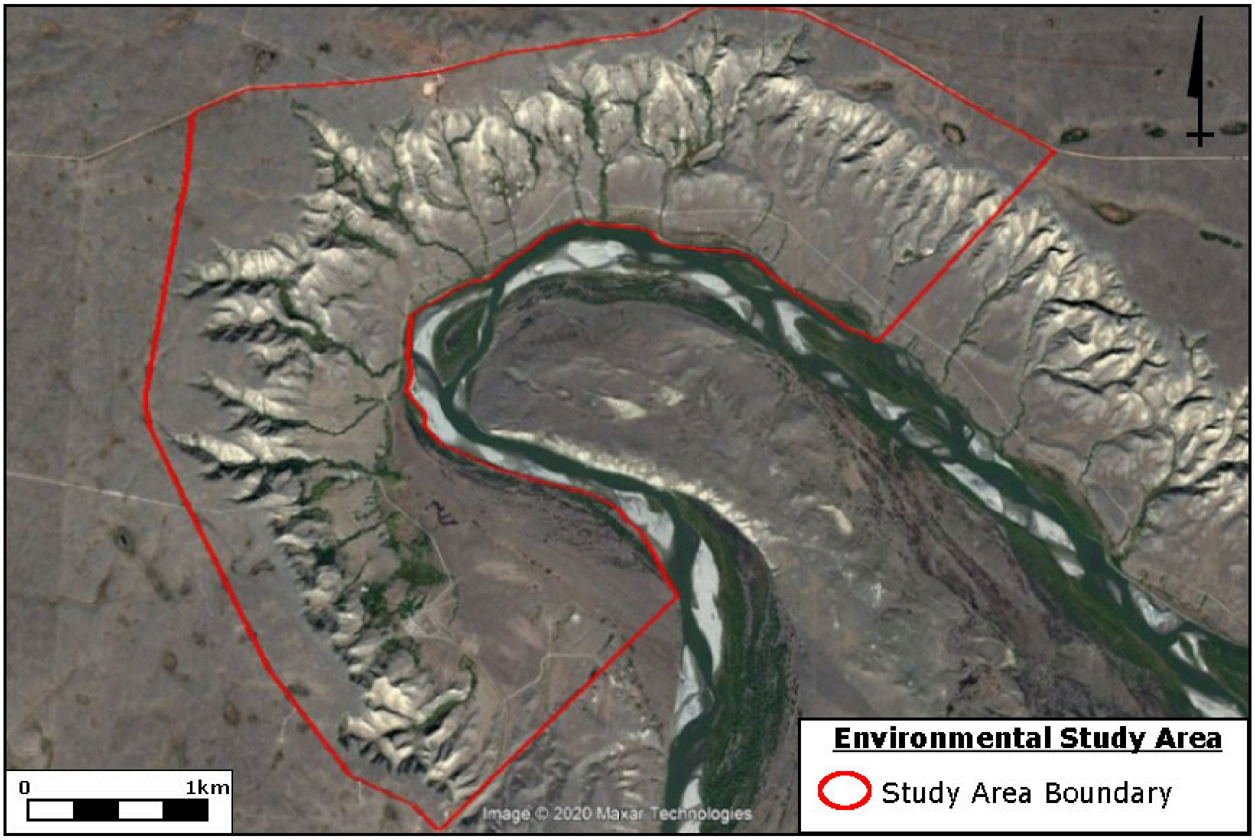


Figure 2.1: Area of investigation.

The study area is in the Dry Mixedgrass Natural Subregion (Figure 2.2) of the Grassland Natural Region of Alberta (Downing and Pettapiece 2006). The Grassland Natural Region of Alberta is the northernmost extension of the North American Great Plains, which extends from Mexico into

Canada to roughly 53° North latitude. In Canada, the Grassland Natural Region extends from the Rocky Mountains in the west to southeastern Manitoba in the east.

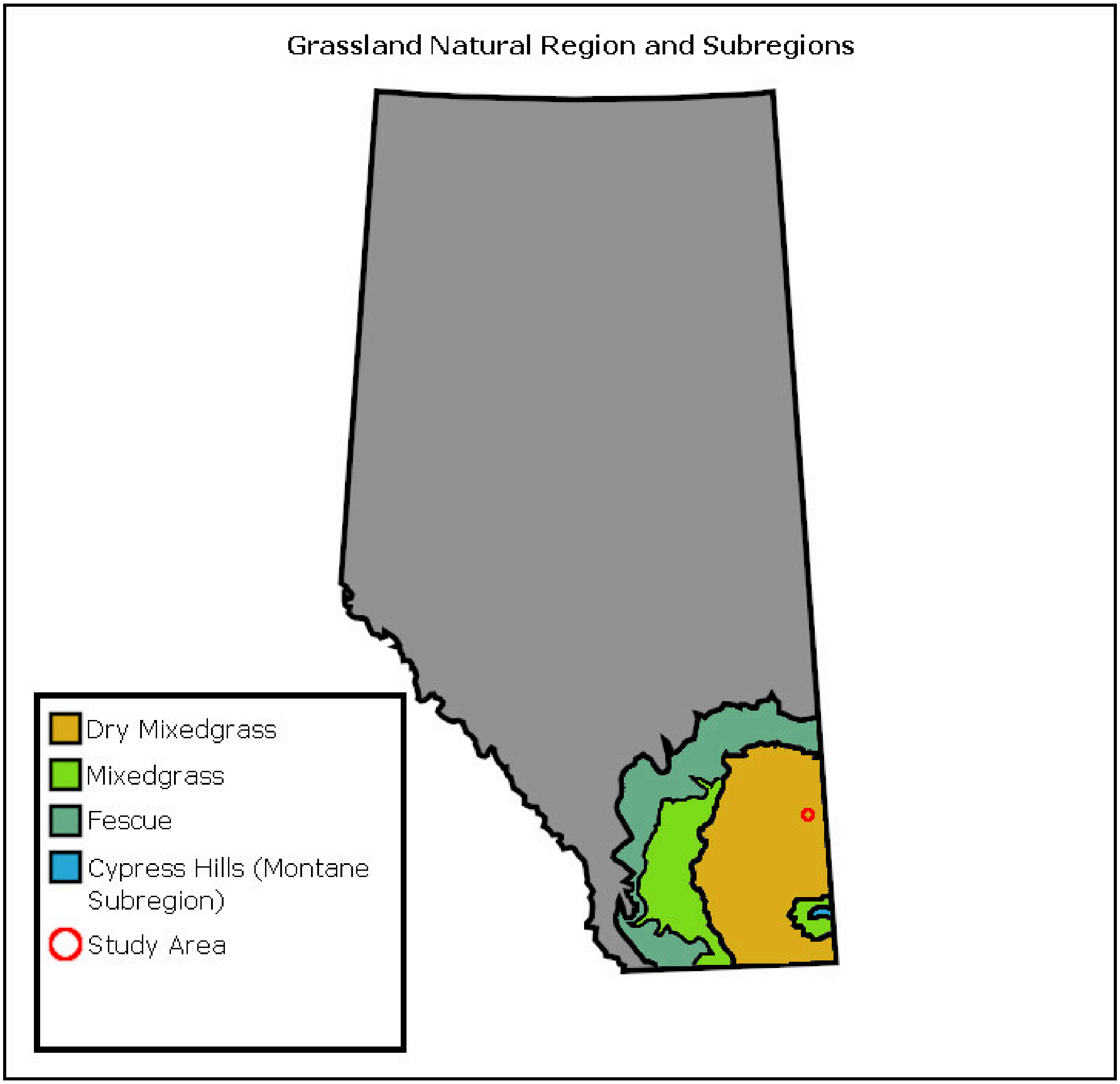


Figure 2.2: Grassland Natural Region, including Subregions; Cypress Hills are a Montane Subregion outlier within the Grassland Natural Region.

2.1 Geology

The bedrock surface at and near the study site (Figure 2.3) are all Upper Cretaceous formations and of the Belly River group, except the oldest bedrock surface of the Lea Park formation (Prior et al. 2013). The formations were laid down in the late Cretaceous between ca. 74 and 84 million years ago (Cullen and Evans 2016; Eberth 1990; Payenberg et al. 2002) and reflect changes at the margin of the Western Interior Seaway, the shallow sea that extended across what is now North America from Canada to the Gulf of Mexico.

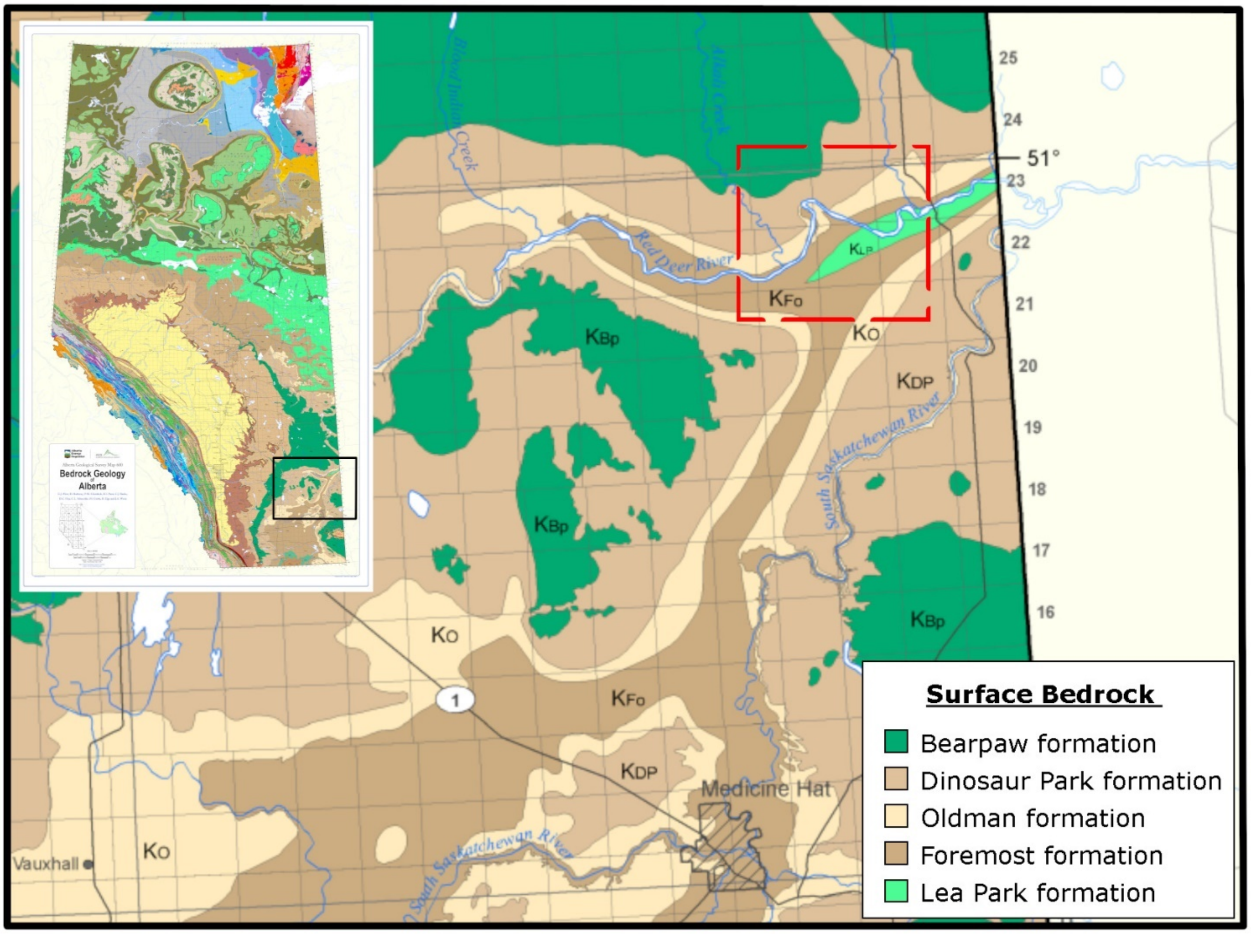


Figure 2.3: Uppermost bedrock near study area, all late Cretaceous age; note very wide pre-Pleistocene river channels compared to modern rivers and horseshoe bend of Red Deer River extending outside pre-Pleistocene channel; adapted from Prior et alia (2013).

The bedrock formations (Prior et al. 2013) from youngest to oldest are the following. The Dinosaur Park formation (KDP) is sandstone interbedded with siltstone and mudstone, with the upper sediments deposited in a marginal marine environment and the lower sediments deposited in a fluvial and estuarine environment. The Oldman formation (KO) is sandstone, siltstone, and mudstone, with layers of siderite (iron carbonate [$FeCO_3$]) concretions, deposited in a non-marine environment and divisible into upper siltstone and lower sandstone units. The Foremost formation (KFO) is sandstone, siltstone, carbonaceous mudstone, and coal, with layers of siderite concretions, formed in non-marine to marginal marine environments. Coal seams in this formation are near the top. The Lea Park formation is non-calcareous mudstone with minor siltstone components and rare, thin sandstone beds formed in an offshore marine environment. This is the only region of surface bedrock Lea Park formation in the southeastern portion of Alberta. The Lea Park formation is mostly concentrated in a wide northwest-southeast band beginning 190km north of the study area, near Lloydminster.

Cummings et alia (2012:989) provide a succinct post-Cretaceous geological history of the area, an area extending from the Rocky Mountains to the Pre-Cambrian Canadian Shield, which they designate the Western Canadian Sedimentary Basin (WCSB). In the Paleogene, from 47 million to 5 million years ago, gravels from the erosion of the Rocky Mountains were deposited over the area (Leckie 2006). The oldest gravels are at the top of the Cypress Hills to the southeast, and younger Paleogene gravels exist on other uplands. During this time large rivers flowed from the Rockies across what is now Hudson Bay into the Atlantic. The river valleys from this time are significantly deeper and wider than modern river valleys (McPherson 1968). The study area is on the northern edge of one such Paleogene river valley (Figure 2.3), which downcut through several late Cretaceous formations (Prior et al. 2013) and has been identified as the pre-glacial Bow River valley (Stalker 1961; McPherson 1968).

According to Cummings et alia (2012), during the Pleistocene, glaciers deposited 10-350m of glacial sediments over the bedrock and filled in pre-glacial river valleys. These sediments originate from the WCSB (usually sand, silt, and clay), and from the Rocky Mountains and Canadian Shield (larger igneous and metamorphic gravels to boulders). In the terminal Pleistocene and early Holocene, glacial meltwaters carved the channels of modern rivers.

2.1.2 Geomorphology of the lower Red Deer River Valley

There has been a spate of studies of the geomorphology of the Red Deer River and several of its tributaries, all within Dinosaur Provincial Park (O’Hara and Campbell 1993; Barling 1995; Evans 2000; Evans et al. 2004), but only McPherson (1968) has examined the formation history of the stretch of the river where my study area sits.

The following description of the geomorphology and formation history of the lower Red Deer River valley is summarized from McPherson (1968). McPherson investigated an approximately

210km length of the Red Deer River from its mouth to a point roughly 53km upstream from Dinosaur Provincial Park. On the upper 100km of this length, the river valley is about 1.6km wide on average. The lower 110km, is on average 6.4km wide. The transition from a narrow to a wide river valley occurs approximately at the mouth of Blood Indian Creek, northeast of Jenner, Alberta, where the surface bedrock shifts from the Oldman to the Dinosaur Park formation (Figure 2.3). The Red Deer River valley along the entire 210km is incised 60m-90m below the surrounding prairie. The river flow measured at Empress (see Figure 2.6 for location) has a mean annual discharge of 42.5-127.5m^3/sec and an average mean annual discharge of 68.3m^3/sec.

McPherson divided the river valley landforms into nine physiographic types (not including bedrock outcrops), of which eight are present near the study area (Figure 2.4). The modern floodplain (1) is stratified medium to fine-grained sand, silt, and clay. Near the study area, the modern floodplain is relatively narrow and is constrained by alluvial fans and bedrock. Alluvial terraces (2) are the same alluvium as the floodplain and sit 1.2m to 4.5m above the river. They are of recent age as evidenced by their smooth, uneroded surfaces, weak soil development, and

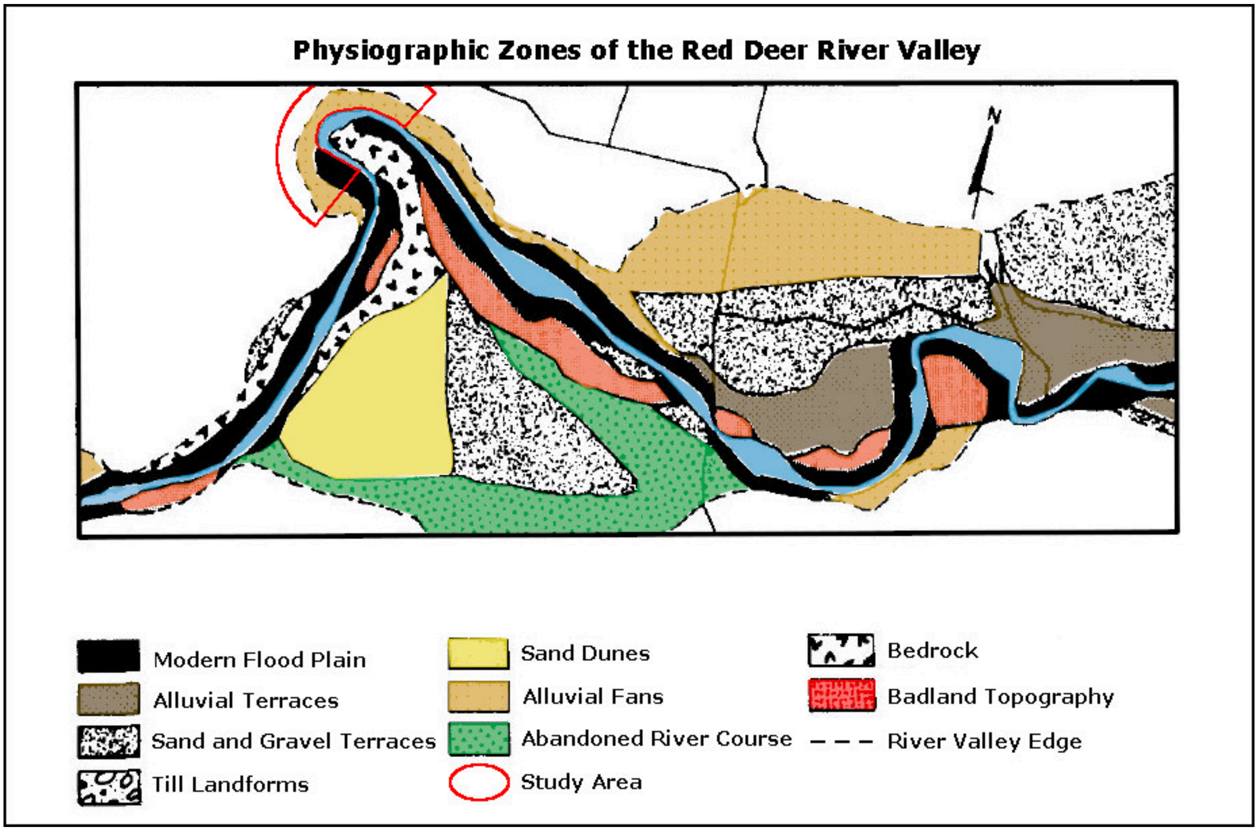


Figure 2.4: Landforms of the lower Red Deer River Valley in and near the study area (outlined in red); adapted from McPherson 1968:Figure 2, Map Sheet D.

undecayed organic matter within the sediment. Sand dunes (3) are reworked floodplain and terrace alluvium and a minor component of the river valley in most places. The largest dune field is approximately 800 hectares and begins roughly 4km south of the study area. This dune field has both stable and active dunes up to 12m high, a few of which are parabolic. Alluvial fans (4) are erosional features of the valley wall. They extend out from the wall with slopes of 1°-3° and overlie fine-grained alluvium and glacial till, indicating they are relatively young deposits. Slump topography (5) is where a large section of the valley wall has subsided. There are no slumped sections near the study area. Badlands topography (6) is an area of deeply incised gullies. The largest area of this physiographic type is at Dinosaur Provincial Park, upstream from the study area. There are a few small sections of minor badlands topography indicated by McPherson near the study area where bedrock or sand and gravel terraces are eroding into the modern floodplain. Abandoned river courses (7) are present in several sections of the river. A large, abandoned river course runs from the Bindloss bridge (see Figure 2.6 for location) roughly west-southwest for 11.6km. This abandoned river course appears to be a meltwater channel incised into the sand and gravel terrace then infilled by alluvium. The bed of the channel lies 9.1m lower than the modern river channel and 14.6m lower than the surface of the alluvial terrace covering it. Sand and gravel terraces (8) are poor to moderately sorted and stratified sediments. The presence of Pre-Cambrian igneous and metamorphic stones precludes a pre-Pleistocene local origin. These sediments were likely deposited by outwash from the melting Keewatin ice sheet followed by trenching during the early post-glacial period to create the terraces. There are large areas of sand and gravel terraces downstream from the study area. Glacial till landforms (9) are the last physiographic landform type identified by McPherson, but none are present in or near the study area.

The major stratigraphic sequence of the river is alluvium overlying sand and gravel overlying bedrock. The riverbed itself is cut into the alluvium which continues, on average, another 30m to the sand and gravel below, with a maximum depth of 45m. The sand and gravel may extend a further 30-45m below the alluvium before contacting bedrock. Where the valley is wide, sand and gravel terraces sit between the valley walls and the lower alluvial terraces near the floodplain. Alluvial fans of the valley walls overlie the sand and gravel, as seen in a borehole near Bindloss bridge, indicating the sand and gravel extends to the valley walls.

McPherson proposed the following sequence for the formation of the lower Red Deer River valley (Figure 2.5). Meltwaters from the retreating Keewatin ice sheet incised a channel into the glacial till down to bedrock. Where the lower Red Deer River is in the pre-glacial Bow River valley, in-filled by 90m of glacial till during the Pleistocene, the meltwater channel cut a wide valley. Where the river is outside the pre-glacial valley, the glacial till is thin, often only 15m thick, and the meltwater incised a deep, narrow valley.

The study area is in the lower approximately 110km of the Red Deer River, which is in the pre-glacial river channel. At a point roughly 36km upstream of Alkali Creek, the Red Deer River diverts from the center of the pre-glacial river valley to ride along its north wall (Figure 2.3). The aforementioned abandoned river course south of the study area continues to follow the pre-glacial valley wall but the modern river channel cuts into the north wall bedrock before turning sharply southeast back to the center of the pre-glacial channel. Due to this sudden diversion, the study area itself is in a narrow horseshoe valley deeply incised into bedrock, like the narrow upstream river valley. McPherson neither investigated nor speculated why this happened only in this part of the river.

After the period of initial entrenchment, the young river valley began to accumulate sand and gravel. These deposits accumulated as high as 45m above the modern river channel.

In the early post-glacial period, another period of entrenchment occurred, incising a channel more than 60m into the accumulated sand and gravel, i.e., more than 30m below the modern river channel. This entrenchment period created a series of stepped sand and gravel terraces and abandoned river courses, which eventually were filled by both alluvial and eolian sediments. At the valley walls, alluvial fans began to accumulate over the sand and gravel. In the narrow upstream valleys, and presumably at the study area, the sand and gravel were completely washed away.

At some point, a new episode of deposition began. The medium to fine-grained alluvium that characterizes the modern river channel and floodplain accumulated up to 45m thick above the incised sand and gravel in the wide valley and above bedrock in the narrow valley. McPherson notes the causes of this period of aggradation lie in the South Saskatchewan River valley, perhaps due to higher water levels to the northeast caused by isostatic rebound (1968:239). Higher water levels in the South Saskatchewan River would slow the waters of the Red Deer, allowing sediments to build up. This alluvium is also the source material for the sand dunes in the river valley. The most recent phase in the history of the Red Deer River is a new period of incision in the last few millennia, which has created the young alluvial terraces.

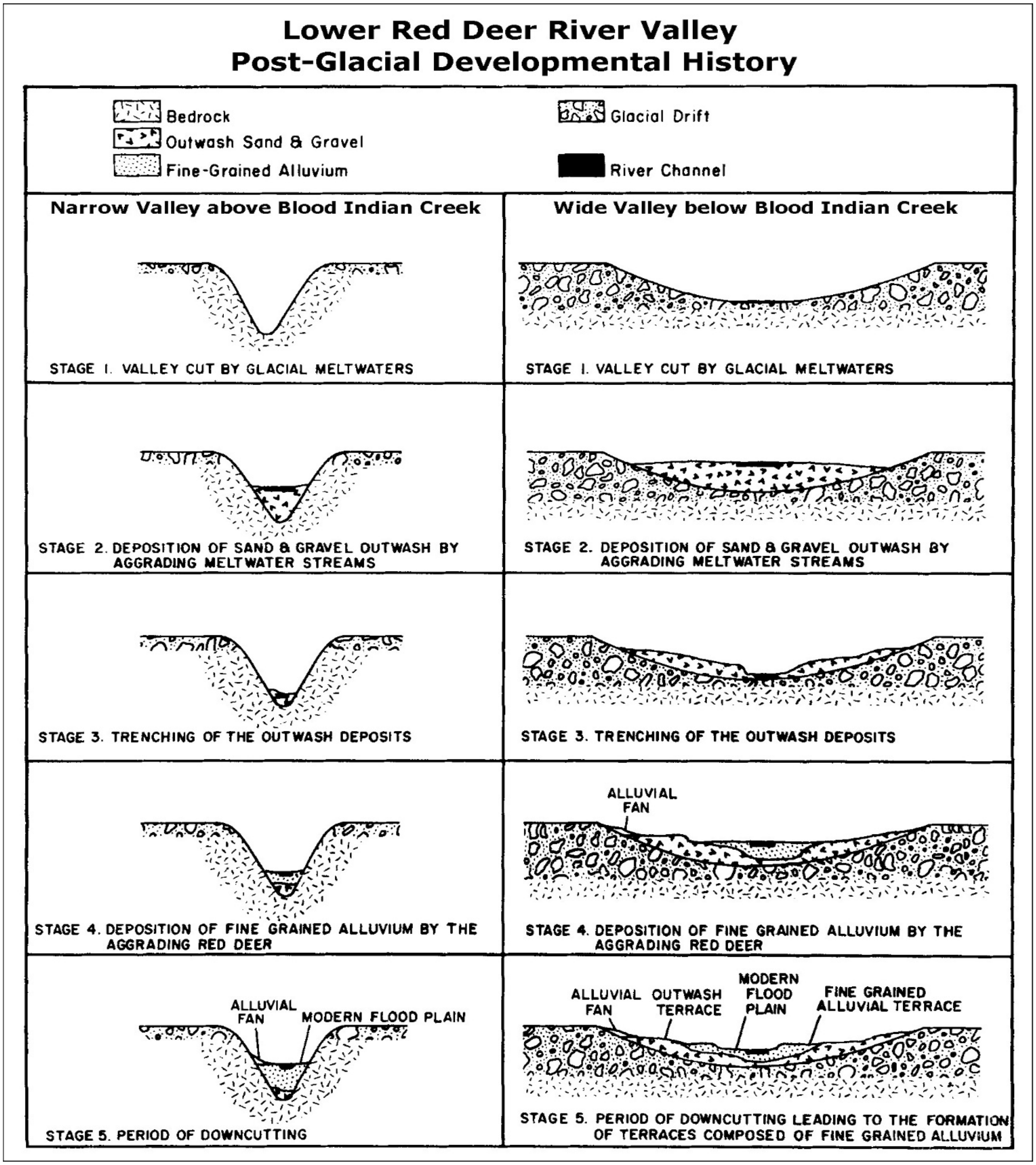


Figure 2.5: Formation history at the study area is within the wide valley stretch of the river but is likely more similar to the narrow valley formation history due to the surface bedrock. Adapted from McPherson 1968:Figure 6.

2.2 Topography

The topography of the Canadian prairies is based on glacial erosional and depositional processes during the Pleistocene and during glacial retreat. There are three basic topographic zones in the study area. The upland prairie is hummocky with occasional small depressions, or sloughs. The lowland prairie consists of smooth, alluvial fans with a slope of less than 7%. In between is the steep, eroding valley wall with erosional gullies coalescing into small, deeply incised coulees cutting through the lowland alluvial fans to empty into the river.

In many of the coulees in the study area, the slope approaches level for a short length, usually less than 200m, sometimes around the mid-point of the eroding valley wall, but more often where the steep erosional gully transitions to the alluvial fan. In these areas, water collects, possibly due to an impermeable or less-permeable layer in the subsoil, e.g., clay, a petrocalcic horizon, or a transition to bedrock, and creates perched wetlands (Melly et al. 2017). The perched wetlands we visited (Figure 2.10) had slope fens with sedges (Cuperaceae), floating vegetation mats, and sometimes cattails (*Typha* sp.). The ecological and cultural implications of perched wetlands in the prairie landscape may be an interesting topic of future research.

2.3 Hydrology

According to Cordes et alia (1997), the Red Deer River has its source in the Sawback Range of the Rockies near the Alberta-British Columbia border. The river flows through south-central Alberta before joining the South Saskatchewan River in Saskatchewan just 8km east of the Alberta border. Along the way the Red Deer River drains 40,000km^2 of land. There is one dam, Dickson Dam, upstream from Red Deer, Alberta. Reflecting regional precipitation differences, only 26% of the river is upstream from Red Deer but provides 76% of the inflow. Of this, just 10% of the river is in the Rockies and the Foothills but provides 50% of the total inflow.

2.4 Soil

Downing and Pettapiece (2006) describe the major soil orders in the prairie region surrounding the study area. The soils are approximately 60% Orthic Brown Chernozem, 25% Solonetzic soil, and 10% Solonetzic Brown Chernozem, a soil type intermediate between the previous two. There is an area of Vertisols in the Acadia Valley area (Figure 2.6). Regosols are found in frequently disturbed areas such as dunefields and floodplains and Gleysols are found in wetlands.

According to the Agricultural Regions of Alberta Soil Inventory Database [AGRASID] (2020) there are six soil units around the study area. Of these, the most important are those at the sampling column locations (Figure 2.9). At sampling column 1, the soil unit is ZUN16/I3h, where ZUN16 indicates the major soil series and I3h indicates the landform. Landform type I3h is inclined to steep with high relief. ZUN16 is described as 80% ZUN and 20% ZER-zbr. ZUN series is described as miscellaneous undifferentiated mineral (inorganic) sediments with no water table and usually an Orthic Regosol. ZER-zbr series is described as a Brown soil zone variant of miscellaneous eroded mineral (inorganic) sediments with no water table and usually a Rego Brown Chernozem. Both of these soils describe colluvium occurring on a steep midslope position in an area with outcroppings of more than three sources of parent material. Although this description aptly describes the area surrounding sampling column 1, the column itself was removed from a slope fen in the coulee streambed. The sampled sediments appear to indicate either a Rego Gleysol or a Gleyed Regosol at this location.

At sampling column 2, the soil unit is CFCH1/H1l, where CFCH1 indicates the major soil series and H1l indicates the landform. Landform type H1l is hummocky with low relief. CFCH1 is described as 15 % Maleb series (upper slope), 35% Cranford series (mid-slope), 35% Chin series (mid-slope), and 15% Ronalaine (lower slope). The three upper to mid-slope series are all orthic brown chernozems while Ronalaine, the lower slope series, is a solonetzic brown chernozem. This soil unit is a roughly triangular block with an area of 374 hectares on the upland prairie between the bluff edge and a meltwater channel north of the river.

Sampling column 2 is at the base of an upland depression and therefore should be a Ronalaine series solonetzic brown chernozem. Ronalaine parent material is well draining glacial till of moderately fine texture, i.e., sandy clay loam, clay loam and silty clay loam. The sediments in sampling column 2 appear to be more than 60% clay, indicating an Orthic Vertisol. There are only two vertisolic regions on the prairies of Alberta, one surrounding Drumheller and one surrounding the hamlet of Acadia Valley (Downing and Pettapiece 2006; Brierley et al. 2011).

The latter area (Figure 2.6) is an area approximately 32km long, extending from north of Acadia Valley to the Red Deer River and 21km wide, extending west from the Saskatchewan border. This area of Acadia Valley Orthic Vertisols (AGRASID 2020) is centered around a drainage that becomes Kennedy's Coulee and drains into the Red Deer River. The southwest corner of this

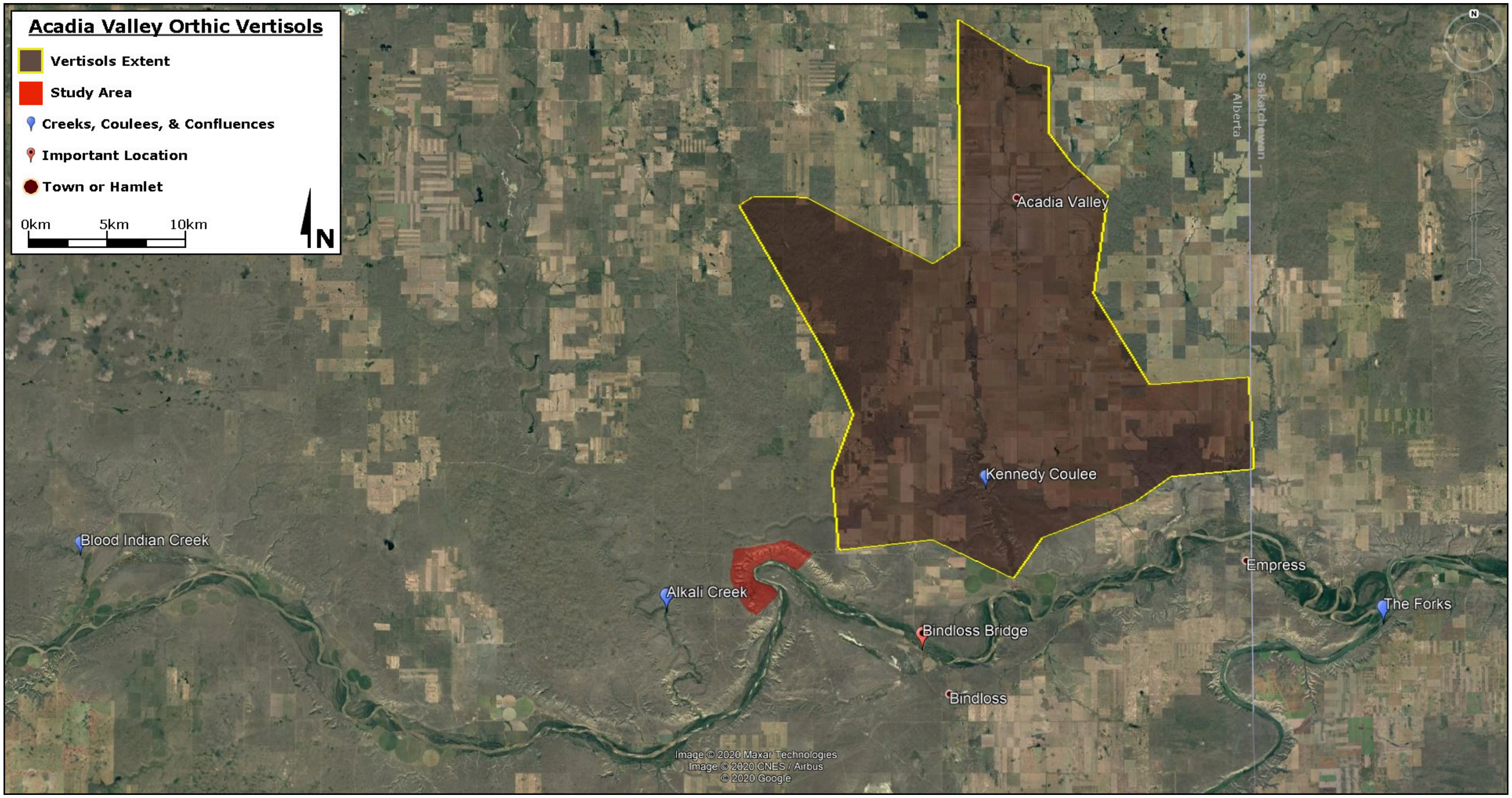


Figure 2.6: Acadia Valley Orthic Vertisols extent.

vertisolic region lies only 3.5km east of sampling column 2. It may be there is a small outpost of Acadia Valley Orthic Vertisols at the sampling column 2 location.

Alternatively, the fine texture of the sediments may be due to factors related to wind, precipitation, and vegetation. The prevailing winds are from the west and southwest (Campbell and Campbell 1997), placing the depression on the lee side of the river valley bluffs. Such a location provides excellent conditions for aeolian deposition of fine sediments (Artz 1995). Furthermore, a depression that is an ephemeral slough with no outlet, where water is introduced through precipitation and slope wash only, and the slopes are stabilized by grassland vegetation, tends to collect fine rather than coarse textured sediments (Bickley and Clayton 1972).

At sampling column 3, in a coulee on an alluvial fan in the river valley, the soil unit is BUT4/I3l, where BUT4 indicates the soil series and I3l indicates the landform. I3l indicates inclined to steep slope with low relief. BUT4 is described as 80% Bunton series (mid-slope), an orthic brown chernozem, and 20% Verdigris series (lower slope), a cumulic regosol. Cumulic regosols are regularly disturbed and covered by new sediment. A-horizons develop during periods of stability but are then covered. The result is a series of buried Ahb horizons separated by C horizons of parent sediment. This soil unit has an area of 1326 hectares and is a long, thin strip of land between the riverbank and the eroding valley wall, paralleling the river for approximately 28km kilometers. This soil unit comprises landforms described by McPherson (1968) as alluvial fans and the modern floodplain. In these locations, soils form and are then covered by alluvial material either from the river or the alluvial fans. The sediments at sampling column 3 do appear to be a cumulic regosol, though they are heavily gleyed indicating the sediments are commonly saturated with water at this location.

2.5 Climate and precipitation

McGinn (2010) provides a good overview of precipitation and climate on the Canadian Plains. The study area receives 300mm of average annual precipitation, placing it in the driest region of the Canadian Plains (McGinn 2010: Figure 1, p107). A total of 70%-80% of the precipitation falls as rain, and the wettest month is July. The southern prairies receive, on average, 2,400 hours of sunshine annually. Ground level wind speed averages 14-22km/h. In winter, southern Alberta is also subject to warm Chinook winds, which can rapidly increase temperatures by 20ºC or more. In Empress, the nearest town for which there are records, Longley (1967) reported an average of 11 Chinook days (temperature above 2.5°C) per year from 1931-1965.

The nearest meteorological station is Acadia Valley AGCM, for which the Alberta Climate Information Service has records available from 1 April 2005 to present (Alberta Climate Information Service [ACIS] 2020). As recorded at Acadia Valley AGCM meteorological station, the annual average air temperature is 3.6°C. The hottest month is July, with an average minimum and maximum air temperature of 11.2°C and 26.3°C, respectively. The highest temperature recorded was 41.1°C. The coldest month is January, with an average minimum and maximum air temperature of -18.5°C and -7.7°C, respectively. The coldest temperature recorded was -45.2°C.

The study area is slightly warmer than the average for the entire Canadian Plains, as reported by McGinn (2010). McGinn reports an annual mean maximum air temperature of 8.1°C and minimum air temperature of -4.1°C. At Acadia Valley AGCM the annual mean maximum air temperature is 10.2°C and the annual mean minimum air temperature is -2.9°C. McGinn reports a 22° difference between summer and winter mean maximum temperatures and a 28°C difference between summer and winter mean minimum temperatures. At Acadia Valley AGCM the difference between mean maximum temperatures is 34°C and 29.7°C between mean minimum temperatures.

2.6 Flora and fauna of the Grasslands Natural Region of Alberta

The Red Deer River valley is an ecotone in the Dry Mixedgrass Natural Subregion and is important to many species. Downing and Pettapiece (2006:83-85) provide an account of some of the modern plants and animals common to the several habitats found in this natural subregion. In this subregion, the grasslands are defined by a mix of drought-tolerant short and medium grasses. The short species, blue grama grass (*Bouteloua gracilis*) is usually the most abundant constituent of a community and the medium species, thread-and-needle grass (*Stipa* spp.), June grass (*Koeleria macrantha*), and western wheatgrass (*Pascopyrum smithii*), are the less abundant constituents. Various forbs account for the remaining species in the vegetation community. The proportions of these constituents are usually 60% *B. gracilis*, 20% *Stipa* spp., and 20% forbs (Linowski, personal communication 2017). However, *Stipa* can become the foremost component in landscapes frequently disturbed by fires, flooding, or human activity. (Linowski, personal communication 2017) or on lower slope positions and calcareous soils (Downing and Pettapiece 2006). Heavy grazing may also benefit short species over medium species.

On the grasslands, Richardson's ground squirrel (*Urocitellus richardsonii*) is a key species providing food for predators such as the ferruginous hawk (*Buteo regalis*) and American badger (*Taxidea taxus*). Its burrows are reused by other mammals, amphibians, snakes, and the burrowing owl (*Athene cunicularia*). The disturbance created by its burrowing creates spaces for early successional forbs and shrubs. Prairie birds mentioned include the horned lark (*Eremophila alpestris*), McCown's longspur (*Rhynchophanes mccownii*), chestnut-collared longspur (*Calcarius ornatus*), Baird's sparrow (*Centronyx bairdii*), Sprague's pipit (*Anthus spragueii*), sharp-tailed grouse (*Tympanuchus phasianellus*), and upland sandpiper (*Bartramia longicauda*). Localized areas of sagebrush support populations of pronghorn (*Antilocapra americana*), as well as greater sage grouse (*Centrocercus urophasianus*), lark bunting (*Calamospiza melanocorys*), and lark sparrow (*Chondestes grammacus*).

Within the Grasslands Natural Region there are several other habitat types besides upland grasslands, each with its own characteristic flora and fauna. In sand dunefields, grasses, such as *Stipa* spp., *K. macrantha*, and *Calamovilfa longifolia* (sand grass) are sparse and lower areas between dunes may have *Artemisia ludoviciana* (silver sagebrush or silver wormwood), *Shepherdia argentea* (buffalo berry), *Elaeagnus commutata* (wolf willow), and *Rosa arkansana* (prairie rose). Sand dunes provide habitat for the western hog-nosed snake (*Heterodon nasicus*), sharp-tailed grouse, grasshopper sparrow (*Ammodramus savannarum*), mule deer (*Odocoileus hemionus*), and Ord's kangaroo rat (*Dipodomys ordii*). In fact, the dunefield just south of the study area is the home of the northernmost North American population of Ord's kangaroo rat.

Badlands and rock outcrops have similar vegetation to dune fields. These dry and rocky places provide nesting habitat for golden eagle (*Aquila chrysaetos*), ferruginous hawk, prairie falcon (*Falco mexicanus*), rock wren (*Salpinctes obsoletus*) and mountain bluebird (*Sialia currucoides*). Small mammals and reptiles also make their homes in these rocky habitats, including several bat species, bushy-tailed rat (*Neotoma cinerea*), yellow-bellied marmot (*Marmota flaviventris*), Nuttall's cottontail (*Sylvilagus nuttallii*), American porcupine (*Erethizon dorsatum*), prairie rattlesnake (*Crotalus viridis*), bull snake (*Pituophis catenifer sayi*), garter snakes (*Thamnophis* spp.), and the short-horned lizard (*Phrynosoma hernandesi*).

Riparian areas of river valleys, streams and coulees are a rich ecotone environment comprising less than 500km² (1%) of the land area in the Grasslands Natural Region but provide resources and habitat for many species which would not otherwise exist in the Natural Region. Johnson and Lowe (1985:112) describe the riparian ecotone as "a reticulum of interlaced species interactions and ecological processes [that] forms a continuum between the wettest deepwater habitat and the driest upland habitat."

Johnson and Lowe (1985) define two environmental gradients within riparian zones. The intrariparian gradient parallels the stream course from the mouth to the source and, in the idealized model, is a gradient from the area of most to least water. The transriparian gradient runs perpendicular to the stream and is a transition from the deepest waters of the stream to the dry uplands where the riparian zone transitions to the surrounding vegetation regime. This gradient is a measure of diminishing soil moisture as one travels up bank and away from water. At the dry periphery of both gradients, the species composition may be the same both within and without the riparian zone but the individuals within are more numerous or robust (Johnson and Lowe 1985:114).

Riparian zones in the Dry Mixedgrass Natural Subregion have a very diverse species composition (Downing and Pettapiece 2006; Cordes et al. 1997). Tree species are most commonly *Populus deltoides* (cottonwood) and *Salix amygdaloides* (peach-leaved willow). Shrubs include other *Salix* spp. (willows), silver sagebrush, buffalo berry, wolf willow, *Amelanchier alnifolia* (saskatoon or serviceberry), *Symphoricarpos albus* (snowberry), *Cornus stolonifera* (dogwood red osier), and *Prunus virginiana* (chokecherry), among others. In saturated soils, *Carix* spp. (sedges), *Equisetum* spp. (horsetails), and *Eleocharis* spp. (spikerush) are common.

In the rivers of the Grasslands Natural Region, there are lake chub (*Couesius plumbeus*), flathead chub (*Platygobio gracilis*), white sucker (*Catostomus commersonii*), fathead minnow (*Pimephales promelas*), and brook stickleback (*Culaea inconstans*). Meandering streams and oxbow lakes provide habitat for amphibians and snakes and many invertebrates. American beaver (*Castor canadensis*) and muskrat (*Ondatra zibethicus*) are not uncommon and there are numerous shorebirds such as killdeer (*Charadrius vociferus*), willet (*Tringa semipalmata*), American avocet (*Recurvirostra americana*), and great blue heron (*Ardea herodias*). Belted kingfisher (*Megaceryle alcyon*), bank swallow (*Riparia riparia*), and northern rough-winged swallow (*Stelgidopteryx serripennis*) occupy holes in stream cutbanks. Tall shrub communities provide habitat for numerous bird species, as well as deer mouse (*Peromyscus maniculatus*), Nuttall's cottontail, and both mule deer and white-tailed deer (*Odocoileus virginianus*).

Notably absent from the above ecological communities is the American bison (*Bison bison*). More than any other species, the bison is *the* iconic species of the Great Plains. Historical accounts by Europeans on the Canadian prairies from 1690-1880 compiled by England and DeVos (1969) indicate millions of bison in the area prior to the late 1800s and somewhere between 40 and 60 million individuals across North America. More recent works, incorporating carrying capacity and other ecological methods, estimate Precontact bison populations up to around 30 million individuals (Epp and Dyck 2002; Shaw 1995).

England and DeVos (1969) studied the historical accounts to understand the ecological effect of bison on the landscape. While Roe (1939) disproved the old notion that bison created and extended the grasslands by destroying trees, England and DeVos did find evidence of bison devastating young trees and brush around water sources, leaving only mature trees standing with their bark rubbed smooth by bison using them as scratching posts. Cordes et alia (1997) described historical observers, such as the Palliser expedition, recording large herds of bison in the lower Red Deer River valley and noting their surprise at the dearth of cottonwoods. Cordes et alia also concede First Nations burning of the grasslands may have been a contributing factor or even the major factor in low poplar density in the river valley. On the other hand, England and DeVos describe bison traveling in wooded and brushy areas creating deep trails as they moved single file through the vegetation, rather than trampling all of it. They further speculate observations of such trails in current grasslands may be a good indicator the area was once wooded, though the reasons for the vegetation shift are likely particular to the location.

The most important ecological effects of large bison herds on the prairie were likely overgrazing and wallowing. England and DeVos describe how both First Nations and European observers noted bison would intensely graze an area before moving on, leaving behind barren areas, short grass, and barely enough forage for horses. Such bison disturbances created ideal conditions for early successional forbs and woody shrubs, important food sources for other prairie inhabitants.

Pronghorn are described by England and DeVos as having been as numerous on the prairies as bison, perhaps even more numerous, with a population in the tens of millions. Their historic range extended north to north-central Saskatchewan, northwest to Rocky Mountain House (and possibly as far as the Peace River grasslands), east to Manitoba, and south into Mexico. By 1945, their Canadian range had contracted southward to Sullivan Lake, Alberta and westward to Wood Mountain, Saskatchewan. Pronghorn forage on forbs and woody browse, such as sagebrush, which prefer disturbed areas in the grasslands. Given the lack of systematic extermination of pronghorn, such as was suffered by the bison, it appears the large population of pronghorn required the large population of bison to create the disturbances necessary for pronghorn to forage (England and DeVos 1969:90-91).

Elk (*Cervus canadensis*) and mule deer were also commonly recorded in historical accounts. Both species were important prey animals to First Nations groups when bison were scarce. Mule deer are still present on the Alberta prairies, but elk are not. Elk were commonly observed on the prairies until the late 1800s. By the 1880s, elk were only rarely seen and only near wooded areas such as the Cypress Hills, as described in Macoun's 1882 account cited by England and DeVos. England and DeVos believe non-hunting factors are the cause of the decline in Elk but do not elaborate as to which. White-tailed deer were not mentioned in the historical accounts compiled by England and DeVos, but their population has increased and expanded in Alberta recently (Knopff et al. 2014).

Moose (*Alces alces*) were also once present in the Grassland Natural Region. England and DeVos (1969) noted that much of the data for modern moose distribution was taken solely from records in wooded areas, leading to the assumption that moose are confined to that habitat. They found journal entries from Anthony Hendry, who journeyed on the Canadian prairies in 1754-1755 CE. He traveled through the study area, having followed Sounding Creek, he crossed over to the Red Deer River and followed it to the South Saskatchewan, along which he returned to Fort Poscoyac. Hendry recorded 48 moose kills during his travels on the prairies but does not state whether they were taken on the grasslands or in the river bottoms. England and DeVos ponder whether there may have been more browse on the prairies then, drawing moose to the grasslands, or whether they were solely confined to the rivers and coulees.

According to England and DeVos, Hendry also recorded “wild goats” seen or killed near tributaries of the Red Deer River. England and DeVos believe these were Rocky Mountain (Bighorn) sheep (*Ovis canadensis canadensis*) venturing out from the mountains. Hares, such as the snowshoe hare (*Lepus americanus*) and white-tailed jackrabbit (*Lepus townsendii*), and ground squirrels are occasionally mentioned in the historical sources but, in general, most observers focused on the large mammals to the exclusion of most other, less spectacular, species.

Laliberte and Ripple (2004) investigated the ranges of North American carnivores and ungulates, including the following species of the Grasslands Natural Region of Alberta. Mammalian carnivores once present or abundant but now greatly reduced or absent from the Grassland Natural Region are grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), gray wolf (*Canis lupus*), swift fox (*Vulpes velox*), lynx (*Lynx canadensis*), river otter (*Lontra canadensis*), fisher (*Martes pennanti*), American mink (*Mustela vison*), and wolverine (*Gulo gulo*).

Some carnivores have expanded their range since European colonization, including striped skunk (*Mephitis mephitis*), short-tailed weasel (*Mustela erminea*), least weasel (*Mustela nivalis*, the smallest member of the order Carnivora), red fox (*Vulpes vulpes*), American badger, and raccoon (*Procyon lotor*). The coyote (*Canis latrans*) has expanded its range 40% beyond its historic bounds. The long-tailed weasel (*Mustela frenata*) appears to be one of the only species to have its range neither expand nor contract.

The large carnivores were generally dependent on large populations of bison and cervids to predate or scavenge upon and disappeared from the Grasslands Natural Region along with them. The expansion of small to mid-size predators appears to be a consequence of the loss of large carnivores in these areas, a process known as mesopredator release (Soulé et al. 1988). One exception in Alberta appears to be the cougar (*Puma concolor*), which population appears to be currently expanding both numerically and geographically in tandem with the white-tailed deer population (Knopff et al. 2014). Observations of cougar along the Bow River and a breeding population in the Cypress Hills (Knopf et al. 2014) indicate a historical population in the Red Deer River valley is not outside the realm of possibility.

Many of the above species are dependent on the riparian zones within the Grasslands Natural Region. Many of the grasslands dwellers were primarily or secondarily dependent on the presence of the vast bison herds. With European colonization of the prairies, the extermination of the bison, and the introduction of modern agriculture, grasslands animal and plant communities have changed, and are continuing to change, significantly.

2.7 Local vegetation

On 13 July 2017, I accompanied botanist Dr. Cathy Linowski on a tour of the area near the sampling locations to identify common species of the vegetation communities, indicator species, and unusual species that might imply human manipulation of the botanical environment by members of past human communities. I discuss the locations and notable aspects of the identified communities and species below.

2.7.1 Local riparian structure

The Red Deer River valley can be considered a series of transriparian gradients extending from the river to the upland prairie. When we look at it this way there are two basic gradient types in the study area, the grassland gradient, and the wooded coulee gradient.

Using the riparian vegetation communities identified by Cordes et alia (1997) in the Red Deer River valley (Figure 2.7), the grassland transriparian gradient has only two zones. The first zone is the floodplain, which is severely attenuated in the study area – less than 20m in some places. The vegetation community here is riverbank complex, which is a mix of species from all riparian vegetation communities compressed into the narrow strip of floodplain between the river and the first alluvial terrace edge. The second zone is the grassland community, which stretches from the first alluvial terrace edge all the way to end of the transriparian gradient at the upland prairie. Species composition may change dependent on a wide variety of factors, including slope, moisture, and soil type, but the basic grassland structure remains.

The wooded coulee gradient is a transriparian gradient of the Red Deer River but at the same time, it is the intrariparian gradient of the particular coulee. This wooded coulee gradient is more diverse than the grassland gradient. This gradient functionally extends, or decompresses, the floodplain, allowing the riparian vegetation communities to express themselves more fully along the transect from the river to the upland prairie.

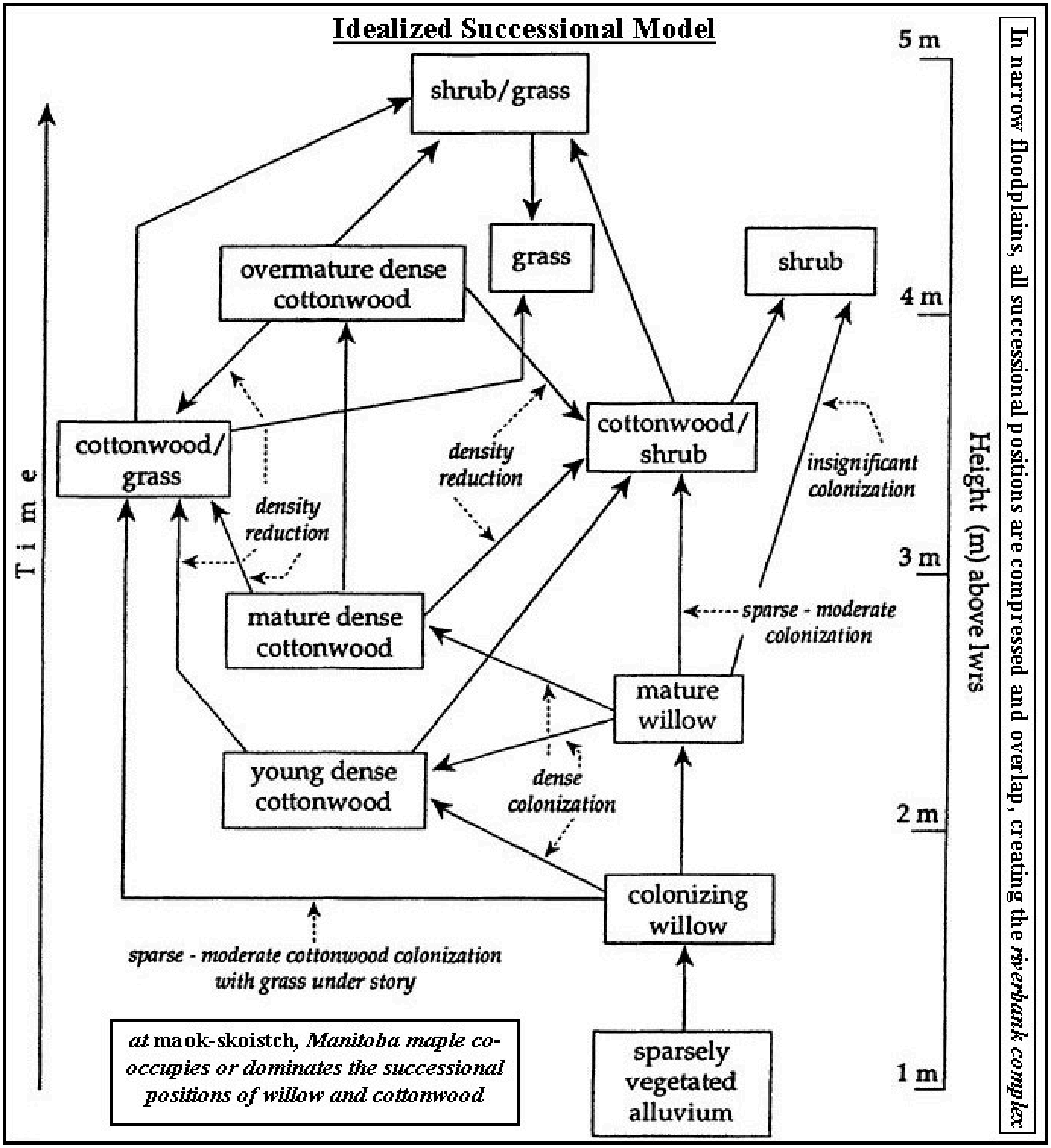


Figure 2.7: Idealized successional model for the Lower Red Deer River Valley floodplain and coulees, including Manitoba maple (adapted from Cordes et al. 1997:Figure 6).

At Ravine #5 (Figure 2.8), the coulee in and around which we focused our sampling, there are perhaps six vegetation communities. On the floodplain is a thin zone of sparsely vegetated alluvium, which is regularly disturbed by the river. Still on the floodplain, a dense stand of Manitoba maple (*Acer negundo*) begins immediately in the channel incised by coulee outwash. There may be a small stand of colonizing sandbar willow (*Salix exigua*) in between the first two

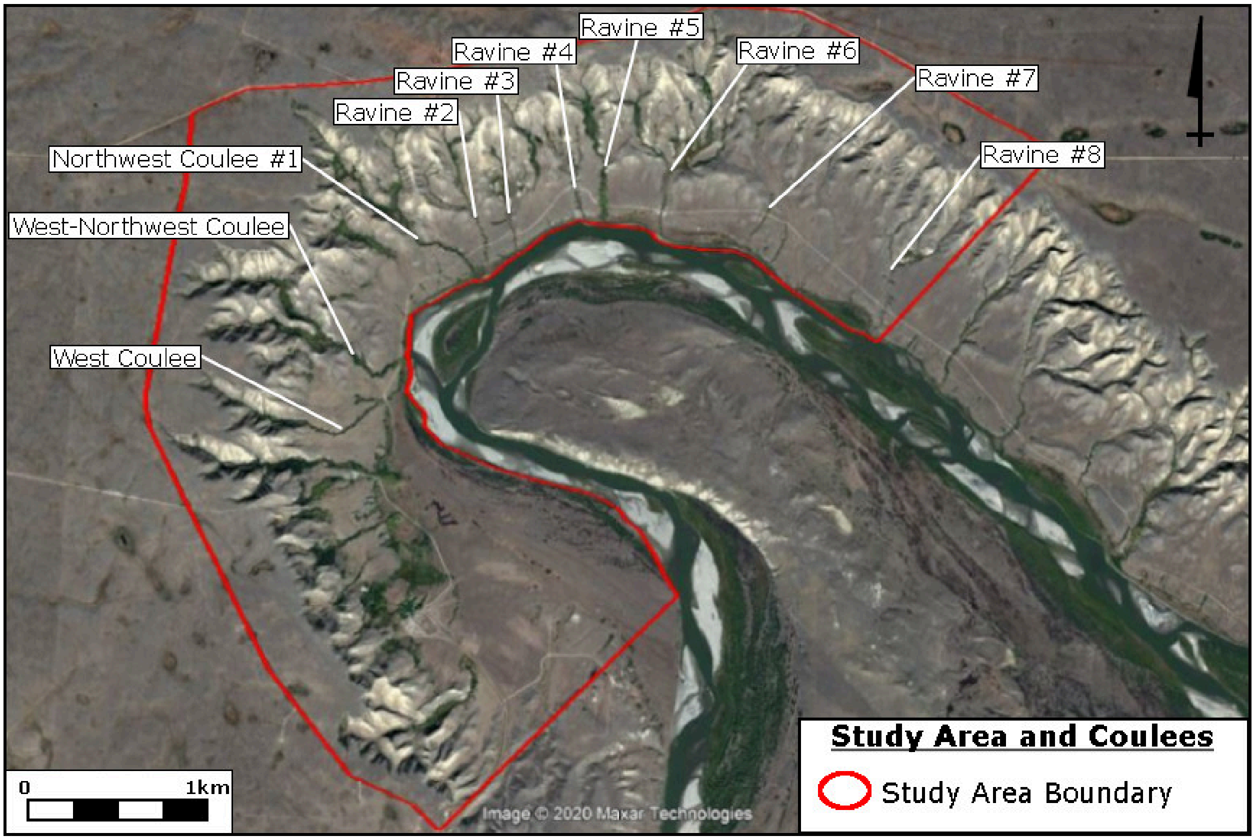


Figure 2.8: Coulees in the study area.

zones but we did not investigate this close to the river. The Manitoba maple extends approximately 200m upstream in a nearly pure stand, then a transition to mature peach-leaved willow trees occurs a short way downstream from the sampling column 3 location. Within the Manitoba maple zone there are only a few individual cottonwoods near the transition to the willow trees. The willow zone is much shorter than the maple zone and at the “tree-line” 300m upstream from the coulee mouth (at sampling column 3), willow is the only tree species. Beyond sampling column 3, there is an abrupt transition to a zone of shrub or shrub and grass, which follows the drainage channels in the coulee a further 630m, to nearly the upland prairie. In the shrub zone, there is a 300m long stretch of herbaceous wetlands (slope fen) in the central channel of the coulee. Beyond the shrub zone is a final riparian grassland community, 50-175m long depending on location, which traverses the remainder of the slope up to upland prairie. Several coulees also have perched wetlands among the incised bluffs (Figure 2.10), where enough water collects to support trees, tall shrubs, and even slope fens with floating vegetation mats.

Each coulee also has its own transriparian gradient extending from its central channel to the grasslands on the valley alluvial fans. The coulees are usually so narrow though that this “transcoulee” gradient can be considered the compressed riverbank complex described above.

2.7.2 Sampled communities

We collected modern surface composite samples (MS1-MS7) at seven locations and sediment columns in three locations (Figure 2.9) as described in Chapter 5: Methods and Methodology. Linowski identified species in each location (Table 2.1).

MS1 was collected on the upland prairie in low hummocky terrain. Linowski identified this location as classic dry mixedgrass prairie with a *Stipa*/*Bouteloua*/forb ratio of 60/20/20. The species composition is typical for prairie locations in the study area. A common forb in this community is *Krascheninnikovia lanata* (winterfat), which is an early spring grower and high in protein and nutrients, making it an important food source for grazing and browsing animals lean from winter, including bison, pronghorn, deer, and horses. A notable species is *Opuntia fragilis* (brittle prickly pear), which is the most northerly occurring *Opuntia* species.

MS2 was collected on the upland prairie bluff near the head of Ravine #5, the coulee that is the locus of this study. This location was also identified as classic *Stipa*-dominant dry mixed grassland. The area is submesic and becomes increasingly xeric proximal to the bluff edge. There are numerous stone circles nearby and these circles create a slightly more mesic environment suitable for sedge and narrowleaf milkvetch (*Astragalus pectinatus*). The nearby interfluvial ridge, or spur, provides a suitable environment for low woody shrubs, wolf willow and prairie rose.

The MS3 collection location is a sub-xeric bluff edge, at a similar topographic position as MS2 but with a more xeric species composition and structure than the classic dry mixed grassland of the MS1 and MS2 locations. Pasture sage dominates at the bluff edge and transitions to *Stipa*-dominant classic dry mixed grassland distal from the bluff.

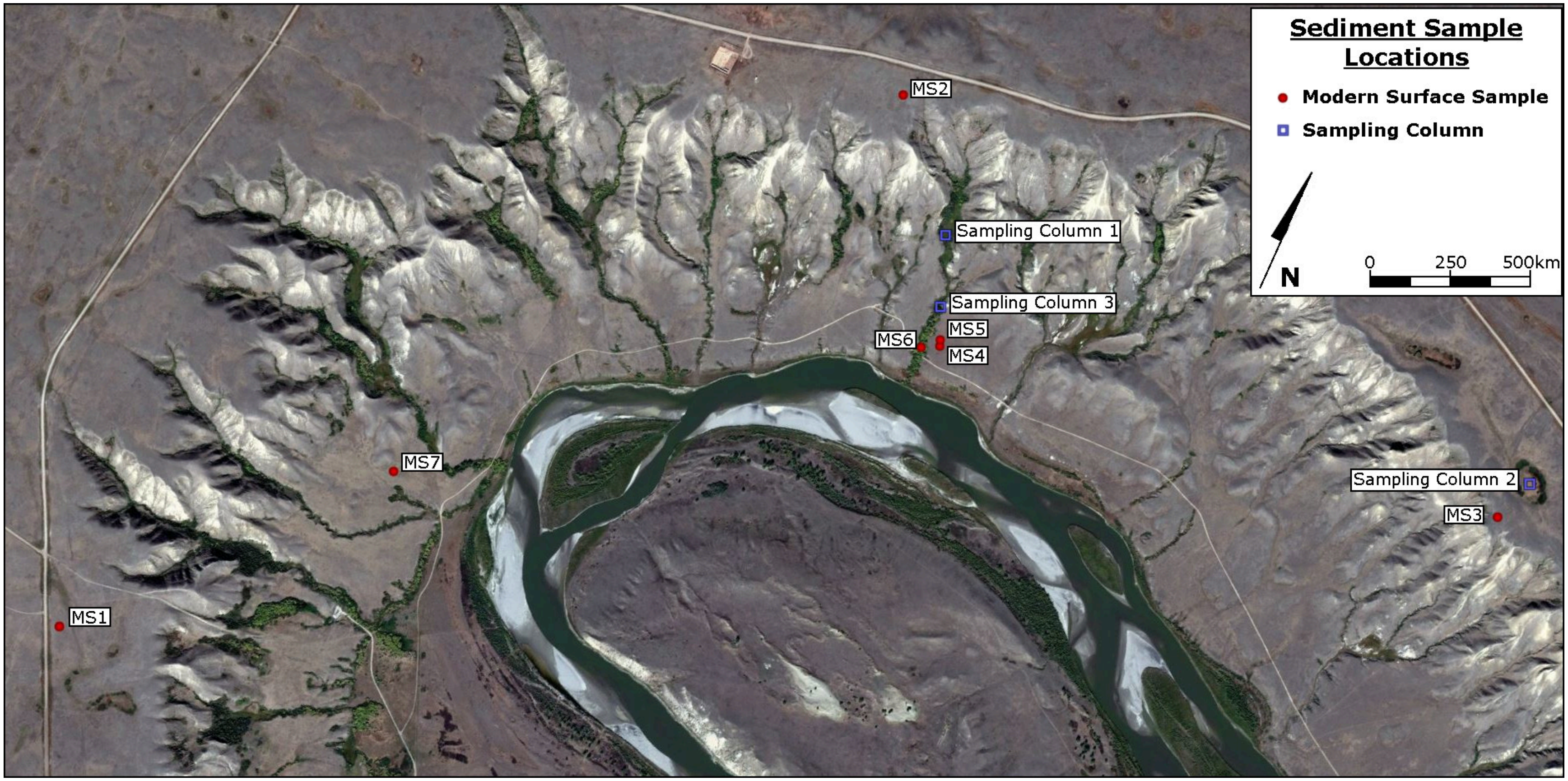


Figure 2.9: Locations of modern surface composite samples (MS) and sampling columns.

Table 2.1: Vegetation identified by Linowski at the sampling locations.

Location	Scientific name	Common name
Sampling column 1, ravine 5 coulee, open	*not visited by Linowski*	
coulee edge and slope	*Symphoricarpos albus*	snowberry
	Astragalus pectinatus	narrowleaf milkvetch (locoweed)
	Equisetum arvense	field horsetail
	Rumex crispus	curly dock
coulee bottom	unidentified mid-length grass and sedge	
Sampling column 2, upland depression		
depression edge	*Symphoricarpos albus*	snowberry
	Artemisia ludoviciana	silver wormwood (white sagebrush)
depression interior	*Hordeum jubatum*	foxtail barley
	Poa palustris	fowl bluegrass
	Ambrosia spp.	ragweed
	Castilleja sp.	owl's clover
	Rumex crispus	curly dock
	Polygonum amphibium	water smartweed
	Artemisia tilesii	stinkweed
	Achillea millefolium	yarrow
sampling column 3, ravine 5 coulee, wooded		
coulee edge and slope	*Shepherdia argentea*	silver buffalo berry
	Glycyrrhiza lepidota	wild licorice
	Rhus trilobata	skunkbush sumac (sourberry)
	Symphoricarpos albus	snowberry
	Prunus virginiana	chokecherry
	Stipa spp.	needle-and-thread grass
	Bouteloua gracilis	blue grama grass
bottom	*Mentha arvensis*	wild mint
	Phleum pratense	timothy (introduced)
	Angelica spp.	angelica
	Carix aquatilis	water sedge
	Cornus sericea	dogwood red osier
	Salix amygdaloides	peach-leaved willow

Table 2.1 (cont.): Vegetation identified by Linowski at the sampling locations.

Location	Scientific name	Common name
MS1 location, classic dry mixed grassland		
	Stipa spp.	needle-and-thread grass
	Bouteloua gracilis	blue grama grass
	Artemisia frigida	pasture sage
	Krascheninnikovia lanata	winterfat
	Ratibida columnifera	coneflower
	Haplopappus spinulosus	spiny iron plant
	Grindelia squarrosa	curlycup gumweed
	Gutierrezia sarothrae	broomweed
	Solidago spp.	goldenrod
	Opuntia fragilis	brittle prickly pear
	Koeleria macrantha	June grass
	Melilotus officinalis	sweet clover (introduced)
	Agropyron cristatum	crested wheatgrass (introduced)
MS2 location, classic dry mixed grassland	*same composition as MS1, and also:*	
in stone circles nearby	*Carix* spp.	sedge
	Astragalus pectinatus	narrowleaf milkvetch (locoweed)
	Chondrilla juncea	rush skeletonweed
interfluvial ridge nearby	*Elaeagnus commutata*	wolf willow, silverberry
	Rosa arkansana	prairie rose
MS3 location, sub-xeric bluff edge		
	Artemisia frigida	pasture sage
	Stipa spp.	needle-and-thread grass
	Koeleria macrantha	June grass
	Erigeron caespitosus	tufted fleabane
MS4 location, dry mixed grassland	*same composition as MS1, and also:*	
	Pascopyrum smithii	western wheatgrass

Table 2.1 (cont.): Vegetation identified by Linowski at the sampling locations.

Location	Scientific name	Common name
MS5 location, dry mixed grassland	*same composition as MS1, and also:*	
	Carix spp.	sedge
	Stipa spp.	needle-and-thread grass
MS6 location, ravine 5 coulee bottom, disturbed riparian, closed canopy		
	Acer negundo	Manitoba maple (box elder)
	Clematis sp.	clematis vine
	Urtica dioica	stinging nettle
	Chenopodium berlandieri	pitseed goosefoot
	Mentha arvensis	wild mint
	Tussilago farfara	coltsfoot
	Elymus canadensis	Canada wildrye
	Lithophragma glabrum	starflower
	Tiarella trifoliata	threeleaf foam flower
	Hordeum jubatum	foxtail barley
	Prunus virginiana	chokecherry
MS7 location, classic dry mixed grassland	*same composition as MS1, and also:*	
	Atriplex canescens	salt sage
	Kraschenninnikovia lanata	winterfat

MS4 and MS5 collection locations are both dry mixed grassland on the lowland alluvial fans near Ravine #5. The MS4 location species composition is dominated by western wheatgrass and the MS5 location is dominated by a mix of needle-and-thread grass and sedge. The MS7 location is about 1.8km west of Ravine #5 and is also on a lowland alluvial fan but is the classic *Stipa*-dominant dry mixed grassland.

MS6 was collected in the coulee bottom of Ravine #5 approximately 80m from where the coulee mouth opens onto the narrow floodplain of the Red Deer River. This area is characterized by woody riparian vegetation with a mostly closed canopy. Chokecherry lines the coulee here. All trees in this location are Manitoba maple, which indicated to Linowski that this area maintains higher relative soil moisture throughout the summer. The understory vegetation at this location is early successional, indicating frequent disturbance, most likely fluvial. Both aspects of this location are likely due to the proximity of the river.

Sampling column 3 was taken from the same coulee, Ravine #5, approximately 150m upstream from MS6. This area has a similar woody riparian character with a slightly different species composition. The coulee edge and slope are lined with chokecherry, buffalo berry, snowberry, and wild licorice. The coulee bottom vegetation includes sedge, angelica (*Angelica* spp.), timothy (*Phleum pratense*), wild mint (*Mentha arvensis*) and dogwood red osier. The trees in this location are all tall peach-leaved willow, the tallest tree on the prairies after cottonwood (Cordes et al. 1997), and not a single Manitoba maple. The presence of trees indicates this area also has sufficient soil moisture through late summer. This location is at the coulee "tree-line" of the riparian soil moisture gradient; all upstream woody vegetation is shrubs.

Sampling column 2 was collected in the center of an upland depression, or slough, which appears to be periodically inundated. The dominant species are foxtail barley (*Hordeum jubatum*), fowl bluegrass (*Poa palustris*), and ragweed (*Ambrosia* spp.). Woody shrubs line the edge, predominately snowberry and an occasional taller shrub species, likely chokecherry.

The sampling column 1 location, which is the least accessible, was not visited by Linowski due to time constraints and the heat of the afternoon. I was able to make some tentative identifications of the local vegetation. The sampling area is a wide shallow area of the Ravine #5 coulee bottom, located roughly 2/3 up the length of the coulee from the mouth. This area was completely dominated by an unidentified mid-length grass, with some sedge mixed in. Along the edge of the coulee were occasional woody shrubs. Just below a stand of unidentified shrubs on the western edge of the coulee, where we staged our equipment, I identified what appear to be snowberry, field horsetail (*Equisetum arvense*), narrowleaf milkvetch, and possibly curly dock (*Rumex crispus*). It turned out this location is a slope fen with a floating vegetation mat. The wetland nature of the area is also indicated by a stand of cattails approximately 50m upstream from the sampling location.

2.7.3 Unusual communities and species

Besides the sampled areas, Linowski guided me to several locations of interest (Figure 2.10), with species outside their normal range or uncommonly dense within a vegetation community.

Atriplex canescens (salt sage or fourwing saltbush) absorbs salts from the soil and groundwater. This made it desirable for First Nations groups as a cooking spice and herb and may have been traded between groups (Linowski, personal communication 2017). Linowski identified an area with an unusually high concentration of *A. canescens* in the study area. This salt sage patch is roughly 10 hectares and lies approximately 500m southwest of the MS7 collection location. It is east of the truck path not far from the ranch house and appears to sit in the floodplain, on the second or third alluvial terrace above the river. The valley wall to the west has springs and the highest density of wooded coulees.

Elymus cinereus (Great Basin wild rye) is unusual for the area and is present in a large patch immediately adjacent to the large patch of *A. canescens*. This species is more usually found to the southwest, in Montana, Idaho, and the Great Basin region generally. It is also a plant that is difficult to establish. Linowski speculated that these two factors may indicate the species might have been intentionally brought to the area by First Nations groups or European settlers. *E. cinereus* is a clumping grass that grows about 2m tall, has edible seeds, and is excellent for weaving and cordage.

Acer negundo is common near coulee mouths in the study area but is also present well upslope when perched wetlands are present in the incised bluffs. *Maok-skoistch* is far west of the western edge of the usual range of *A. negundo*, around central Saskatchewan. *A. negundo* has a life span of around 60 years and many of the trees here are mature and large, with trunk diameters of 40-50cm. The Northern Cheyenne of nearby Montana used *A. negundo* in many ways, including collecting sap for sugar and syrup and to make candy; as a preferred firewood due to its long-lasting coals or as incense due to its sweet smell; ceremonially during the Sun Dance; and for carving bowls (Hart 1981). The wood was also used for instruments, including what may be the oldest known flutes in North America, dating to ca. 620 CE (Bakkegard and Morris 1961). If *A. negundo* was not introduced by non-human pathways, it may have been brought to the area by Old Women's Phase groups, generally considered the ancestors of the Blackfeet First Nations,

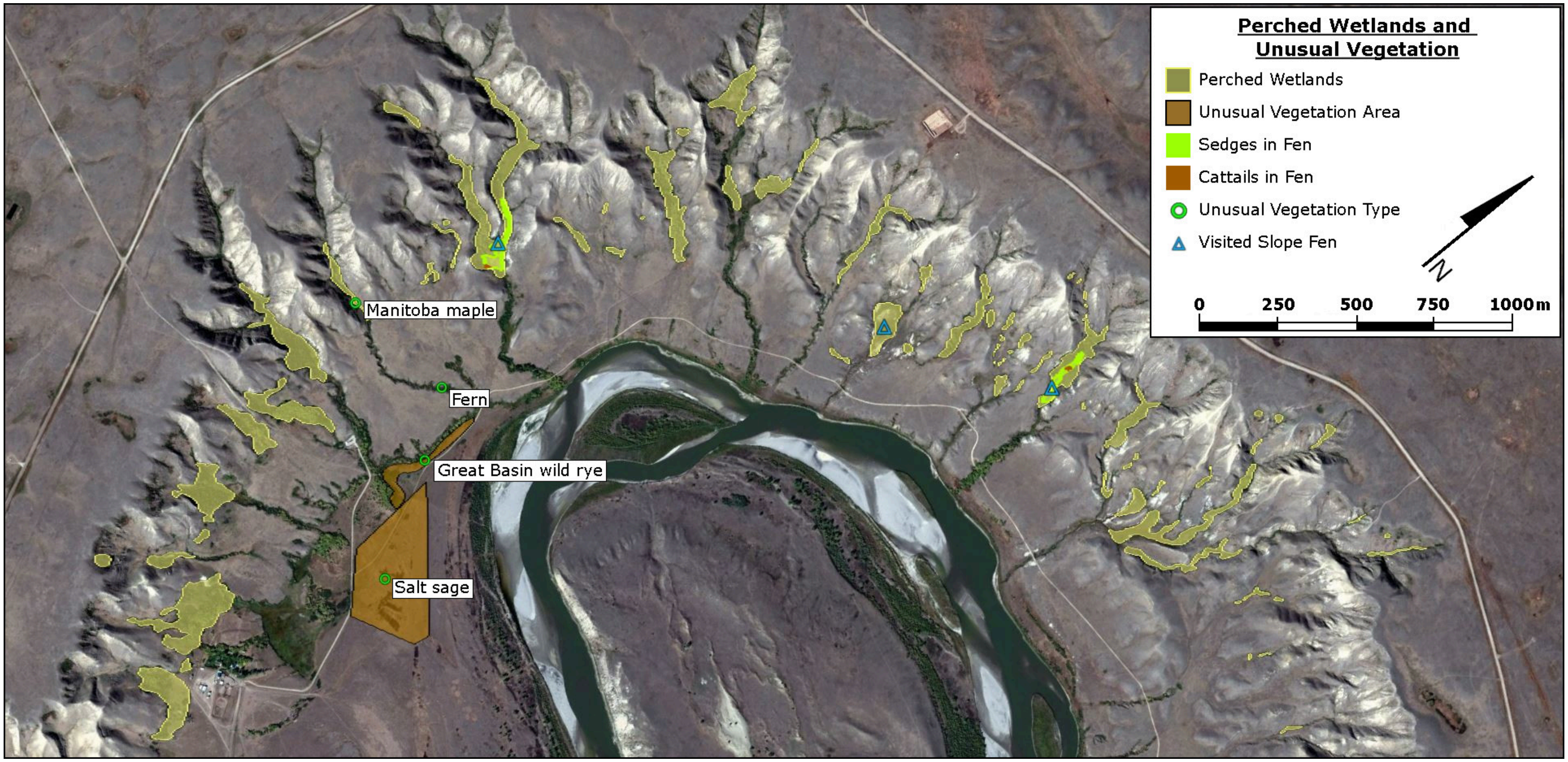


Figure 2.10: Perched wetlands (inferred from aerial photos); slope fens I visited all had floating vegetation mats and sedges, two had cattails; unusual vegetation areas identified by Linowski. Maple is common at coulee mouths and occasionally in upslope perched wetlands.

who once extended into eastern Saskatchewan (Walde et al. 1995). Or it may be a more recent introduction by European settlers.

Under the dense, closed canopy of tall shrubs in the smaller, shallower wooded coulees, conditions are suitable to allow fern (*Cryptograma* spp.) to grow. The nearest fern population is in the Cypress Hills 140km away (Linowski, personal communication 2017). The presence of fern here underlines the difference between the mesic microclimates in the coulees – created by the seeps and springs and maintained under the shade of trees and shrubs – and the arid climate on the dry grasslands.

2.8 Conclusion

In the Dry Mixedgrass Natural Subregion, there are a wide variety of plants and animals existing on the grasslands and in several other smaller habitats. These habitats provide heterogeneous resources for the inhabitants of the Subregion. The riparian gradients in river valleys, such as that of the Red Deer River, are especially rich ecotones. The human inhabitants of the area were not separate from the ecosystems described above but were and are an integral, highly influential part of them. From almost as soon as the glaciers receded, they were able to sustain themselves and, quite often, promote biodiversity through their cultural practices. The lives of the humans within the region surrounding the study area are the focus of the next chapter.

Chapter 3

Paleoenvironments and Cultural Ecosystems

In the previous chapter, I described the modern environmental setting of the study area, including the climate, geology, topography, soils, hydrology, and the plant and animal communities. The modern environmental setting is the end point of the environmental history of the area. In this chapter I incorporate the time factor by reporting on several paleoenvironmental studies from the prairies, foothills, and boreal forest in the vicinity of the study area. I also provide an overview of the human presence on the Northern Plains and the plains periphery through time. I try to situate the archaeological material cultures within the environmental framework and explore the ways in which human behaviours articulate with the rest of the ecosystem.

Investigating the paleoenvironment through proxies such as phytoliths, pollen, and plant and animal fossils allows us to obtain a rough idea of the climate, precipitation, and floral and faunal members of past ecosystems. Archaeology provides information on how people lived, what resources they used, how they organized themselves, and, to a certain extent, what their belief system was. If we have enough information on these, we can begin to understand how humans fit into the ecosystem – how they related to the other members of the ecosystem, the plants and animals around them. To make inferences about past ecosystems, we first need a theoretical framework.

3.1 Ecological frameworks

In the science of ecology, there are two paradigms for understanding ecosystems, traditional ecology, and new ecology. Oetelaar and Oetelaar (2007) provide a good synopsis of these two paradigms, which I paraphrase here.

Traditional ecological models are based on notions of stability and homeostasis and come from engineering, while new ecological models are based on disturbance and renewal and come from chaos theory. In traditional ecology, an environment exists in a stable state of equilibrium between all member organisms. When this system is disturbed, it undergoes a process of self-correction until equilibrium and stability is restored. Time is conceived as a cycle and disturbances are external, infrequent, of short duration and of minor impact. The concept of carrying capacity comes from traditional ecology and is the population which can be maintained at equilibrium. Traditional ecology provides the framework for cultural ecology, human ecology, and evolutionary ecology. In these theoretical frameworks, humans are external to the environment and all behaviours are adaptations to the environment, designed to optimize resource use. Traditional ecology is usually applied to hunter-gatherer societies but not usually to agricultural or horticultural societies.

New ecology puts humans of all societal types back into ecosystems. This new ecological framework exists under several monikers, including new ecology, historical ecology, human ecodynamics, long-term socioecology, evolutionary cultural ecology, and environmental history. New ecological systems are dynamic, disturbances are vital, and the state of the system at any given moment is historical and contingent, i.e., dependent upon all previously existing states. In these systems time is directional, which means states build on the preceding states and once the system has changed from one state to another the previous state is irretrievable. Disturbances in this framework are constant, with wide-ranging, often interconnected effects, and are usually not external but internal, arising from the community itself. In the new ecology, humans are internal, never external, to the ecosystem, and we are important agents of disturbance and change (Oetelaar and Oetelaar 2007:69). In many ways this ecology is not new but old, older than modern scientific epistemology, and represents a rediscovery or reformulation of an Indigenous view of our place in the world (Berkes et al. 2000).

Complementary to new ecology is Niche Construction Theory (NCT), as described by Smith (2016), which proposes that organisms do not just respond to environmental changes but change their environment in ways beneficial to themselves. These environmental changes spur further responses by organisms and the cycle continues in a feedback loop resulting in organisms constructing environmental niches for themselves.

Humans are fantastic at changing their environment in ways beneficial to themselves and adjusting their behaviours to create feedback loops. Although Smith is interested in the advent of domestication and agriculture, the theory begins with foraging societies influencing the composition and distributions of beneficial species within their environment. Smith proposes certain environmental conditions are prerequisites for domestication, including a region of abundant and diverse resources with a stable climate where people can create permanent or semi-permanent settlements. As people live in an area, they become increasingly familiar with the habits and properties of the species within it and how to properly interact with them, a concept referred to as Traditional Ecological Knowledge, or TEK (Berkes 1993). TEK is passed down through “stories, myths, rituals, and … inter-generational [instruction]” (Smith 2016:321). Over time a society develops a strong sense of connection and belonging to the lands in which they live, what Smith (2016:321) terms “corporate ‘ownership’”. Furthermore, according to Smith, this social connection to land requires the society to develop social constructs regulating responsibilities towards, interactions with, and access to resources. The social connection to land also can spur communal projects to demonstrate this connection, for example in the form of cemeteries, mounds, or monuments. TEK, connection to land, and the development of social rules regarding how one behaves towards the land are fundamental to most human societies, not just sedentary proto-agriculturalists.

3.2 The human role in the environment

3.2.1 Ecological renewal cycles

Continual renewal is vital to the health of an ecosystem. In their discussion of indigenous land management in the Canadian boreal forest, Berkes and Davidson-Hunt (2006) provide a good summary of renewal cycles and forest succession, which I paraphrase here. Renewal promotes diversity and diversity promotes resilience in the face of disturbance. Disturbance is the first step in the renewal process. Any disturbance to an ecosystem (a community of organisms) sets in motion a chain of events, whereby certain community members must respond to the immediate disturbance and other community members must respond to those primary responses and other community members must respond to those secondary responses, and so on. This chain of responses causes changes to the composition of the community until either a temporary equilibrium is achieved, or a new disturbance sets the process in motion again. Disturbances therefore constantly renew the ecosystem.

Within the plant community of an ecosystem, the changes caused by a disturbance usually consists of a sequence of plants replacing each other, called a succession. Early successional plants take advantage of the original disturbance but are replaced by intermediate and late successional plants until the “climax” vegetation is reached, which is a temporary equilibrium.

Each stage generally contains fewer species types than the previous stage until the climax stage, which can be nearly a monoculture. For example, a typical forest succession involves a highly diverse pioneering herbaceous vegetation being replaced by a less diverse brushy vegetation, being replaced by an even less diverse climax vegetation of trees. The succession can be interrupted and reset to the early successional stage at any time by a new disturbance. In this way, disturbance can promote diversity.

Disturbances rarely affect an entire ecosystem, instead different areas are disturbed at different times. This creates a highly diverse environment of numerous areas in different stages of succession called a heterogeneous mosaic (Peacock 1998). A heterogeneous mosaic attracts a wide range of animals which prefer different habitats, thereby creating immense biodiversity. For this reason, most human modifications to an environment occur as a disturbance to the floral community.

3.2.2 Modification methods and management scales

In this section I will describe the methods by which environments were modified and the effects these methods had. This section is largely summarized from Peacock's (1998) doctoral dissertation, in which she investigated methods of wild food production on the Canadian Plateau in British Columbia.

The technical methods by which environments were modified by hunter-gatherers are surprisingly simple, but their reasons for performing these methods and how they were organized were complex and linked to ideology and spirituality. These methods were organized by Peacock into a hierarchy of scale based on the level at which the methods and effects occurred. These levels are the species level, the community level, and the landscape level.

3.2.2.1 Species level

At the species level, the desired goal is to enhance the longevity, reliability, and productivity of an individual plant or all the plants of a single species in a population. The species level methods are selective harvest; digging and replanting; tending, tilling, and weeding; sowing and transplanting; and pruning and coppicing.

Selective harvest, as the name implies, is harvesting only a chosen fraction of an available resource based on certain criteria. These criteria are usually interrelated. Harvesting based on a species' annual growth cycle involves only harvesting at certain seasons or when conditions are right. Many species evolved annual fluctuations in their production of edible fruits, seeds, and nuts in which several years of light production are meant to thin the populations of the animals that consume the fruits, seeds, and nuts, followed by a year of heavy production meant to overwhelm the survivors and increase the chances of reproduction and propagation (Zeanah 2017). In this situation, humans might limit their harvest to heavy yield years.

Plants are also selectively harvested based on a plant's reproductive status. Harvest is usually related to nutrition levels, palatability, and potency, which are often connected. An example would be harvesting a yucca just as the bloom stalk is beginning to sprout, when the build-up of stored energy is at its maximum, which makes the harvested stalk both more nutritious and more palatable.

Plants may be harvested based on their maturity, by which individuals of a species are not harvested until certain desired qualities have been attained. A good example would be timber harvested for certain construction-related qualities. Similarly, size is another common criterion for selective harvest. Peacock describes ethnographic reports in which only medium-sized root plants are harvested, allowing small plants to grow and large plants to go to seed. Additionally, harvesters would go through their harvest and replant the smallest collected roots at the end of the day.

The final criterion for selective harvest is a preference for one location over another. A medicinal plant might have or be perceived to have greater potency if it is collected from a hard to reach location. A highly productive patch for one resource might also be productive in other resources, diminishing time and effort to harvest multiple resources. The effects of selective harvest on a population include a thinned population and an alteration of the age structure of the population, both of which may decrease intra-species competition and increase productivity.

In her doctoral dissertation, Castle (2006) investigated anecdotal evidence that prairie turnip harvest appeared to increase the prairie turnip population, a situation she called the prairie turnip paradox. The prairie turnip (*Pediomelum esculentum*) is a hardy long-lived perennial which spends much of its life dormant below ground. When the plant grows above ground, it emerges in early spring, flowers by May, and, once the seeds are ripe, the above-ground plant breaks away by late June or early July to tumble and disperse its seeds. Seeds can remain in the ground for a long time before germinating. Likewise, plants can remain at the seedling stage for quite a long time until the conditions are right for it to mature into an adult plant. Castle found that when harvested, there were more seedlings recruited to take the place of the adult than on otherwise undisturbed ground. Castle did not find that the population increased because of harvest, however.

Castle did find that the reported traditional harvesting methods had the potential to maximize the sustainable yield of a prairie turnip patch. Traditional harvesters reported concern for the plant population and for future harvests. The harvesters used a combination of cultivation techniques and several selective harvest techniques. They harvested only when the seeds were ripe, which was a narrow window before the plants tumbled and the subterranean parts became invisible. They left the plant tops with the seeds at the harvest hole. They harvested only a fraction of the plants available, ranging from 1 in 2 plants to 1 in 20 plants. Finally, they would harvest infrequently, rotating harvest areas over several years. Castle found that the reported harvest of 1 in 3 plants in an area every three years were likely unsustainable in her study environments. She calculated however that a harvest of 1 in 20 plants every year or a harvest of 1 in 3 plants every five years were both sustainable. Harvesting in the manner reported, where the plant top with ripe seeds was left at the hole, while also harvesting only 1 in every 3 plants every five years tripled the sustainable yield over all other methods.

Castle concluded that while burning creates favorable conditions for overall grass dominance on the prairie, harvest disturbance creates conditions favorable for forbs, which are the majority of edible and medicinal plants on the prairie. Harvesting using traditional techniques does not increase the populations of edible and medicinal plants, but they can greatly increase the sustainable yield of those plants.

As in the above case of the prairie turnip, the other modification methods employed at the species level are commonly associated with horticulture. A digging stick was commonly used to harvest roots and medicinal plants. Digging generally has the effect of incidentally preparing the earth for new growth by aerating it and increasing moisture retention capacity. Weeding was often done while digging, with the effect of removing competition from undesirable species, for example removing toxic death camas from meadows of the very similar edible blue camas (Peacock 1998:42). Replanting roots and seeds of harvested plants maintained productive population levels and sowing seeds could expand the population increasing productivity. Transplanting utilized species from one area to another extended the range of a species and allowed easier or more frequent access to the species for humans. Pruning removes old growth to encourage new growth or increase productivity. Pruning could be intentional, such as removing old snowberry shoots in the Great Basin to promote new shoots to grow, which were harvested for arrow shafts. Or it could be incidental to the harvesting process, such as with some berries, including Saskatoon berries, which are harvested by removing the entire branch. Coppicing usually occurred when all above-ground portions of a plant were harvested for various purposes, leaving the rhizome intact to grow anew. Similar to pruning and coppicing was individual burning, in which, for example, individual hazelnut bushes were burned to promote new growth and increase productivity.

An interesting recent article (Hoffmann et al. 2016) describes an engineered garden feature in the Katzie First Nation, in the vicinity of Vancouver, British Columbia, which was designed to increase the productivity and reliability of wapato. Wapato (*Sagittaria latifolia*) is a perennial aquatic to semi-aquatic herb, common across North America, the tubers of which were an important and widely traded winter foodstuff on the Northwest Coast. The engineered feature was a pavement of tightly packed fire cracked rock and cobblestones, all roughly 12 cm in diameter, constructed with the purpose of hindering the wapato rhizome from growing too deep, which enabled an easier and more productive tuber harvest. The feature was constructed in an existing wetland and the hydrology of the location was engineered to maintain a permanent water depth of 15 to 30 cm. The wetland diversity remained, as evidenced by other recovered macrobotanical remains, but the wapato population produced tubers more reliably and more efficiently, placing this feature within the category of species level environmental modification.

All of the species level methods employed mimicked naturally occurring disturbances. The majority of species managed in these ways by the indigenous inhabitants of the Americas were perennials. Thus, the techniques work because these plants reproduce both sexually and vegetatively and are long lived species. These human disturbances increased species density, increased productivity in the short and long terms by increasing yield and longevity and extended the range of many species. Many, if not most of these activities could be accomplished simultaneously, while working in a single productive location of multiple species, a community.

3.2.2.2 Community level

At the community level, the goal is to create and maintain the productivity, reliability, and diversity of a community, a habitat, or a location. This was usually achieved by creating associations of edible, useful, medicinal, and culturally significant plants by manipulating successional sequences. At the community level, fire was the main tool, though other intermediate disturbances could be capitalized upon as opportunity arose.

Fire was used for a wide variety of purposes, including clearing paths, clearing understory growth, creating berry patches, creating grazing and browsing areas for game, enhancing biodiversity, creating clearings, expanding grasslands, retarding forest encroachment, altering faunal community composition, creating dead wood stands, clearing areas for visibility and hunting, and controlling insects and mosquitos (Berkes and Hunt-Davidson 2006, Carson et al. 2014, Oetelaar and Oetelaar 2007, Peacock 1998). The main effect of fire is to reset growth to an early successional stage and to introduce nutrients back into the soil more quickly than decomposition. Most edible plants are early successional vegetation (Berkes and Hunt-Davidson 2006). Natural fires are larger, hotter, less frequent, and more disastrous than anthropogenic fires. Anthropogenic fires are also set during wetter seasons such as early spring or late fall when they can be better controlled and are safer. Burning at these times prevents uncontrolled spread, minimizes intensity, protects soils from heat damage, and, especially in spring, introduces nutrients to the soil in time for the growing season, making succession plants healthier and more productive.

Community level disturbances were created or maintained through burning or other intermediate level disturbances and the effect was to create a variety of habitats or communities. These communities vary by the types of species associated with each community, the specific composition of each community, and the richness and diversity of each community. These habitats were often early successional stages and were open habitats which included a diverse array of sun and fire tolerant species, which in turn attracted a variety of animals to them. The effect of creating communities of varying composition was to create a landscape of highly diverse and productive, shifting resource zones.

3.2.2.3 Landscape level

At the landscape level, the goal is to combine all the species level and community level efforts to create and sustain a heterogeneous mosaic, which provides all of a society's resources. The tools at the landscape level are no longer physical but cognitive and comprise the political decision-making system as well as the social systems regulating management and harvesting. These tools are required to organize the timing of the harvest for each resource, the amounts to be harvested, which areas will be allowed to rest and renew themselves, and how harvest in areas will be rotated or alternated. In indigenous traditional frameworks, these landscape management methods are often based in spirituality and ritual responsibilities.

The key component of these various methods described above is that they are all forms of disturbance under the control and direction of human societies. The methods used at each level are interconnected and interact with each other constantly. While humans often take an active, intentional role in modifying succession, for the most part the human role is to merely create a disturbance and let nature take its course. Generally speaking, the resource management methods described above are less about influencing the natural resources and more about influencing human behaviour (Oetelaar and Oetelaar 2007).

3.2.3 Ontological frameworks of environmental modification

At its core, human behaviour arises from a society's worldview or ontology, which is itself heavily influenced by how a society understands knowledge and knowledge creation, or epistemology. The methods of shaping human behaviour are by necessity rooted in the ontology and epistemology of a society. By the same token, epistemologies and ontologies are, in return, shaped by human behaviours.

The ontology of most modern societies, in many ways, is centered around the notion of the separation of humans from nature. The ontological view of humans as separate from nature and the linked notion of human mastery and control over nature, have their epistemological roots in Christianity, Classical Greek philosophy, and Humanist writings of the Italian Renaissance in the early Modern period of Europe (Bauckham 2006). Modern epistemology is, to a greater or lesser extent, grounded in the scientific method (Berkes et al. 2000). In the early Modern Period in Europe, a new economic system, Capitalism (Wood 2009), a new epistemology, Science, and this new ontology of humans as masters of nature were all brewing together and building on each other to create what we think of as “Western Civilization”.

“Western” economy, ontology and epistemology are central to the traditional ecological frameworks (*sensu* Oetelaar and Oetelaar 2007) described above and are reflected in how our society controls human behaviour in agriculture, forestry, and resource management. Following Berkes and Hunt-Davidson (2006), behaviour is controlled by top-down governmental policies and guided by commercial concerns which are modulated by the current state of scientific thinking. For example, modern forest management is based on the idea of promoting growth of a commercially profitable monoculture in most areas, while setting aside protected conservation areas to preserve ‘natural’ forest. Neither of these practices promote biodiversity because both try to maintain habitat at a climax stage by suppressing disturbances and renewal cycles (Berkes and Hunt-Davidson 2006:43). While Indigenous environmental modification in the Americas is increasingly viewed within the new ecological framework, the mechanisms controlling human behaviour on all levels are still discussed from a Western ontological perspective of scientific ecology and economic principles, instead of an indigenous, traditional ontological perspective (Oetelaar 2014).

Oetelaar has written a series of recent articles (2014; Oetelaar and Oetelaar 2006, 2007) in which human environmental modification in southern Alberta is examined from an indigenous traditional perspective based on ethnographies and histories of the Siksika (Blackfoot), Piikani (Peigan), and Kainah (Blood) First Nations, collectively referred to as the Nitsitapii. From this perspective, the Nitsitapii territory is a made up of named locations connected by a system of trails. These named locations were created by spirit beings ancestral to the Nitsitapii and are locations of spiritual power, which is why there are resources there. Each of these places has stories, rituals, and songs associated with it. The stories tell of the deeds of the ancestral beings and, within these stories, knowledge of how to acquire and maintain resources is transmitted as ritualized action. Performing the correct actions at the correct places results in the continued abundance of resources. Current abundance is evidence that the ancestors correctly performed the ritual actions in the past. For the Nitsitapii, the annual journey from sacred place to sacred place is a pilgrimage and a journey through Nitsitapii history.

The annual pilgrimage with its stories and rituals is both a reflection of and a contributor to the Nitsitapii worldview. In the Nitsitapii worldview humans are natural beings, the same as plants, animals, streams, and mountains (Oetelaar and Oetelaar 2007:66; Oetelaar 2014:11). It is the responsibility of human beings to maintain proper reciprocal relations between themselves and all other beings, natural and spiritual. Maintaining these relationships regenerates and renews the land and its resources. In this traditional framework, humans play a central role and have great responsibilities. Resources are not managed according to economic or ecological principles but rather as part of a social and spiritual system of rituals and relationships. From a religiously ingrained code of conservationist ethical conduct (Oetelaar and Oetelaar 2007), a system of ritual behaviours, repeated over centuries, created a managed landscape that was optimized to the Nitsitapii worldview. This framework aligns closely with Niche Construction Theory as described by Smith (2016).

Oetelaar (2014) applied the traditional Nitsitapii framework to several cases, including the construction and operation of bison jumps and pounds, the maintenance of sacred groves, and the origin of submontane forest in the Cypress Hills. The major components of a bison jump are the collection basin, the drive lane, the precipice or pound, the bonebed, and the processing area. The collection basin is a grazing area optimized for bison through burning, which, in the described area, promotes a fescue grassland. The burning is a ritual which recreates the story of Napi's fire-leggings. The drive lane is constructed and operated according to instructions given to the Nitsitapii by Beaver in the legend of the twin brothers and in the story of the woman who performed the first buffalo calling ritual. The jump or pound itself could be abandoned on the recommendation of a spirit being or due to a dream or vision of a community member, sometimes because it was too successful. In resource management terms, the bison population would be allowed to rest and recover. Bonebeds were likely burned out of respect for the animals. A processing area at Head-Smashed-In was a pavement of cobbles hauled up from the river 2 km away, again likely as a ritual of respect. Repeated use of areas like these would have created a spiritual attachment to the place, which would have also brought ritual responsibilities. These responsibilities are the traditional equivalent of modern resource management methods.

According to historical reports, travelers on trails in Nitsitapii territory always seemed to end a day's journey at a pleasant, wooded grove near a spring or stream – what Oetelaar and Oetelaar

(2007) refer to as sacred groves. These groves were cleared and maintained by burning, which also would enrich the soil, especially if burned in the spring before the growing season. This also protected the grove from summer wildfires and canopy fires. Repeated use enriched the soils through the deposition of refuse, ash from hearths, and bodily waste. These activities may also have introduced edible and useful plants from other areas to grow in the groves. Within the traditional framework, these groves were created by ancestral and spirit beings, and they were maintained for future use through the performance of ritual.

The final and most controversial example presented by Oetelaar and Oetelaar (2007) is the possible introduction of submontane forest, specifically lodgepole pine, to the Cypress Hills. Current theories of non-human origins for the vegetation of Cypress Hills are not well-supported by current evidence. The Oetelaars propose that humans may have incidentally introduced or intentionally transplanted this vegetation from the Rocky Mountains. The inhabitants of the area would make offerings before harvesting plants and would dispose of plant resources with reverence. The proposed method of introduction may have been incidental to either offerings of, or disposal of submontane plant resources within the Cypress Hills. The introduction may also have been an intentional experimental transplant that succeeded.

Berkes and Hunt-Davidson (2006) describe the traditional modifications to the Canadian boreal forest environment made by the Shoal Lake Anishnaabe of the Iskatewizaagegan No. 39 Independent First Nation and their beliefs regarding how the forest should be used. Traditionally, the Shoal Lake Anishnaabe would set a canopy fire in an area of the forest to kill the trees and create a space for berry bushes. This practice was banned in the early twentieth century as "wasteful" by a government focused on timber rather than non-timber forest products. Since then, the Shoal Lake Anishnaabe have been forced to depend on natural fires and logging industry clear-cutting to create spaces.

As described by Berkes and Hunt-Davidson (2006), the modification disturbance begins with *Nopoming* (climax phase forest) which is subjected to *Ishkote*, either anthropogenic or natural burning. This results in *Ishkwaakite* (newly burned trees) where the fire-killed trees are standing deadwood (harvested for firewood) and herbaceous growth is just beginning. *Ishkwaakite* can progress to either a garden or a blueberry patch.

Gitigaan (planting or garden) is established where there are deep loamy soils, and the forest is mixed hardwoods. Once the dead wood is cleared away the *Gitigaan* is established and burned every spring for planting. Once the *Gitigaan* is abandoned, it can be recognized by its distinctive soil profile and the vegetation imprint can last for up to 50 years. Some of the islands in Shoal Lake are maintained as *Gitigaan* and known as *Gitigaan Minis* (island gardens).

Ishkwaakite not suitable for *Gitigaan* have thin, rocky or sandy soils. These areas are known as *Oshkwaakite* (older burned trees) and are left for 3 to 5 years until a blueberry patch develops. This patch is productive for about 2 years until honeysuckle starts to overshade the blueberry bushes. At this point, the blueberry patch is burned to regenerate the succession and increase blueberry productivity. A blueberry patch that is maintained by fire is known as *Miiniikaa* and once it is abandoned the succession continues until the area is *Nopoming* again.

A similar modification is practiced in logging clear-cuts which are known as *Gaagiidazhigiishkaakweyag* (there the trees were cut down) and which can become *Miiniikaa*, but not *Gitigaan*, though some site preparation is required. Sometimes a *Miiniikaa* is established and other times it fails, and the area reverts to *Nopoming*. This indicates that fire is likely required to introduce nutrients into the soils in many areas, as well as create a space for successional vegetation.

The Berkes and Hunt-Davidson (2006) article was begun as a discussion between the Shoal Lake Anishnaabe First Nation and forestry management entities which wanted to shift focus to commercially profitable timber and maintain certain protected conservation zones. The Anishnaabe elders were asked which plants were more important and should be protected in higher numbers. The elders responded that all plants are equally important, and all should be protected, from the landscape scale on down. The Anishnaabe view all plants as useful and as potential medicines. Learning the uses of the plants around them is a life-long process and new medicinal uses can be learned from others, from visions or dreams, and from shaking tents (ceremonies to communicate with spirits). The Anishnaabe view is that if we do not know which plants are useful, then we cannot make decisions about what should be protected and what can be lost. The Shoal Lake Anishnaabe believe the Creator placed them in their land with all the resources they need to live. They see it as their duty to “maintain these gifts” (Berkes and Hunt-Davidson 2006:42) and harmful practices can bring down reciprocal harm upon an individual or their family. They feel a duty not to influence abundances or habitat distributions and view burning as the "land reveal[ing] itself in its multiple manifestations" (2006:43). The elders of the neighboring Pikangikum First Nation also interviewed by Berkes and Hunt-Davidson (2006), view burning as a modification of the natural succession process without destroying or disrupting it, because the forest returns. Echoing Shoal Lake Anishnaabe beliefs, the Pikangikum elders felt a similar responsibility to their environment, which they translated as "as was, as is", meaning that everything on the land in the past should be there today and tomorrow (2006:42).

The Nitsitapii, the Anishnaabe, and the Pikangikum First Nations all share similar ontological frameworks, in which they are responsible to and for the natural and spiritual beings in the world. Maintaining proper relationships with the world to which they belong is central to their interactions with the world, including how they modify the environment using vegetational succession to enhance biodiversity. These traditional ontological frameworks stand in stark contrast to modern, Western ontology, as described above.

Traditional Ecological Knowledge gained over generations of observing, interacting, learning, and teaching finds its complement in the methods to increase abundance and enhance diversity – what we may term Traditional Ecological Resource Management, or better still, and from an Indigenous viewpoint, Traditional Ecological Relationship Maintenance (TERM). "Resource Management" indicates a level of mastery, control, and human externality – a Modern notion of non-human nature as objects to be used, profited from, or destroyed as we see fit (Moore 2017). "Relationship Maintenance" indicates a level of equality, reciprocity, and human internality, more in line with many Indigenous worldviews (Hernandez 1999). Placing human influence in terms of relationships implies a continual unfolding process of humans and non-humans learning about each other, interacting, and changing – akin to lifelong interpersonal relationships. Just as individual humans in a community maintain interpersonal relationships ranging from friendship to animosity, relationships between humans and the non-human world are likewise inescapable and entail a spectrum from friendly, through neutral, to antagonistic – from sweetgrass to poison ivy or from dogs to rattlesnakes.

3.3 Paleoenvironments and their associated biological communities

There have been numerous paleoenvironmental studies on the Northern Great Plains of Canada and the United States, only a few of which have occurred in the vicinity of the study area. Below

I have divided the timeline into several periods based on major climate periods, beginning with the Last Glacial Maximum (LGM) and ending with Modern conditions. I will describe each period from the available studies, including as much as possible the climate and moisture regimes, vegetation, and a summary of what we know about the activities of the groups associated with the material cultures of the period.

The culture-historical system I am using is that refined by Peck (2011) for southern Alberta from previous Canadian Plains culture-histories. I chose to use this work because it is the most recent book-length summary of the entire period of human occupation of the area until the arrival of Europeans. For a full treatment of the development of this culture-history and past and current debates within that development, I refer the reader to this work. Unless otherwise noted, descriptions of the archaeology and behaviours associated with each material culture are summarized from Peck. All date ranges of the discussed material cultures are from Peck, which I converted to calibrated/calendar years BP (cal BP) using the most recent calibrations in Reimer et alia (2013). I also chose to use the term ‘Precontact’ rather than ‘Prehistoric’ within the cultural-historical framework, which is in line with recent trends in North American archaeology Personally, I find flaws in both terms because they center nearly a thousand generations of Indigenous history around the very recent period of European colonization, but I neither have a better replacement nor would I presume to propose one on my own.

3.3.1 The Pleistocene and the arrival of humans on the American continents

The defining feature of the Pleistocene is a cycle of long, cold periods (glacials), during which continental ice sheets form and spread, interrupted by occasional, relatively short, warm periods (interglacials), during which the ice sheets disappear (Tzedakis et al. 2017). The glacial-interglacial cycle is correlated to changes in summer insolation at high northern latitudes due to regular changes in the Earth’s orbit and tilt known as the Milankovitch cycle (Emiliani and Geiss 1959). For the past 1 million years, each glacial cycle lasts approximately 100,000 years before starting anew (Past Interglacials Working Group of PAGES (PIWG) 2016; Tzedakis et al. 2017). The duration of glacials and interglacials is determined by measuring the ratio ($\delta^{18}O$) of two oxygen isotopes, ^{16}O and ^{18}O, in deep sea sediment cores (Emiliani and Geiss 1959). The ratio, $\delta^{18}O$, measures how much water is locked up in glaciers on land rather than in the ocean (PIWG

2016; Tzedakis et al. 2017). The beginning and end of interglacials is determined by inferred sea levels when δ¹⁸O crosses certain threshold values (PIWG 2016).

As described by Railsback et alia (2015), glacials and interglacials are known as Marine Isotope Stages (MIS) and referred to by number. The Holocene, the current interglacial, is MIS1 and the preceding glacial period is MIS2. All interglacials are odd-numbered and all glacials are even-numbered. Within glacials, there are temperature fluctuations. Warm periods in which ice sheets recede are called interstadials and the periods when cold returns and the ice advances again are known as stadials. These are currently represented in the MIS system as lettered sub-stages, e.g., MIS5e was the beginning of the Last Interglacial (ca. 130,000 cal BP). MIS3 and MIS2 are a mislabeled interstadial and stadial, respectively and are historical artifacts within the system. The boundary between (sub-)stages is counted as the midpoint between the peak of one (sub-)stage and the trough of the next, or vice versa (Figure 3.1).

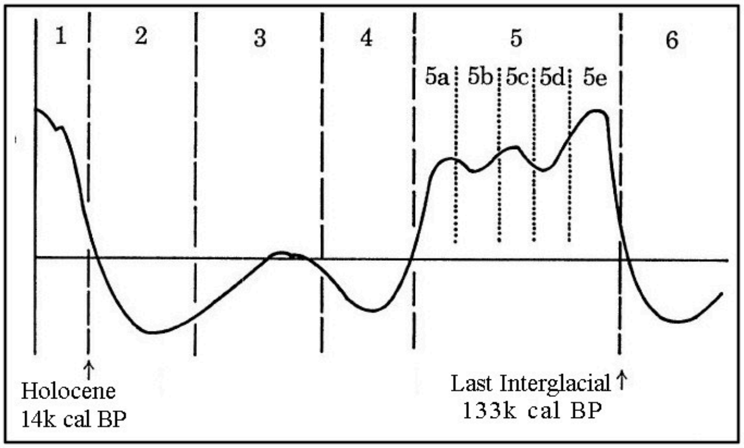


Figure 3.1: Example of MIS stages with boundaries at slope midpoint; adapted from Shackleton 1969:Figure 1.

The story of the entrance of humans into what was truly a New World begins at the peak of the MIS3 interstadial, ca. 36,000 cal BP. Waters (2019) presents a synthesis of current research into the earliest peopling of the Americas and which I summarize here. Genetic research is one of the most interesting recent developments and provides a rough chronological framework for gene flow and drift. Around 36,000 cal BP an Ancestral Indigenous American (AIA) genetic population emerges in Eurasia from the East Asian population. The AIA population maintains gene flow with the East Asian population for 9,000 years, ending around 25,000 cal BP. During this time the climate is cooling and the MIS3 interstadial ends and the MIS2 stadial begins at 29,000 cal BP.

The AIA population also maintained gene flow during this time with an ancient Siberian/northern Eurasian (Ma'alta) population which also ends at some point between 25,000 and 20,000 cal BP. The Last Glacial Maximum (LGM) falls within this timeframe, occurring ca. 21,800 cal BP. The LGM is the trough of MIS2 and represents the farthest extent of the Laurentide and Cordilleran ice sheets. During the LGM atmospheric CO_2 levels are around 180-190ppm, the lowest recorded in Earth's history (Meltzer and Holliday 2010; Piperno et al. 2015). The LGM is also when the climate began the warming trend that would become MIS1, i.e., the Holocene. MIS1 technically begins ca. 14,000 cal BP (the midpoint between the LGM and the Altithermal) but usually the Holocene is considered to have begun at the end of the Younger Dryas cooling interval ca, 11,500 cal BP. Concomitant with the onset of warming, deglaciation in southwestern Alberta along the Cordilleran-Laurentide ice sheet interface may have begun as early as 21,650-21,310 cal BP (Campbell and Campbell 1997).

From this point on, the AIA population is isolated from other human populations. At some point between 22,000 and 18,100 cal BP an Ancient Beringian (AB) genetic population emerges from the AIA population but maintains gene flow with AIA until ca. 11,500 cal BP. It is unclear whether the two populations split in Eurasia then travelled together (or one group on the heels of the other) into eastern Beringia, or whether the split occurred in eastern Beringia. During this time the climate is warming. The first glacial Lake Missoula megaflood occurs ca. 18,800 cal BP (Atwater 1986). The Cordilleran and Laurentide ice sheets begin separating in southwest Alberta, which would become the southern end of the Ice-Free Corridor (IFC), perhaps as early as ca. 18,250 cal BP (Dyke 2004:393), though it is more likely deglaciation began about 1,000 years later (Margold et al. 2019).

A brief return to cold conditions began at some point between 18,800 and 17,700 cal BP and ended ca. 17,000 cal BP. During this time the glacial front readvanced in the Great Lakes region but was stable in southern Alberta.

Between ca. 16,300 and 12,800 cal BP, the warming trend continued. This period is known variously as the Late-glacial Interstadial and the Bølling-Allerød warm interval. Using the MIS classification system, this is when MIS2 becomes MIS1 ca. 14,000 cal BP. During this time, the

IFC was rapidly developing, reaching 53.5° North latitude (Edmonton, AB) by ca. 15,000 cal BP (Margold et al. 2019). The IFC likely fully opens by 14,600 cal BP; the last blockage at the Cordilleran-Laurentide saddle, somewhere between 62°N and 65°N, collapsing and allowing meltwaters to enter the Arctic Ocean (Margold et al. 2019). Meltwater Pulse-1A also occurs at this time (14,600-13,800 cal BP), during which sea levels rise 14-18m in a span of just a few centuries – 9m of which is likely due to the opening of the IFC (Gregoire et al. 2012). Rising sea levels close the Bering Land Bridge, separating American/Beringian and Eurasian populations of terrestrial organisms. Towards the end of this period, ca. 13,300 cal BP, bison are dispersing northward into southern Alberta (Wilson et al. 2008).

Between 17,500 and 14,600 cal BP two more genetic populations emerged from the AIA population, the Northern Native Americans (NNA) and Southern Native Americans (SNA). The NNA population moved from Beringia into the Great Lakes region of North America and never left. The SNA population dispersed into and inhabited all other regions of the American continents. Whether the two populations split in Beringia and entered the trans-glacial lands separately or entered together and then immediately split in two is unclear from genetic evidence.

It is also unclear what route or routes they used, following the Pacific coast, traversing the Ice-Free Corridor, or both. ^{10}Be, ^{14}C, and OSL dates indicate the Pacific coast route was passable by around 16,000 cal BP and the Ice-Free Corridor was passable by around 13,000 cal BP. There are currently no archaeological materials along either proposed route pre-dating archaeological finds south of the ice. While there are a few other interesting genetic stories reported by Waters, it is clear there is no evidence for an in-migration of a far western Eurasian genetic population following a proposed Atlantic ice-edge route.

Waters also provides a brief overview of some of the oldest archaeological sites in the Americas during this period. The ages range from 16,000 and 15,500 cal BP (OSL dates on projectile points) at the Gault and Debra L. Friedkin sites along Buttermilk Creek in central Texas to 13,300 cal BP at the Wally's Beach site in southern Alberta. The northernmost site is Wally's Beach, and the southernmost site is Monte Verde (14,200 cal BP) in southern Chile. The easternmost sites in North America, and hence the farthest from the Pacific coast and the IFC, are at the Paige Ladson site in Florida (14,550 cal BP) and the less securely dated site at

Meadowcroft Shelter in Pennsylvania (15,000-14,000 cal BP). Davis et alia (2019) report initial occupation of the Cooper's Ferry site in the Columbia River basin in Idaho ca. 16,500-15,300 cal BP – providing support for the Pacific coast route.

At the end of this warming interval and into the following Younger Dryas cold interval, the first named material cultural traditions, Clovis and the Western Stemmed Tradition, appear in the North American archaeological record. There are no paleoenvironmental proxy data available from this period on the southern Alberta Plains due to the presence of ice sheets or peri-glacial and immediate post-glacial landscape instability.

3.3.2 The Younger Dryas cold interval and early Holocene

At some point between 12,900 and 12,700 cal BP, the Younger Dryas interval begins, which is a reversion to cold, glacial conditions and lasts approximately 1200 years before warming resumes ca. 11,700 cal BP (Meltzer and Holliday 2010). The cause of the climatic shift was almost certainly a slowdown or stoppage of the meridional overturning circulation (MOC) which moves warm tropical water to the North Atlantic (Meltzer and Holliday 2010; Kennett et al. 2015). The disturbance to the MOC was most likely caused by a large pulse of fresh water from glacial Lake Agassiz, probably north along the IFC and the Mackenzie River into the Arctic Ocean (Meltzer and Holliday 2010; Murton et al. 2010). It may otherwise have been caused by a large amount of ice being dislodged by rising seas and sent into the North Atlantic (Meltzer and Holliday 2010), or even a cosmic impact by a comet or asteroid exploding in the atmosphere over the North Atlantic and shocking or melting the ice sheets (Wittke et al. 2013; Kennett et al. 2015).

During the Younger Dryas, according to Meltzer and Holliday (2010), CO_2 levels were approaching 265ppm and an abrupt 40‰ increase in atmospheric ^{14}C occurred, indicating reduced uptake of ^{14}C in the ocean and disturbance to the MOC. Insolation was higher than at any time in the preceding 70,000 years and there was a 20% greater difference in seasonal insolation than at present, i.e., summers received 20% more sun and winters 20% less sun than they do currently. According to Meltzer and Holliday, this reversion to cold under conditions conducive to warming made the Younger Dryas unlike any previous stadial, with varied effects depending on spatial, temporal, and seasonal position. Furthermore, the uniqueness of the period may have been a major contributor to the megafaunal extinctions during the terminal Pleistocene.

Mammoth went extinct on the North American Plains at the beginning of the Younger Dryas – the most recent specimen dates to ca. 12,740 cal BP (Waters and Stafford 2007). Wilson et alia (2008) presented evidence for diminution of bison as a response to the changing climate and possibly to human predation. *Bison antiquus* transitioned through *B. occidentalis* beginning ca. 11,600 cal BP, at the end of the Younger Dryas, to eventually become modern *B. bison*. The end of the Younger Dryas coincides with a genetic bottleneck for bison, though they were able to rebound and thrive on the Plains while many other Pleistocene megafauna went extinct.

There are only a few paleoenvironmental records from the vicinity of the study area which extend back this far in time. These records indicate a cool and moist environment.

The oldest paleoenvironmental data are from Mariana Lake in the boreal forest of Alberta (Hutton et al. 1994), 566km north-northwest of the study area and Moon Lake in the tallgrass prairie region of southeastern North Dakota (Valero-Garcés et al. 1997), 955km southeast of the study area. The Moon Lake record indicates a cool and moist environment ca. 13,500 cal BP continuing through the Younger Dryas and into the early Holocene until ca. 11,700, after which the region experienced a gradual decrease in moisture.

The Mariana Lake record indicates a cool environment with increasing moisture from a century or two before the Younger Dryas and into the early Holocene, when a drying trend begins. The oldest recorded plant community, beginning ca. 13,100 cal BP is one of sparse grass and forbs. By the middle of the Younger Dryas, ca. 12,500 cal BP, a white spruce dominant forest had established itself. In the early Holocene, ca. 11,500 cal BP, black spruce-sphagnum peatlands develop as well, creating a mosaic of white spruce forest and black spruce-sphagnum peatlands from ca. 10,700 cal BP. Beginning ca.10,200 cal BP, the Mariana Lake region begins to warm up and dry out as peatlands shrink and white spruce decreases, while birch increases.

At the end of the Younger Dryas and at the beginning of the early Holocene we can begin to include paleoenvironmental records from locations closer to the study area but far enough from each other to exhibit local differences within a period of warming temperatures and lessening moisture. The earliest of these is also the closest to the study area. Beaudoin (1992) reported on macrobotanical remains collected during construction of dugouts (livestock ponds) near the study area, as close as 33km and as far as 187km. These macrobotanical remains were unidentified wood, *Populus* wood (some beaver-gnawed), and seeds of several aquatic and mesic plants, and indicate a cool, wet environment from ca. 11,900 to ca. 10,500 cal BP.

Oetelaar (2004) presented evidence from the Tuscany site (EgPn-377) on the northwest outskirts of Calgary, 267km west-northwest of the study area, and in the Fescue Grasslands Natural Subregion. At the Tuscany site, vegetation is established by 11,400 cal BP and quickly transitions to a parkland environment with open spruce and poplar forest, that is stable throughout the early Holocene. Conditions are cool and wetter than modern during this time.

Near Prince Albert, Saskatchewan, approximately 430km from the study area, Wolfe et alia (2006) found evidence for sand dune activity ca. 11,100 cal BP as the area transitioned from a post-glacial grassland or parkland to boreal forest.

Grimm et alia (2011) report on the paleoenvironmental record at Kettle Lake, 555km southwest of the study area in far northwest North Dakota near the Saskatchewan border. From the end of the Younger Dryas ca. 11,700 cal BP, the Kettle Lake area is cool and wet but exhibits a warming and drying trend. At ca. 10,730 cal BP there is a brief but severe drought leading into a period of more frequent drought. From ca. 10,700 to ca. 9,300 cal BP the area is humid with brief droughts every one to three centuries. At the end of this period, ca. 9,300 cal BP the area experiences the most severe drought of the Holocene, indicating the transition to the mid-Holocene and the Altithermal.

Archaeologically, the Younger Dryas and early Holocene coincide with the Early Precontact Period. This period encompasses the earliest, classified, well-attested, and widely recognized material cultures in North America, beginning with Clovis. In Alberta, the material cultures of the Early Precontact Period are Clovis phase, Folsom phase, Sibbald phase, Agate Basin/Hell Gap complex, Alberta phase and Scottsbluff/Eden phase. This period lasts approximately 3,500 years from ca. 13,000 to ca. 9,500 cal BP.

The Clovis phase likely existed between 13,125 and 12,925 cal BP, with a potential maximum age of 13,250 cal BP and minimum age of 12,660 cal BP, depending on margins of error and calibration (Waters and Stafford 2007). In this chronology, Clovis is a rather short-lived material culture relative to most other North American Precontact cultures, lasting approximately 200 years but perhaps as long as 450 years. The genesis of Clovis was prior to the Younger Dryas cold interval and its demise occurred with the onset of the Younger Dryas or shortly thereafter.

The fluted Clovis point is the main diagnostic artifact of the culture, but other strongly characteristic artifacts include cylindrical beveled bone points and large blades. Presumedly ceremonial artifacts include very large, well-crafted Clovis points and bifaces, often cached; designs engraved on stone and bone (Lemke et al. 2015); and the use of red ochre.

Clovis materials, mostly Clovis points, are distributed across North America, east of the Rocky Mountains. These are most dense in the eastern half of the United States, which was forested at that time (Strong and Hills 2005; Gingerich 2011), but are also present on the Great Plains, and in certain areas west of the Rockies, including a pocket of density in southern California. But, when we look at Clovis point density and modern population density in the United States (Figure 3.2), we find a very strong overlap, indicating a possible collection bias rather than an accurate distribution of Clovis culture.

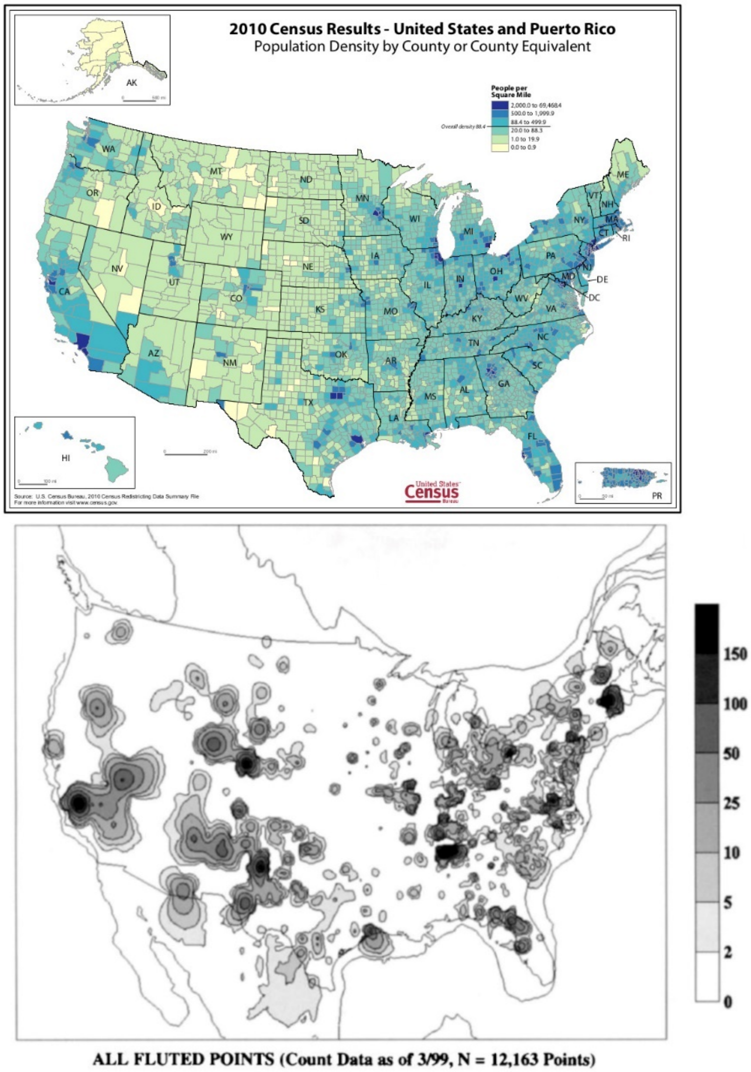


Figure 3.2: Top, US population density 2010 (United States Census Bureau 2018); bottom, fluted point finds density (Anderson and Gillam 2000:Figure 9).

There is a continuing debate over whether a Clovis people traversed the Ice-Free Corridor and dispersed southwards into North America or dispersed northward from the southeastern United States, entering Alaska through the Ice-Free Corridor (Ives et al. 2013; Waters 2019). Furthermore, the dispersal of

Clovis material culture may have been a diffusion of technology among existing people rather than a migration of a new people into these areas (Meltzer 1995). Hughes (1998) indicates this may have been a diffusion of atlatl technology, while Bradley and Collins (2013) speculate on the possibility of a revitalization movement among people experiencing a changing climate and witnessing the disappearance of scores of species of megafauna. Peck (2011) sees crude crafting of Clovis points on local lithics in Alberta and skilled craftsmanship on high quality exotic lithics to the southeast as evidence for Clovis movement from the ICF or Columbia River region into Eastern North America – though, logically, the opposite could just as easily be true. In any case, the debate will not be settled until there are many more securely dated Clovis sites than exist now (Waters and Stafford 2007).

Clovis culture is frequently considered to be organized around specializing in hunting Pleistocene megafauna, specifically Proboscideans, i.e., mammoth and mastodon (Cannon and Meltzer 2004). An analysis of faunal remains at 76 Clovis sites by Grayson and Meltzer (2002) found megafauna at only 14 sites, at which there does indeed appear to be a strong bias toward proboscideans. Clovis occupations appear to be based on game availability rather than habitat type, indicating they may have been larger fauna generalists and opportunists of other resources, e.g., berries, nuts, fish, small game (Rivals and Semprebon 2012). Cannon and Meltzer (2008) present evidence that resource availability was (and is) highly variable across the landscape at continental scale. Cannon and Meltzer found resources in the eastern North America were dispersed among many small patches, allowing Clovis phase people a wider selection of food items at smaller travelling distances. In the West, by contrast, resources were focused on larger but more distant patches, limiting food choices and requiring longer, and therefore less frequent, travel. Ecotones, places with a wide diversity of animals, plants, and other resources, would have been highly desirable occupation locations (Rivals and Semprebon 2012), especially in the North American West (Cannon and Meltzer 2008).

In Alberta, there are no Clovis sites, only isolated point finds in disturbed contexts, predominately fields and developed areas (Peck 2011).

The Folsom phase material culture derives from the Clovis phase and existed from ca. 12,740 cal BP to ca. 11,960 cal BP. The transition from Clovis to Folsom appears to have occurred in less than a century. The Folsom and Midland points are diagnostic of Folsom culture, the former having and the latter lacking a long central flute. Folsom lithics may reflect a concern with efficiency and a desire to conserve high quality lithic material. Folsom points may be designed to control fractures in a way that allows resharpening multiple times. Flakes are removed bifacially from a core until it is spent, at which point it is crafted into a bifacial knife. On the other hand, the high degree of craftsmanship exhibited in Folsom points has been theorized to be related to hunting magic (Bradley 1993) or purely for aesthetics (Kornfeld et al. 2010:81). Bone artifacts, including bone needles, are also well-crafted, leading Kornfeld et alia (2010) to speculate Folsom phase people may have crafted all perishable goods with similar care.

A bison skull with a red zigzag painted on it was recovered in Oklahoma, indicative of the economic and likely spiritual importance of bison to Folsom people (Bement 1999). Folsom culture and mobility appear to be centered around bison. The focus on bison will be the major through-line connecting all cultures on the prairies of Alberta until the deliberate and functionally total extermination of the bison on the Great Plains by White settlers in the late nineteenth century.

Folsom culture is prevalent on the Great Plains from Texas to Alberta, possibly as far as northeastern British Columbia, and extends from the eastern front range of the Rockies to the prairie Midwest of the United States. An increase in site types from Clovis may indicate an increase in specialized activities. In Alberta, there are no Folsom sites, only surface-collected points, most commonly in the south and southwestern portions of the province. These points are commonly made of exotic lithics from the south or southeast. Two final points of interest noted by Peck, Folsom may have had domesticated dogs and postholes at the Hell Gap site in Wyoming link Folsom to some of the earliest archaeological evidence for structures in North America.

Peck (2011) discusses a Sibbald phase, contemporaneous with Folsom, dated to ca. 12,475 cal BP. Not well understood or defined, Peck sees Sibbald as a possible movement of people from the south into Alberta, who created a specialized niche in the front range of the Rockies and in large open mountain valleys. Sibbald may indicate the beginning of regionalization, occupying the mountains alongside Folsom on the Plains.

Folsom culture may be tied to Younger Dryas conditions, as it arose near the onset and disappeared near the end of this climate interval. On the other hand, environmental changes may have occurred on a temporal and spatial scale such that humans may not have noticed them (Meltzer and Holliday 2010).

By ca. 11,960 cal BP the Hell Gap/Agate Basin material culture replaced Folsom in Alberta and lasted nearly a millennium, until ca. 11,000 cal BP. The Hell Gap/Agate Basin type site is in Wyoming, but material is distributed across the Northern Plains from Alberta, through Montana, Wyoming, and North Dakota, as far south as Colorado and western Kansas. In Alberta, the few sites are generally in the Foothills and are small campsites with domestic activities rather than the large kill sites recorded in the south. The southern sites are nearly as rare, though Hell Gap and Agate Basin points are the most common surface find in Montana.

Hell Gap and especially Agate Basin points are well-crafted lanceolate points, often exhibiting parallel flaking. Hell Gap/Agate Basin is not well described due to the rarity of sites, but the culture appears to be bison-centered while also incorporating other smaller mammals, fish, mussels, and birds into their diet as needed. There is not much evidence of settlement and mobility patterns but there is some evidence for structure use and a tendency towards local lithics, possibly indicating reduced mobility or social connections compared to Folsom and Clovis.

Following the Hell Gap/Agate Basin complex, the Alberta phase material culture appears ca. 11,000 cal BP and lasts 800 years until ca. 10,200 cal BP. Alberta is widely distributed on the Plains, from northeast British Columbia to Oklahoma and east from the Rockies to far southwest Manitoba and Nebraska. Despite the wide distribution, the diagnostic Alberta points, another broad lanceolate point, are rare in excavated sites and are often in poor context. The other diagnostic lithic, the Cody knife, places the Alberta phase in the Cody tradition. There is no evidence currently to link the Alberta phase to the preceding Hell Gap/ Agate Basin complex.

The Scottsbluff/Eden phase follows the Alberta phase in the Cody tradition, appearing ca. 10,200 cal BP and lasting approximately 650 years until ca. 9,550 cal BP. The diagnostic lithics are the Cody knife and the Scottsbluff and Eden projectile points. Both points are well-crafted lanceolate points, though the Eden point is usually elongated and knapped to create a distinctive diamond-shaped cross-section. Exotic lithics are common; especially brown chalcedony, or “Knife River Flint”, in Alberta, which is the material used for a quarter of Scottsbluff/Eden phase lithic artifacts in the province.

True Knife River Flint specifically describes a brown chalcedony acquired from the Knife River quarries in North Dakota. Unfortunately, the term is commonly applied as a blanket term for all brown chalcedony and visually similar lithic material used in tool manufacture on the Northern Plains (Kirchmeir 2011; Evilsizer 2016). I prefer to use the term brown chalcedony rather than Knife River flint, to avoid confusion about the source of the material.

Scottsbluff/Eden phase is widely spread from northeast British Columbia south to Texas and from the Rockies east to Ontario and Michigan. Sites are more common south of Montana than in Canada and in Alberta sites are more often campsites than kill sites. Bison hunting by entrapment was a common strategy but other mammals from moose to ground squirrel were also hunted, as were birds, turtles, mussels, and fish.

From Hell Gap/Agate Basin complex through Scottsbluff/Eden phase the environment on the Northern Plains was relatively wetter but was warming and drying. The Scottsbluff/Eden phase is considered the last Early Precontact Period material culture in the region. There are two material cultures in Alberta during the transition from the Early to the Middle Precontact Period, Plains/Mountain complex and Lusk complex. I will discuss these in the next section. As this transition coincides with the onset of the warmest temperatures of the Holocene.

3.3.3 The Altithermal

The Altithermal (also known as Hypsithermal, Mid-Holocene Thermal Maximum, or Mid-Holocene Climatic Optimum) was a period warmer and dryer than modern caused by the highest levels of insolation and the highest seasonality of insolation experienced by the Earth during the Holocene. The Altithermal was not uniform in its duration or effects, instead the particular circumstances – for example time period, location, topography, or hydrology – of any given location influenced how human, animal, and vegetation communities experienced it and responded to it (Walker 1992). Generally, the Altithermal lasted between 3,000 and 5,000 years, though the onset and amelioration of this warmest Holocene interval both usually occurred earlier in the West and later in the East (Oetelaar 2011).

Whether due to the decreased time-depth or to an increased interest in a period with temperatures warmer than modern, we can add several more paleoenvironmental records to our survey of the region surrounding the study area. First, let us return to the previously discussed records.

Moon Lake, North Dakota (Valero-Garcés et al. 1997) enters the Altithermal ca. 8,300 cal BP. This period of highest warmth and aridity continues for nearly 4,000 years until ca. 4,400 cal BP. At Moon Lake there are three periods of highest aridity at 7,500-7,100 cal BP, at 6,300-6,000 cal BP, and at 5,600-5,300 cal BP. At Kettle Lake, North Dakota, the Altithermal begins ca. 9,200 cal BP and also ends ca. 4,400 cal BP. Grimm et alia (2011) describe the Altithermal here as a period of high moisture variability on a multi-decadal scale with severe droughts alternating with humid periods. This description is very similar to Moon Lake, and both exit the Altithermal at the same time. The onset may also have occurred at the same time for but is obscured by differences in methodologies.

At Mariana Lake (Hutton et al. 1994), the warming and drying trend began ca. 10,200 cal BP but the height of the Altithermal, when warmth and aridity were at their maximum, occurred between ca. 8,300 and 7,400 cal BP. During this time, the sphagnum peatlands almost disappear but wetter pockets remain, as evidenced by the continued presence of black spruce, fir, and larch species. During this period and after, ca. 8,300-6,300 cal BP, poplar species attain a maximum population as a proportion of the forest community. At ca. 7,400 cal BP the sphagnum peatlands rebound. While not explicitly stated by Hutton et alia, it would appear the Altithermal at Mariana Lake could be interpreted to have extended from the beginning of the warming and drying period ca. 10,200 cal BP through the period of maximum poplar, ca. 6,300. Interpreted this way, the Altithermal onset and end were both earlier than at the other locations discussed here.

At the Tuscany site (Oetelaar 2004) in Calgary, the early Holocene spruce and poplar parkland community transitioned to grassland by ca. 8,300 cal BP. Grassland continued until ca. 7,600 cal BP when Mt. Mazama ash capped the sediments. From ca. 7,600 to ca. 5,000 cal BP, the Tuscany site experienced maximum aridity and landscape instability. These environmental transitions are roughly contemporaneous with the next sites I will discuss in the Cypress Hills of Alberta and Saskatchewan.

The Cypress Hills are localized uplands on the Canadian Plains of southeast Alberta and southwest Saskatchewan. The elevation and local conditions allow a modern vegetation mosaic of grasslands, poplar forest, conifer forest, and wetlands, which contrasts drastically with the surrounding mixed grasslands (Sauchyn and Sauchyn 1991; Klassen 2004). During the LGM, the

Cypress Hills were a nunatak, an area of unglaciated land rising above the surrounding ice sheet (Robertson and Klassen 2006; Oetelaar and Oetelaar 2007).

At Harris Lake on the northwest side of the Cypress Hills West Block in southwest Saskatchewan, 147km southeast of the study area, Sauchyn and Sauchyn (1991) report a paleoenvironmental record based on pollen beginning ca. 9,120 cal BP. At this time, the vegetation was similar to Aspen-parkland, with *Populus*-forest and a grassland-shrub complex, and few conifers. Over time the area trended towards a prairie-like environment. By ca. 7,700 cal BP and lasting until ca. 5,000 cal BP, grassland and saline-tolerant species comprised most of the vegetation community. During this period there was a steep drop in the *Populus* population and an increase in *Pinus* and *Picea*, though the populations of these two species remained low. Peak aridity occurred between 7,700 and 6,800 cal BP.

At Elkwater Lake on the northeast side of the Cypress Hills in southeast Alberta, 145km southeast from the study area, Klassen (2004) reports a paleoenvironmental record from the Stampede site (DjOn-26) using data from paleosol, phytolith, stable carbon isotope, and C/N ratio proxies. Modern vegetation is an aspen woodland, which may be a mid to late successional community trending towards spruce forest. The site sits alongside a creek, which runs along the base of the north-facing hillside and empties to the west into Elkwater Lake. These factors allowed this site to maintain a more mesic vegetation community during the Altithermal than at Harris Lake, 26km due east. During the earliest period, from ca. 8,000 to 7,000 cal BP, the site is not grassland, but it is unclear whether it is forest or wetland, as the creek is much closer at this point than later in time. From ca. 7,000 to 4,500 cal BP, the site experiences peak aridity and the area is grassland.

Wolfe et alia (2006) record a period of mid-Holocene dunefield activity, beginning ca. 7,500 cal BP and coinciding with the Altithermal, in what is now the aspen-parkland surrounding North Battleford, Saskatchewan and the boreal forest transition in the area around Prince Albert, Saskatchewan. At Prince Albert, the area receives at least 100mm less precipitation than modern and the vegetation is parkland and grassland. Dunefield activity here lasts from ca. 7,500 cal BP until ca. 5,000 cal BP. At North Battleford, the area receives at least 50mm less precipitation than modern and the vegetation is grassland. Here, the dunes are active from ca. 7,500 cal BP until ca. 4,700 cal BP. This is in accord with records indicating the boreal forest extended to the shores of the Arctic Ocean during the Altithermal, the aspen parkland extended up to 5° (555km) farther north to 59° N latitude (in Alberta), and the grassland extended 1° farther north (111km) to 54° N latitude (Strong and Hills 2005).

The last site with a paleoenvironmental record extending into the Altithermal comes from Chappice Lake, Alberta (Vance et al. 1993), which is 88km south of the study area. Chappice Lake likely had an environment most similar to conditions on the upland prairie at the study area, as they are at very similar latitudes and elevations and are both in the modern Dry Mixedgrass Natural Subregion. Vance et alia (1993) used several proxies to infer water levels at Chappice Lake. The record begins at ca. 8,100 cal BP, already in the Altithermal, when the lake experiences extreme fluctuations between high water levels and drying out completely. Beginning ca. 6,800 cal BP and lasting until ca. 5,000 cal BP, Chappice Lake remains smaller than previous water level high-stands and has ponded, highly saline waters. The lake experiences seasonal water level fluctuations but the extreme fluctuations of the Altithermal are over. The environmental conditions at Chappice Lake during this time appear to be more similar to those at Moon Lake and Kettle Lake in North Dakota than those at sites that, though closer, are at higher elevations or latitudes, such as in the Cypress Hills or at Mariana Lake.

These paleoenvironmental records reveal a time of increasing warmth and aridity, as indicated by the paleovegetation reconstructions. The records of fluctuating lake water level indicate the trend was not slow and constant but began as long severe droughts interrupting otherwise relatively moist conditions. This transitioned to a period which was more arid, generally, but the droughts became shorter and less severe. At the end of the Altithemal on the Canadian Plains, around 5,900 cal BP (Oetelaar 2011; Vance et al. 1995), conditions and vegetation communities transitioned to those of modern times. The terminal-Altithermal amelioration appears to have happened earlier in the west (ca. 5,900 cal BP) and later in the east (ca. 4,800 cal BP) (Barnosky et al. 1987; Vance et al. 1995; Yansa 2007; Oetelaar 2011).

The Altithermal was a time of instability on the Plains, in which relatively wet conditions were interrupted by long and severe droughts. The archaeological record is often sparse during this period and there is an unsettled debate whether this is due to abandonment of the Plains or to erosional factors destroying some sites and deeply burying others (Oetelaar 2004). Additionally, the eruption of Mt. Mazama in Oregon and the subsequent ash-fall across the northwest introduced a new environmental factor for plants, animals, and humans to contend with in the middle of the Altithermal period. The material cultures present in Alberta during the onset of the Altithermal were the Plains/Mountain complex and Lusk complex, which corresponds with the transition from the Early to the Middle Precontact Periods. The Middle Precontact Period lasted approximately 7,000 years on the Northern Plains and the first half of the period occurred during the Altithermal. The material cultures present during this time were the Country Hills complex, the Mummy Cave complex, the Maple Leaf complex, and the Gowen complex.

Beginning ca. 9,550 cal BP and lasting approximately a millennium until ca. 8,500 cal BP, the Plains/Mountain complex people lived at the eastern edge of the Rocky Mountains, at the interface with the Plains, from Wyoming to Alberta. They may have specialized in the forest or forest edge as well as the Foothills. Besides bison, Plains/Mountain complex people also hunted deer, elk, moose, and bighorn sheep, the latter being the focus at the Maple Leaf site in Crowsnest Pass in southwestern Alberta. The presence of grinding stones indicates they were likely incorporating seeds into their diet as well.

On the Plains at this time, the Lusk complex appears ca. 9,300 cal BP and also lasts about a thousand years until ca. 8,350 cal BP. Lusk is not well understood, following the Cody tradition material cultures on the Plains but not apparently related to them. Lusk is also intensifying resource use by grinding seeds and hunting a wide variety of animals in addition to bison. They also may have been extracting marrow from bison bones. Lusk points are broad lanceolate points but are often found in association with smaller corner-notched points.

Often the transition from the Early to the Middle Precontact Period is described as a transition from hand-held spears or thrown javelins to atlatl launched darts (Hughes 1998). There is evidence that Early Precontact Period peoples were already using the atlatl (Hutchings 1997; Hughes 1998), indeed that Clovis may represent the diffusion of atlatl technology, as mentioned above. Hutchings (1997) conducted an experimental archaeology study to determine how velocities affect impact fractures of projectile points. His results indicate most fractures of Early Precontact Period points, beginning with the Clovis material culture, are consistent with atlatl use and, due to his material choice during experimentation, in fact may be an under-representation of high velocity fracturing. Hughes (1998) studied weapons systems from an engineering standpoint and determined the shift from larger lanceolate points to smaller notched points indicate a shift to fletched atlatl darts. Fletching increased accuracy without having to precisely balance the point and the shaft, increased velocity, and increased lift, meaning smaller dart points and shafts allowed the hunter to maximize the increased velocity and lift (Hughes 1998:397). In other words, fletched darts fly farther, faster, and with more accuracy. The experimentation required to craft a precision weapon, according to Hughes, may possibly be reflected in the variety of point styles found in Lusk complex sites (Peck 2011).

The intensification of resources and shift to fletched dart technology may have been responses to the new Altithermal environmental conditions. However, Lusk and especially Plains/Mountain complex peoples may not have experienced peak Altithermal conditions due to differential onset. Vegetation communities in the Foothills (Oetelaar 2004) and the Cypress Hills (Sauchyn and Sauchyn 1991) do not appear to have fully shifted to the Altithermal regime until the tail end of the Lusk complex ca. 8,350 cal BP.

The Country Hills complex is the first material culture of the Middle Precontact Period. Country Hills complex is relatively short lived, lasting only 250 years between ca. 8,350 and ca. 8,100 cal BP. Country Hills complex sites are found in the foothills and parkland of Alberta, Montana, and Wyoming. Faunal remains and the presence of brown chalcedony lithics implies a Plains or Plains peripheral lifestyle. Country Hills complex people hunted bison by entrapment in pond or wetland locations. Antelope, canid, and deer remains have also been recovered at sites.

The Mummy Cave complex appears ca. 8,100 cal BP and continues for roughly 500 years until ca. 7,600 cal BP. Blackwater and Bitterroot side-notched points are diagnostic of the complex. Mummy Cave complex sites are found in Alberta and Montana and perhaps Idaho and Wyoming. Faunal remains of bison, elk, pronghorn, and gopher may indicate a Plains lifestyle. Bison may have been *Bison occidentalis*.

One Autumn, around 7,600 cal BP (Hallett et al. 1997; Zdanowicz et al. 1999), Mt. Mazama in southwest Oregon erupted, spewing ash across most of the intermountain West and the western edge of the Prairies, including all of southern Alberta. M*aok-skoistch* is only 82km, a journey of less than a week on foot, from the eastern extent of the Mazama ash-fall, as mapped in Oetelaar and Beaudoin (2005:Figure 1). Oetelaar and Beaudoin (2005) provide an interesting account, summarized here, of the possible effects of the ash-fall in southern Alberta, as well as how it may have been experienced by the people living there.

People would have heard explosions, similar to thunder but odd for the time of year. About half a day later, people would have seen a dark cloud approaching with intense, dramatic lightning. If the ash-cloud arrived during the day, ash would have begun falling as the sun developed a blue halo before darkness engulfed the world. If it arrived in the night, more likely given the time of year, the people would have awoken to a sun that did not rise. The darkness would have continued uninterrupted for several weeks or even a month.

Cold would accompany the darkness. The winter would have been longer and colder, with frosts occurring in spring and summer. Temperatures 2-4°C colder than usual would have continued for perhaps six years after the first ash-fall. That first year, frosts would have killed most of the berries and edible and medicinal plants – those that survived being buried or crushed by the deep ash, and those that managed to break through the ash in the spring. The ash would have adulterated the water, killing many aquatic plants and animals, and made the water murky and acidic. Springs would have been the only source of clean, fresh water.

The plant and animal populations would have been significantly reduced and would remain so for over a decade. Ash and dust would have been everywhere, in the air, in the water, and in the food. Though not likely fatal, the ash would have irritated lungs and eyes and increased tooth-wear. The usual methods of dealing with scarcity, eating undesirable foods, moving to other areas, or seeking aid from neighbors, would have been fruitless, the ash affecting everywhere and everyone equally. If people at the time viewed their homelands as a sacred landscape in which their movements and actions had both an economic and ritual purpose (as described above in section 3.2.3), for the people affected, the Mazama ash-fall would have represented a catastrophic destabilization of their ontological system. People would have been forced to develop new cultural practices – new and adapted rituals and technologies – to mitigate against starvation, intensify resources, and reconstruct their society and their world in a way that satisfactorily accounted for the cataclysm which had befallen them.

There is a gap in the archaeological record, approximately corresponding to the three centuries following the Mt. Mazama eruption and ash-fall of ca. 7,600 cal BP (Peck 2011). Whether this gap is due to abandonment of the Plains during this time or to a current lack of data, only time and future investigations will tell.

Maple Leaf complex is the longest-lived material culture on the Northern Plains, appearing ca. 7,250 cal BP and lasting approximately 1,300 years until disappearing ca. 5,900 cal BP. Maple Leaf complex only exists in Alberta, in the Foothills and the Cypress Hills and maybe on the Plains. Among the usual lithic tools, Maple Leaf complex people used split pebbles to make tools, a technology not previously evident in the Alberta archaeological record. Maple Leaf complex people appear to prefer small ambushes of bison at natural traps but also hunted moose, mule deer and other smaller game. There is some scant evidence for structure use but there are few features at Maple Leaf sites.

Alongside the Maple Leaf complex was the Gowen complex, which appeared ca. 6,700 cal BP and lasted about 800 years until disappearing ca. 5,930 cal BP. The Gowen complex was first defined in central Saskatchewan (Walker 1992) and Gowen complex sites are predominately found there but there are two possible sites in Alberta, in the Foothills and Front Range. Gowen complex sites are often small camps or small kill sites. Gowen complex people hunted both bison and smaller game such as pronghorn, canids, and muskrat. There are a wide variety of tools crafted of local lithics from Gowen complex sites, including hafted bifaces, gougers, drills, spokeshaves and anvils. Bone tools include awls and a tube of unspecified use. Excavated features include several hearth types, including a smudge pit with the remains of an unidentified *Chenopodium* species.

The Altithermal was a time of environmental hardships, long and severe droughts, and even a major volcanic eruption. After the Altithermal, as temperatures dropped and precipitation increased, the remainder of the Middle Precontact Period took place during a long period of stability and more clement conditions similar to modern.

3.3.4 Onset of modern conditions and biotic communities

After the Altithermal, conditions at all the sites included in this survey ameliorate to modern climate, precipitation, and vegetation regimes. In most locations, the environment experiences relative stability but a few exhibit increased instability approaching the present. It appears that studies reporting on moisture fluctuations capture instability, while studies of vegetation do not. This seems to indicate moisture fluctuations during this time are not of sufficient duration and intensity to register in vegetation records, which is consistent with the lag time of decades to multiple centuries between environmental changes and vegetation changes (Meltzer and Holliday 2010).

At Mariana Lake, Hutton et alia (1994) report modern boreal forest conditions and vegetation by 5,730 cal BP, including a decline in fir, possibly due to the spread of peatlands.

At Moon Lake, North Dakota Valero-Garcés et alia (1997) report modern moisture conditions by 4,470 cal BP, with a dry phase at 3,000-2,900 cal BP and another at 1,100-700 cal BP. The latter dry phase corresponds almost exactly to the Medieval Warm Period.

At Kettle Lake, Grimm et alia (2011) report wetter conditions overall, similar to modern. They also report that moisture continues to vary on the scale of decades, similar to but less severe than the preceding Altithermal.

At the Tuscany site in Calgary, Oetelaar (2004) reports the onset of modern grassland and landscape stability ca. 5,000 cal BP. This date is inferred from artifacts (Oxbow projectile points) rather than directly dated.

At Harris Lake in the Cypress Hills, Sauchyn and Sauchyn (1991) record the onset of cooler and wetter conditions ca. 5,000 cal BP, when herbaceous species and *Populus* decline while aquatic species, conifers, and other trees increase. Between ca. 4,500 and ca. 3,200 cal BP there is a large increase in forest, including lodgepole pine, and white spruce increases the most. By ca. 3,200 cal BP there is an increase in pine species and the modern vegetation community is established. There is more tree pollen recorded during this time than at any previous time.

At the Stampede site at nearby Elkwater Lake, Klassen (2004) reports grassland and peak aridity until ca. 4,500 cal BP. There is a gap in the record here but by 3,200 cal BP the modern aspen woodland or forest vegetation community is established and continues to the present. Obviously, there was a transition from grassland to forest between 4,500 and 3,200 cal BP but the speed of the transition is unknown. This gap corresponds almost exactly to the large increase in forest that occurs at Harris Lake 30km to the east.

At Chappice Lake, the site most similar to the uplands of the study area, Vance et alia (1993) record stable water levels beginning ca. 5,000 cal BP, contemporaneous with cooler, wetter conditions at Harris Lake and the Tuscany site. Water levels gradually rise until ca. 2,800 cal BP.

Vance et alia note that during this period glaciers are advancing in the Rocky Mountains. From ca. 2,800 until ca. 900 cal BP, Chappice Lake is a stable, large, and relatively fresh lake, indicating a period of greater precipitation than evaporation.

Calderwood complex is the first material culture to appear in the archaeological record after the Altithermal. The Calderwood complex begins ca. 5,900 cal BP and lasts approximately 500 years until 5,400 cal BP. Calderwood complex is present across southern Alberta from Crowsnest pass to the Cypress Hills. Peck (2011) questions whether Calderwood is a cohesive material culture as there is no single diagnostic point and their lithic toolkit is unremarkable and made on local lithics. On the other hand, this may mean people were experimenting with different ways of existing in the new climatic conditions. Bison are, as ever, a vital component of Calderwood subsistence and people may have been conducting large bison kills at Head-Smashed-In at this time.

The first cairns on the Plains may have been built by Calderwood complex people, based on evidence from the lowest level of the central cairn at Majorville Medicine Wheel. Peck ponders whether this may be an aspect of creating new communal social forms to conduct large scale bison kills. This speculation does not appear to be borne out by the archaeological evidence. Though cairn building by Calderwood may be related to new social structures which endure for over 900 years into the Estevan and Oxbow phases, small scale bison hunts not large communal hunts are the norm for the next 2,700 years (ca. 5,600-2,900 cal BP).

The Estevan phase begins ca. 5,600 cal BP and lasts approximately 500 years until ca. 5,100 cal BP. This phase is a recent designation by Peck (2011), which he describes as an early or proto-Oxbow phase, possibly originating on the periphery of the Eastern Woodlands. Because Estevan phase is putting a name to what is already often considered an early Oxbow material culture, I will move on to the Oxbow phase.

The Oxbow phase, as defined by Peck (2011), emerges ca. 5,100 cal BP and continues for roughly 400 years until ca. 4,700 cal BP. Oxbow phase material is found on the prairies, as well as in the parkland and boreal forest, in Alberta, Saskatchewan, Manitoba, North Dakota, South Dakota, and Montana. Oxbow dart points are diagnostic of the phase, but other lithic tool types are fairly standard. Oxbow people appear to be hunting bison by stalking; making small kills of only a few animals. There is a wide range of other faunal remains at Oxbow sites, indicating a relatively broad diet.

Increased fire-burned rock (FBR) and charred bone at sites are indicative of stone boiling, one of several new behaviours introduced to the Plains by Oxbow phase people. Stone boiling is a technique that may go back to the Estevan phase and is used to render bone grease necessary for preserving surplus meat. Preserving meat is a resource intensification method that gives people more food security and more time to develop other new behaviours or technology. Oxbow people also appear to be the first to use circular dwellings on the Plains, though probably not true tipis.

Cairns, though perhaps initiated by Calderwood complex people, appears to become more widespread during the Oxbow phase. Cairns are piled stone placed on prominent locations, at which offerings, such as points, geodes, and animal bone fragments, were placed. The addition of spokes and circles to make “medicine wheels” is likely a later innovation.

Cemeteries are also novel on the Prairies. The Gray site in Saskatchewan contains perhaps 200 graves. Red ochre is used in interments and there has been some native copper among the grave goods. Native copper indicates some manner of contact with cultures to the east.

Cemeteries and cairns are both generally considered territorial markers, indicating Oxbow phase people may have felt the need to place claims on the lands in which they lived. Claims which they may have defended against neighboring groups. One such group, the McKean complex people, may have pushed Oxbow phase people off the prairies and into the prairie periphery – into the Foothills, the aspen-parkland and boreal forest.

The McKean complex appears ca.4,800 cal BP and lasts approximately a millennium until ca. 3,800 cal BP. Peck (2011) favors McKean complex as an expansion of mountain groups in Montana onto the Northern Plains after the Altithermal but mentions other possibilities such as a diffusion of technology, an outgrowth of the Oxbow phase, or adoption of McKean culture by neighboring Plains groups. If McKean is a migration, then they emerged from the Big Horn Basin and Black Hills and moved north into southern Saskatchewan before moving west into Alberta and, a little while later, east into western Manitoba. This interpretation is supported by recent spatiotemporal analyses of McKean sites and recovered materials by Fortin (2015). In

Canada, McKean complex sites occur from Alberta, east to Manitoba. In the United States, McKean complex sites are generally limited to the western side of the Great Plains from Montana and North Dakota south to northeast Colorado and western Nebraska.

The McKean complex has several diagnostic and characteristic artifacts. Diagnostic projectile points are McKean (lanceolate), Duncan (stemmed), and Hanna (stemmed), which seem to create a chronomorphic series, each more prevalent at a different point in time within McKean. These points also indicate a McKean bison hunting strategy of ambushing bison in natural trap locations, such as watering holes, where the animals are not likely to run far after being wounded. Barbed points are better for hunters expecting to track an injured and bleeding animal, because the barbs increase injury and bleeding as the animal runs.

In terms of characteristic McKean complex artifacts, shell beads are quite common. Groundstone is another feature of McKean complex assemblages. The oldest stone pipe in Alberta is McKean and groundstone discs and grinding slabs are common McKean artifacts. The latter appear to be common in the south, in Montana and Wyoming, but not in Alberta. This may reflect cultural differences, resource differences, or maybe seasonality. Peck (2011) mentions fossil ammonite septa (the walls separating chambers in an ammonite's shell) as occurring in McKean sites. Ammonite fossils are known as Iniskim – buffalo calling stones – by the later Nitsitapii (Blackfoot confederacy) and provide compelling evidence of their connection to the Old Women's phase material culture (discussed below in section 3.3.5). The possibility of ammonites providing a cultural connection between McKean complex (or other material cultures with the occasional ammonite among the archeological assemblages) and Old Women's phase is unlikely and is more probably a function of the ubiquity of these fossils on the Alberta prairies (Peck 2002).

McKean complex sites are relatively rare on the Northern Plains, perhaps due to a possible preference for wooded areas and ecotones (Fortin 2015). The most significant McKean site in Alberta is the Cactus Flower site at Canadian Forces Base Suffield, 92km southwest of the study area. At this site, McKean complex people were likely ambushing bison at a crossing of the South Saskatchewan River (Brumley 1975). At McKean complex sites, people may have been living in round shelters (though not yet true tipis). FBR from stone boiling is common. Stone-lined hearths and grinding stones are common in the south but not in Alberta, likely indicating earth ovens for plant resource intensification. Webster (2004) found this difference in assemblage to be more likely related to local environment (wooded vs. grassland) rather than any northern vs. southern cultural differences. Faunal remains include pronghorn and mule deer as well as smaller mammals, birds, and aquatic animals. Fortin's (2015) analyses include faunal remains and indicate a McKean generalist hunting strategy rather than a bison focus. McKean complex people also buried the dead, though in a manner completely different than the preceding Oxbow phase people. McKean burials are usually in shallow pits underneath a primary living surface, lack grave goods, and red ochre is not used.

At the beginning of the McKean complex time period, Oxbow continues for several centuries. Likewise, McKean exists alongside Pelican Lake complex for around a century before disappearing.

Pelican Lake complex is another millennium-spanning material culture, appearing ca. 3,900 cal BP and disappearing ca. 2,900 cal BP. There is some discussion as to where to place the Pelican Lake complex in the culture history of the Canadian Plains. Reeves (1970:28-29) places it in his Tunaxa tradition between Hanna and Avonlea, while Vickers (1986:80) finds Pelican Lake to be more closely related to Besant than Avonlea. Peck (2011) sees the Pelican Lake complex as intrusive to the Plains from the east and unrelated to the McKean complex (Peck seems to always favor intrusion by outside groups over other explanations of material culture change). Pelican Lake complex appears to be present only in Manitoba, Saskatchewan, Alberta, and rarely in Montana.

The Pelican Lake complex is described as "the twilight days of bison stalking" (Peck 2011:235). Pelican Lake complex hunters used barbed points, stalked their prey, made small kills away from camp, and brought back selectively butchered sections to camp. The barbed points Pelican Lake complex hunters used were usually more finely crafted than McKean series points. While usually making use of local lithics, occasionally points are made from exotic brown chalcedony, possibly from the Knife River flint quarries in western North Dakota. Peck (2011) cites the stalking strategy and higher quality point craftsmanship as evidence for links to the east. I would add, more care in creating points might also be linked to the stalking strategy as a form of hunting magic or indicating respect for the hunted animal, which would make it more likely to allow itself to be killed (Kimmerer 2013).

Other faunal remains recorded at Pelican Lake complex sites include deer, canids, beaver, mallard, and trout. Lithic toolkits at sites are unremarkable and no bone tools have been recorded. FBR concentrations indicate stone boiling. Stone circles appear for the first time, indicating Pelican Lake complex people possibly used a tipi-like conical lodge. Pelican Lake complex sites are usually small campsites.

The Bracken phase emerges ca. 2,900 cal BP and continues for around 800 years until ca. 2,100 cal BP. Bracken phase sites occur in in southern Alberta and Saskatchewan and northern Montana but not in Manitoba. The Bracken phase is a recent definition by Peck (2011), who separates it from the Pelican Lake complex based on point style and cultural behaviours.

The Bracken point is the diagnostic artifact of the Bracken phase. This point is most similar to a Pelican Lake point without the barbs. It appears to change over time, beginning as a rough Pelican Lake-like point and trending towards Besant-like. If the Bracken phase material culture emerged from Pelican Lake, the lack of barbs on the Bracken point is an indicator of the first major change in Plains life exhibited by Bracken phase people, the large communal bison kill.

Beginning with the Bracken phase and continuing into the Historic Period, the systematic use of pounds and jumps by large groups working together becomes the most common form of bison hunting on the Northern Plains. Jumps were previously used by peoples of the Maple Leaf and Calderwood complexes, but these were occasional. Pounds likely have their origins in the natural traps used by various previous cultures. Beginning with the Bracken phase, major kill sites are used repeatedly (Peck 2011:276), indicating only certain locations have the appropriate mix of topography, bison, and resources necessary to conduct large communal kills.

The Bracken phase is the first material culture to have numerous stone rings at sites, indicating up to 15 or 18 lodges or about 100 people. A larger group is necessary for communal bison hunting but also allows, perhaps even encourages, more complex social structures, and increases a group’s defensive capability. The stone rings also have evidence of an internal tie-down stake and a central hearth, indicating Bracken phase people lived in true tipis.

If Bracken phase people were revisiting good hunting locations, they may have felt the need to protect or lay claim to these locations. This territoriality is reflected in the Bracken phase burials and use of cairns. Based on the archaeological evidence presented by Peck (2011), it appears that when a person died, their body would initially be left in a place where it would decompose. Over the course of the year, or maybe some other specified time, the bones of the dead were collected from their decomposition locations. At a high, prominent place, the group dug a shallow pit and placed in it the remains of the gathered dead. Mourners placed goods in the grave, including projectile points, tools, shell, beads, gorgets, bone decorations, bison and elk teeth, bear claws, eagle talons, native copper, and Pacific marine shells. The remains and goods were covered with red ochre and red ochre was mixed with the earth placed over the remains. Sometimes the group constructed a cairn over the grave, such as the Bracken Cairn in southwestern Saskatchewan.

The people may have been inspired by the existing cairns on the landscape, created over 1,500 years before them by Calderwood, and Estevan/Oxbow peoples. It is easy to imagine burial cairns as places of spiritual power, where ancestors resided and protected groups and the lands in their territory. These burials indicate territoriality, but the grave goods also indicate far-flung connections to other peoples, copper from the east and shells from the west. These connections spanned across nearly the length of the continent, at minimum 2,500km from the Pacific Ocean to the Great Lakes.

As described above in section 3.1 once people are revisiting the same locations for hunting and other important resources, and developing strong connections to the land, the stage is set for cultural behaviours that enhance the abundance of desirable resources (Smith 2016).

Summarizing Peck's (2011) position, Bracken phase is an outgrowth of Pelican Lake phase. The changes in point morphology and settlement pattern, revisiting sites, and the development of cairn burials and possibly territoriality, can reasonably be related to the development of large-scale communal bison hunting using jumps and pounds. Over time, Bracken points become increasingly Besant-like. Though Peck does not explicitly state Besant develops from Bracken, it seems a reasonable conclusion to draw from his presentation of the evidence, especially considering his separation of Besant from Sonota, discussed below.

Outlook and Sandy Creek complexes are two poorly understood material cultures both occurring ca. 2,600 cal BP, alongside the Bracken phase. Peck (2011) describes the Outlook complex as a brief use of the Plains by Early Plains Woodland people, possibly procuring hides and meat for trade in the east. Outlook complex materials are difficult to distinguish from Sonota phase materials 500 years later, which may indicate a common origin. The Sandy Creek complex is described by Peck as possibly early Bracken phase or possibly intermediate between Oxbow and Besant. The latter interpretation does not seem to adequately account for the 2,000-year gap between the two cultures. Both complexes require more attention.

The Besant phase emerges ca. 2,100 cal BP and lasts approximately 700 years before disappearing ca. 1,400 cal BP. The Sonota phase emerges ca. 1,400 cal BP and lasts around 100 years before disappearing ca. 1,300 cal BP. Following Peck (2011), the traditional view of these two phases, is that Sonota is a regional sub-phase of Besant, as described by Reeves (1983). Reeves (1983) defined two traditions in Alberta over the last 4,000 years. The Tunaxa tradition includes McKean, Pelican Lake, and Avonlea phases. The Napikwan tradition includes Besant and Old Women's phases. Besant, in Reeves' formulation, pushed Avonlea to the west and to the Plains periphery.

Peck (2011) finds cause to dispute this history and separates Besant and Sonota into two, unrelated phases. The archaeological terrain of dispute is defined by four cultural traits, namely point style, ceramics, mound burials, and bone uprights. Peck is unwilling to make definitive statements as to the first trait, point style, and instead notes significant overlap in morphology and size among Besant, Sonota, Samantha, and Avonlea points, the former two described as darts and the latter two described as arrows. Peck cites Neuman (1975) as describing the presence of the latter three traits as diagnostic of Sonota. As to the first trait, Neuman describes a preference of Sonota for points crafted of brown chalcedony (Knife River Flint). Neuman places Sonota in South Dakota and North Dakota (the Middle Missouri area), and Manitoba. Syms (1977) agrees with Neuman and adds Sonota materials are present in Saskatchewan and Alberta as well. Byrne (1973) conducted an exhaustive survey of ceramics in Saskatchewan and found Besant to be aceramic. Peck (2011) notes later claims of Besant ceramics are derived from poor contexts.

Following Peck's analysis of the situation, Besant appears to be a continuation of Bracken phase, and, therefore, a descendent of Pelican Lake phase as well. What became of Besant phase people remains unclear, but it does seem related to the Avonlea and Old Women's phases of the Late Precontact Period.

The Sonota phase appears to have developed in the Middle Missouri area of North Dakota, South Dakota, and eastern Wyoming. Sonota lithic artifacts are often crafted on brown chalcedony, possibly obtained from the Knife River quarries in western North Dakota. Sonota groups may have traveled to the quarries to obtain Knife River Flint, but work needs to be done on sourcing to support this. Groundstone atlatl weights have been recovered from Sonota sites. Recovered bone tools include flakers, fleshers, awls, and a possible squash knife. Ceramics are plain or cord-marked pottery with punctate patterns. Sonota ceramics have only been recovered from one site in Alberta and represent just two vessels. Bone uprights are a common feature of Sonota phase sites but only one has been recorded in Alberta. Sonota sites in Alberta are younger than sites in the Middle Missouri area. These sites also only represent bison kill and processing sites; there are no campsites or burial mounds.

Mound burials are present in the Middle Missouri area and Manitoba only, not in Saskatchewan or Alberta. These are secondary burials of remains in pits on average 50cm below the original ground surface. Grave goods are placed with the remains including bison carcass segments; decorations of bear, beaver, and canid remains, Pacific marine shells, freshwater shell, fossils, and native copper; ceramic pots, pipe bowls and beads; and bone tools. The pit is covered with logs and a mound of earth on average 1m high and 22m in diameter caps the burial. As with the Bracken phase burials, grave goods indicate a cultural contact network that extends from the Pacific to the Great Lakes.

Peck (2011) posits that the Sonota phase developed in the Middle Missouri area before Sonota phase groups pushed north and west onto the Saskatchewan and Alberta prairies. These groups may have been focused only on hunting bison for trade in meat and hides to the east and may have been limited to winter hunting at the prairie periphery, or they may have abandoned the Middle Missouri area due to pressures related to the Hopewell Interaction Sphere to the east. In any case, Sonota phase material culture displaced Besant phase material culture within a very short time.

An interesting aspect of the Sonota phase is evidence for site cohabitation with Avonlea phase people. Sonota phase people still used the atlatl system, while Avonlea used the new bow and arrow system. Peck describes a movement of Sonota phase people out of the Middle Missouri area and a coincident movement of Avonlea phase people moving out of northern Minnesota and paralleling Sonota along the prairie periphery. The two groups seem to be cooperating, but the nature of their relationship is unknown. The sites that show cohabitation are older in the east and youngest in eastern Alberta, exhibiting movement from east to west over time. The cohabitation period ends once the groups reach Alberta, after which Sonota phase materials disappear and only Avonlea remains as the sole material culture in southern Alberta and Saskatchewan. With the end of the Sonota phase, the Middle Precontact Period also comes to a close and the Late Precontact Period begins.

3.3.5 Recent fluctuations and intense disturbances

Within the last approximately 1,200 years, the environmental stability that characterised the long period following the Altithermal ended, and a new period of fluctuations began. This current period begins with a warm interval, referred to as the Medieval Warm Period ca. 1,200-800 cal BP (800-1200 CE), followed by a cold interval, referred to as the Little Ice Age ca. 500-100 cal BP (1400-1850 CE).

At Chappice Lake (Vance et al. 1993), the nearly 2,000-year period of lake level stability described above ends ca. 900 cal BP when the lake once again experiences a series of low water and high-salinity events. These fluctuations are not as drastic as the Altithermal and correspond to approximately the last two centuries of the Medieval Warm Period. Lake levels become relatively high ca. 600 cal BP, corresponding approximately to the Little Ice Age. In the last two centuries, Chappice Lake is again experiencing lower lake levels, especially during historically recorded droughts.

The last record I will incorporate into this survey comes from a study of diatoms in several lakes across western Canada and the United States, conducted by Laird et alia (2003). The most relevant lake is in Chauvin, Alberta, 194km north of the study area. Chauvin exhibits predominately arid conditions, similar to modern, from ca. 1,700 to 1,200 cal BP. Wetter conditions occur from ca. 1,200 to 800 cal BP before returning to modern, predominately arid conditions. This wetter period corresponds to the Medieval Warm Period. The next nearest studied location at Humboldt, Saskatchewan, 391km to the east of the study area, exhibited stable conditions in the half millennium before the Medieval Warm Period ca. 1,700-1,200 cal BP, followed by increased fluctuations between wet and dry up to the present. Laird et alia do not report how well these fluctuations may correspond to the Medieval Warm Period or the Little Ice Age.

The Avonlea phase is the first material culture of the relatively short Late Precontact Period on the Northern Plains. The Late Precontact Period is defined by the use of ceramics and the bow and arrow. The Avonlea phase material culture appears ca. 1,300 cal BP and lasts about 300 years until disappearing ca. 1,000 cal BP. There is some debate as to the origins of the Avonlea phase, the two basic positions being either Avonlea developed out of the Pelican Lake phase (Reeves1983; Brumley and Dau 1988) or Avonlea phase represents people moving from the southeast (Klimko 1985), specifically out of the Upper Mississippi River Valley in northern Minnesota (Morgan 1979:220 as cited by Peck 2011:340). Peck (2011) falls into the latter camp based on the temporal and spatial distribution of early Avonlea sites and a possible connection to Brainerd Ware ceramics. Peck sees Avonlea phase people migrating northwest; being pushed by population and resource stress due to the Hopewell Interaction Sphere to the east and pulled by their relationship to Sonota phase people. In their relationship, Sonota phase people may have specialized in prairie resources while Avonlea phase people specialized in parkland and forest resources, which they could then share with each other. Avonlea phase sites are common in Alberta and Saskatchewan and uncommon in Montana, South Dakota, North Dakota, and Manitoba. Avonlea phase people appear to have been comfortable in multiple natural regions, as their sites are present on the prairies and in the parkland, foothills, and mountains.

Avonlea phase people were bow-exclusive hunters. Avonlea side-notched arrow points are diagnostic of the culture. Head-Smashed-In side-notched are only found in the oldest sites and may represent a fusion of Sonota and Avonlea cultures. Brumley and Dau (1988) speculate Avonlea phase people may have considered the bow a special and powerful weapon, tied to spiritual and shamanistic practices, and tried to keep the secret of its manufacture from neighboring groups. Peck cites Vickers (1994), who speculated bows may have been made by craft specialists who tried to keep the details of their manufacture a secret. Both hypotheses are interesting but may be based on unexamined modern assumptions and should not be accepted uncritically. The lithic toolkit is otherwise non-diagnostic and tools are made from local lithics.

Avonlea ceramics exhibit regional variation. The net-impressed variant is most common on the prairies, the parallel-grooved variant is more common in the parkland and the forest transition, and the shouldered plainware variant is most common in northern Montana and southern Alberta.

This last style carries forward into the Old Women's phase, indicating a continuity between the Avonlea and Old Women's phases.

Site types include campsites, jumps, pounds, processing sites, stone ring sites, and ceremonial sites. Avonlea phase people appear to choose camp locations in anticipation of where bison will be. In the spring and summer, occupations are on the open prairies and in fall and winter, camps are made near or along the path to bison overwintering sites. Most sites appear to be reoccupied many times, which may be a factor in the overall sparsity of Avonlea phase sites. Much like the Bracken phase people, Avonlea phase people mortuary practices may also have involved secondary interments of remains in pits topped by cairns.

It appears that once the Sonota phase people and Avonlea phase people settled on the Plains of Alberta, a process of fusion began. The synthesis of these two cultures developed into the following Old Women's phase. Considering the similarities in site distribution, settlement patterns, and mortuary practices, there may also be a link to Bracken and Besant phases in Old Women's phase

The Old Women's phase emerges ca. 1,000 cal BP and continues for roughly 700 years until ca. 300 cal BP. Old Women's phase once extended across the prairies and parkland of Alberta, Montana, and Saskatchewan. Old Women's phase material culture disappears in eastern and central Saskatchewan early in the period, to be replaced by Mortlach material culture. This likely represents a migration of Plains Villager people from the south displacing Old Women's phase people to the west.

There are several Old Women's phase diagnostic artifacts. Cayley series arrow points are side-notched forms of both the Prairie and Plains variants, exhibiting change over time. Otherwise, their lithic tools are unremarkable, and sourced from local lithics, sometimes using a split pebble technique. Old Women's pottery is known as Saskatchewan Basin Complex: Late Variant pottery. The style is characterized by a variety of surface treatments and decorations limited to between the shoulder and the lip of the vessel. Ammonite fossils are not uncommon and are almost certainly the historically known Iniskim, buffalo calling stones, of the Nitsitapii. Iniskim are an important component of Beaver Bundles, the owners of which performed complex ceremonies necessary for successful bison hunts (Ewers 1958).

Bison hunting was communal and was accomplished using jumps, traps, or pounds. Old Women's phase settlement patterns were tied to bison and people moved in anticipation of the movements of the bison. Winter sites are on the prairie periphery and in river valleys. Summer sites are on the open prairies. There are less recorded summer sites because they are smaller and dispersed over a much larger area.

Because of the connection of Old Women's phase to Nitsitapii culture, archaeologists have a better understanding of spiritual and ceremonial behaviours, such as the use of the Iniskim. Old Women's phase used and created stone features for various purposes, often lumped together under the term "Medicine Wheel", when, in fact, these stone constructions are usually accretional structures created and added to by people of several material cultures over long periods of time far predating the Old Women's phase (Brumley 1988; Mirau 1995; Peck 2011:378). One well-documented type of wheel is the death lodge or burial wheel, created as part of the mortuary practices for prominent and highly esteemed individuals. This type usually involves a central wheel or cairn with spokes radiating outward. Spokes and other stone arrangements at this type of wheel may be indicative of significant events in the life of the deceased (Mirau 1995:196). Rock art, i.e., petroglyphs and pictographs such as those found at Writing-On-Stone provincial park, have been linked to Old Women's phase people and may have been used to transmit important spiritual information to the viewer (Peck 2011:379).

After 300 cal BP, the inclusion of European trade goods and the horse leads Old Women's phase people through a short transition period, known archaeologically as protohistoric Old Women's phase, to become the historically known Nitsitapii (Blackfoot Confederacy). During the protohistoric Old Women's phase period, people were experimenting with new ways of living. Trade goods were incorporated alongside traditional materials, often in ways different than the use intended by the manufacturer. The inclusion of the horse meant changes in lifeways as well. People were experimenting with how best to use the horse in bison hunting. The traction power of the horse enabled larger lodges, increased the amount of goods a person could possess and how much food could be preserved and transported (Ewers 1958). Settlement patterns shifted to a heavier use of river and stream valleys to support the water needs of horses. Undoubtedly, these developments had effects on social structures and relationships as well.

Ewers (1958) provides a good overview of Nitsitapii life during the historic period, taken from both written and oral histories. The Nitsitapii still live in the Alberta/Montana area today, as well as having a significant diaspora population.

The Highland phase material culture has a limited presence on the Northern Plains, lasting approximately 150 years from ca. 500 to 350 cal BP. The Highland phase is poorly understood but appears to represent a short Shoshoni occupation on the Alberta prairies. Both the lithic materials and pottery indicate an origin in the Intermountain West. Furthermore, Nitsitapii oral traditions recount a time when the Snake (Shoshoni) people pushed them north of the Bow River. The situation lasted until the early 1700s CE when the Nitsitapii enlisted the help of the Cree, who had European firearms, to push the Shoshoni, who had a few horses by this time, southwards again.

The One Gun phase appears to be an interesting but extremely brief and limited occupation of a Middle Missouri group on the Alberta prairie in the South Saskatchewan River basin in the late 17th or early 18th century CE. The One Gun phase people were from the Middle Missouri area, based on the presence of Cluny pottery, squash knives, pitted handstones or nutstones, grinding slabs, and the use of bell pits and a defensive ditch and palisade structure at one of the two sites. Peck (citing Historic Resources Branch 1997:9-11) notes the defensive structures are similar to those used by the Dakota or the Ojibwa in Manitoba. Peck also cites a report prepared for Parks Canada and the Siksika Nation by Kooyman (1996), who proposed the phase may represent a Hidatsa or Mountain Crow trading party. The fate of the One Gun phase people is unclear. They may have returned to the Middle Missouri area but the presence of Cluny pottery in protohistoric Old Women's phase sites indicate they were incorporated into the local culture. Peck (2011) speculates the presence of Old Women's phase Cayley series points inside the defensive structure may indicate an attack by Old Women's phase people, who captured the survivors and kept them as slaves.

The Historic Period is the final and current period on the Northern Plains. This period begins with the arrival of Europeans to the region, who recorded their direct observations of life on the prairies in a written format and for a European audience. Under this definition, the Historic Period on the Canadian Great Plains begins in 1692 CE with the arrival of Henry Kelsey. Kelsey, and others like him, described their experiences of the region and the Indigenous cultures who lived there, the Blackfoot Confederacy, Gros Ventre, Assiniboine, Shoshoni, Kootenay, Cree, Plains Cree, Flathead, Crow and Nez Percés, to name a few. The arrival of Europeans spurred the ethnogenesis of a new group, the Métis. The European traders, missionaries, and settlers who came into the area introduced an alien worldview and radically different political, economic, and social relations, which they imposed through arms and with the full weight of modern industrial voracity. The intense negotiations and occasionally bloody struggles between groups in the Historic Period continue into the present.

Written climate records have been kept on the Canadian prairies since the beginning of intensive European settlement in the late 1800s CE. These direct records of environmental conditions obviate the need for proxies derived from sediments but are vitally important as the means to test and calibrate proxy data. These modern records, both direct and proxy, describe a series of multi-year droughts and more recently are beginning to show the hydrological, climatic, and ecological effects of the massive amounts of fossil carbon released by industrialisation under the modern capitalist system.

3.4 Summary

In this chapter, I have discussed how humans employ many techniques to increase abundance and diversity in their lands and I have discussed the paleoenvironmental and cultural contexts of the southern Alberta Plains. In this section, I will make some speculations about whether and in what ways past human groups may have been working to create their environments.

In the Early Precontact Period, during the late Pleistocene, there is still very little currently known about when people arrived at any given location in the Americas and even less on their lifeways. Atmospheric CO_2 levels sank to the lowest levels ever recorded during the LGM and rose slowly afterwards. Piperno et alia (2015) grew teosinte in late Pleistocene and early Holocene conditions of reduced CO_2 and temperature and discovered stark phenotypic differences from modern teosinte. The teosinte grown under the altered conditions exhibited maize-like phenotypes. This study by Piperno et alia underscores the fact that the plant species and communities during the late Pleistocene and early Holocene sometimes have no modern analogs and furthermore may not have even exhibited the same phenotypes as their modern descendants. If we combine the dearth of archaeological data in the period with the lack of environmental stability, the influence of continental ice sheets, lower CO_2, lower temperatures, vegetation communities without modern analog, and the possibility of differences in phenotypic expression between past and modern members of the same plant species, it becomes clear we have very little information upon which to make assessments of potential human niche construction behaviours during this period.

We must also ask certain questions. When people rapidly move into a new environment, how long does it take, how many generations, to develop Traditional Ecological Knowledge – a deep understanding of the characteristics, behaviours, and relationships of the members of the ecosystem? If the environment is unstable, how much or what kinds of knowledge remain applicable over longer time periods? If people were much more widely mobile and entering environments without any previous human presence and conditions were unstable, would their ecological knowledge remain shallow – be focused on a relative few but widespread species? Is Clovis visible because it was the first lithic manifestation of TEK, which developed out of a period of necessary geographical and ecological exploration of lands previously unknown to humans? There is a lot of work ahead of us to investigate how humans and non-humans came together to form new ecosystems during the late Pleistocene and early Holocene.

The onset of the Holocene marked an amelioration and stabilization of environmental conditions and a predictability that may have allowed people to deepen their knowledge of their local environments. In other locations in the Americas, the archaeological record provides evidence for ecosystem modification essentially as soon as the Holocene begins – for example opening spaces in the forests of the Neotropics (Piperno 2011; Vecino et al. 2015). At this time in southern Alberta, Early Precontact Period material cultures are often spread over large areas, but peoples appear to have made or begun making connections to certain environments such as woodlands (Clovis phase), the Great Plains (Folsom phase, Agate Basin/Hell Gap complex, Alberta and Scottsbluff/Eden phases), and the Rocky Mountains (Sibbald complex) (Peck 2011).

Plains/Mountain complex and Lusk complex peoples appear to be beginning to specialize and intensify resources in the foothills and mountains, and on the grasslands, respectively. If they were engaging in management behaviours, these would have likely been at the species and community levels. Creating mosaics of graze, browse, early successional vegetation, berry patches, and stands of deadwood for firewood in the valleys would increase the abundance of desirable plants and animals. If the change from lanceolate to notched points indicates a shift to fletched darts, they may have also engaged in behaviours that enhanced bird (presumably large bird) habitat for the fletchings on their darts. In fact, creating diverse mosaics of these resources would have been an excellent strategy for living in the region at any point during the Holocene.

Moving into the Altithermal, people in southern Alberta may have continued to deepen their ecological knowledge but likely had to move into water secure areas, the river valleys, the Foothills, and the Cypress Hills, during the long, multi-decade droughts. Perhaps the instability spurred innovative ways of living. In much the same way we discuss the Dust Bowl or Dirty Thirties drought of nearly a century ago, mid-Holocene people of southern Alberta must have had stories and myths of how people lived during droughts, which provided a template or guide for how to live when the dry times returned. If people were using various techniques to increase abundance and diversity during the warmer and drier Altithermal, perhaps those techniques blossomed as the climate cooled and moistened again.

After the Altithermal, modern climate and vegetation conditions developed and were stable for a long period. The first material culture of the new climate regime, the Calderwood complex, may be hard to define because the people were learning how to live and create a home under the new conditions. They began building cairns, indicating a sense of home and belonging, a connection to the land they were a part of. This may also indicate more complex social relations and the development of the social structures defining how to live with the land in a good way; what duties, obligations, and responsibilities they had to the non-humans of the world,

The Estevan and Oxbow phases had a broad diet and were present in all the natural regions of southern and central Alberta, the foothills, grasslands, parkland, and boreal forest transition. Once again, creating mosaics of diverse resources would suit this lifestyle well. The distribution of sites may indicate people travelled a seasonal round between resource patches. If they did, then revisiting places would amplify desirable resources in them. Cairns and now cemeteries indicate an increased sense of home and belonging in the land.

McKean complex may represent a mountain people moving into the prairies and bringing their mountain derived TEK with them. Likewise, Pelican Lake phase may have been a movement of people from eastern forests onto the prairies and bringing forest TEK. This TEK may have made Pelican Lake phase people more comfortable with river valleys and wetlands and been reflected in what resources they valued and how they obtained them. Both groups would have had to learn and incorporate new knowledge into their social systems.

If Pelican Lake phase developed into the subsequent Bracken and Besant phases, this may indicate the full shift to a prairie lifestyle. Beginning with Bracken phase people, large communal bison hunts were preferred over small kills. Bracken and Besant phase people clearly showed many of the behaviours described by Smith (2016) indicating deep ecological knowledge and ties to the land. They undertook communal projects, such as hunting and cairn burials, requiring complex social structures to regulate behaviour. They reoccupied sites and maintained good pound and jump locations, likely leading to intensification of desirable plants species at these places. They evidenced a deep knowledge of the land and animal behaviours to even conduct communal kills in the first place.

When Sonota and Avonlea phase peoples moved into the prairies from the southeast periphery of the Northern Plains, as described by Peck (2011), bringing the bow and arrow and ceramic technology with them, they appear to have merged (perhaps with Besant groups as well) to create the new Old Women's phase culture. Old Women's phase people continued to use many of the same techniques as Bracken and Besant phase people before them. Because Old Women's phase has been reliably connected to the Nitsitapii, we know quite a lot about their culture and beliefs and how these are deeply connected to how they live in the world and how they relate to non-human beings.

In the Historic Period, TEK was pushed aside and often greatly diminished by settlers, who imposed their ontological, epistemological, and economic systems on the land and the Indigenous people who lived in it. Though diminished, TEK and TERM have survived with knowledge keepers and are now experiencing a resurgence, as well as a new appreciation among scientists. A deeper understanding of Traditional Ecology combined with robust paleoenvironmental and archaeological data can help archaeologists and paleoecologists make stronger inferences about the human role in past ecosystems.

Chapter 4

Methods and Methodology

In the course of this research, I had to adjust my methods several times to adapt to circumstances, mistakes, and setbacks. Certainly, all research must proceed in this manner. The University of Saskatchewan does not have a dedicated archaeological phytolith laboratory, nor the concomitant established protocols, processes, and full range of equipment, as of yet. In hindsight, I see that we occasionally approached things from a palynological viewpoint because that is where our current institutional knowledge lies. This study is one of several first steps to expand into phytolith analysis. The methods I present here do not hide or turn away from these facts but embraces them. Oftentimes techniques and procedures in methodologies are presented in a terse, very matter-of-fact manner with minimum explanation of techniques. Though I am certain this is mostly a function of space requirements in academic journals, it can leave a researcher new to this field feeling a little adrift. While there are excellent handbooks, such as Pearsall (2015), at some point the researcher must dive in and learn by doing. I purposefully present the methods below in a manner that describes the sources from which I drew but also describes how the methods evolved and changed. I believe this approach may be of benefit to others and show that a methodology, as the name implies, is not just how one does research but how one learns to do research, not just through reading the works of others but also by embarking on one's own journey of experimentation and adaptation.

4.1 Fieldwork

The fieldwork was undertaken over the course of three trips in June and July of 2017. The field crew consisted of my research supervisor, Dr. Glenn Stuart, and me, with the assistance of and in consultation with fellow archaeologists, Dr. Margaret Kennedy and Dr. Barney Reeves, and botanist, Dr. Cathy Linowski.

The first trip was a brief reconnaissance trip to familiarize ourselves with the study area and scout potential sampling locations. We looked at a number of coulees (Figure 2.8) to assess their potential. Our selection criteria were the following: a large enough drainage basin or catchment area to hopefully capture the full range of vegetation present, relatively stable soil-forming sediments, a location narrow enough to perhaps provide a local signature but wide enough to avoid pluvial-fluvial scouring of the LFH (Litter, Fibre, Humus) and Ah horizons, and relatively easy access by foot while carrying heavy equipment and soil samples.

The coulees appear to have been named on an *ad hoc* basis over the course of several surveys and we decided to continue using the existing names. As we scouted the area, we found several areas with good sampling potential (Figure 2.9). Ravine #5 is one of the largest coulees and has a nice sized drainage basin. We located three coring locations which fit our selection criteria. From a distance Ravine #3 looked like a good location. It has a good-sized drainage basin and a large perched wetland but it was rejected due to the presence of precipitate at the surface, which may be alkaline deposits indicating an inhospitable environment for phytolith preservation. West Northwest Coulee had a very nice, large perched wetland but closer inspection revealed it was too wet for coring and the surface may in fact be a floating vegetation mat. All other coulees were rejected for having too small a drainage basin, lacking good coring areas, or having potentially good coring areas but which were difficult to access by foot. In the end, we decided Ravine #5 was our best candidate for taking core samples.

We also scouted several depressions on the prairie uplands near the bluff edge for their core sampling potential. An upland depression is more likely be subject to eolian deposition and would allow us to get a better image of the regional or extra-local vegetation. Additionally, we were interested in what differences we might observe when comparing these two different landforms, an upland depression, and a coulee drainage. On the uplands, accessibility and sediment stability are not much of a concern, so the main criterion is size. A suitable depression is large enough to provide data on regional or sub-regional vegetation and deep enough to retain enough water to affect the local vegetation composition, which we hoped to be able to detect as well in the phytolith assemblages.

Most locations we scouted were too small but two were large enough to have some research potential. The first depression is close to several stone cultural features and was rejected due to the fact that it was likely within archaeological site boundaries and would infringe upon First Nations' wishes for us not to disturb cultural areas (as well as requiring a permit for obtaining a core). The second depression is some distance from any cultural features and therefore not within any archaeological site boundaries. We decided this depression would be a good secondary core sampling location to gain information about the prairie uplands.

4.1.1 Core samples

During the second trip we took our samples. We used a hand operated AMS Signature SCS 2” x 6” soil core sampler, which accepts 6” long by 2” diameter (15cm long by 5cm diameter) cylindrical sampling tubes. There is a 3cm gap between the distal end of the sampling tube within the device and the distal end of the sampling device. My original methods (changes discussed below) planned for 3cm thick sub-samples, i.e., the maximum resolution would be 3cm, so we decided to scrape the material from the 3cm gap into a bag as its own field sample. Under this system odd field sample numbers were collected in tubes and even numbers were bagged gap material. For example, C2.1 was the first sample collected in a tube from our second core location and C2.2 was the material scraped from the gap. In order to try to avoid either compressing samples or shorting them, we used a permanent marker to mark 18cm increments on the rod of the coring device, so we knew exactly how far within the core sampling column we were. We cleaned the sampling device between core segments to minimize contamination between samples. We were able to use this method successfully at our second and third core sampling locations but had some trouble at our first location.

For our first core sampling location, we selected an area in Ravine #5 with several desirable traits. The area appeared to be a fen but also seemed solid enough to use our coring device. The area is a few meters downstream from where the various small drainage channels consolidate into one channel, which would allow us to get a full sampling of all areas drained by the coulee. The area is wider than anywhere upstream, which would allow drainage waters to slow down and spread out, thereby minimizing erosion and possibly allow more sediments to settle out of the water column.

We chose an area outside the main channel, cleared away some vegetation, and began sampling. We were able to retrieve our first sample but below 20cmbs the sediment became exceptionally wet and loose. We tried switching to an auger head and collecting sediment samples in bags, but we could not achieve any consistency or uniformity in the samples; one sample might be 2 cm thick and the next 7cm, and even then, the context was highly disturbed. At 43cmbs the sediments became more solid again and we were able to collect three samples with tubes before terminating at gravel at 87cmbs. A metal probe confirmed the presence of a solid basal gravel layer.

We inferred that the top, solid level was something of a floating vegetation mat held in place by the root zone of the vegetation in this area but that beneath that there is a zone of loose sediment where there is subsurface water, possibly flowing water. At the bottom of the sediment column either heavier sediments are settling out of the loose, watery zone or, more likely, the sediments were deposited under different conditions and have a denser composition. The gravel is most likely the sand and gravel fill described by McPherson (1968) and discussed above in section 2.1.2. This first location allowed us to familiarize ourselves with the equipment and forced us to think about how we collected and numbered our samples to achieve more consistent and uniform results.

We were more certain the second core sampling location would have more solid sediments as it was in a depression on the prairie above the bluffs. At this second location, we were hoping for more lacustrine-like sediments, possibly even varves. We were disappointed to find no varves, but the sediments were solid and deeper than we expected. The sediments were also free of gravels and cobbles, indicating aggradation is probably occurring through both low energy sheetwash from the surrounding area and eolian deposition.

At this second location we began using the system of sampling tubes and bagging the gap material. First, we scraped the material out of the gap with a cleaned edge of a margin trowel into a bag labeled with the provenience information; being careful to scrape the sediment at the bottom of the tube flat and not dig into it. Next, we removed the tube with the sample and capped it on both ends before writing the provenience information and noting which end was up. We were able to take 6 tubed and 6 bagged samples down to 105cmbs but friction and suction made the coring device too difficult to remove by hand below that depth.

Our third and final sampling location was in Ravine #5, 250m downstream from the first location. This location is an area where the stream bed is slightly narrower from bank to bank and the vegetation is a little more riparian, with trees and shrubs on the banks and several willow trees in the stream bed surrounded by grasses and forbs. The location we chose is on a slightly elevated area near the left bank that was dryer than the surrounding ground. Our logic was that this location would have lower energy water flows than in the center of the streambed and therefore better conditions for aggradation of phytolith containing sediments. We followed the same sampling procedure we used at the second sampling location, measuring the rod to get uniform samples, and using tubes and bags to obtain 15cm and 3cm sample lengths, respectively.

The sample column was terminated at 153cmbs, at what was almost certainly a tree root, as the sample location was only about 3-5m from several large willow trees. At 153cmbs the coring device hit a movable obstruction, pressure on the device had a 'bouncy' feel, and vapor came out of the sampling hole. On the next sample attempt, the coring device slipped sideways and was able to be pushed to the correct depth, but the sample was more water than sediment. We decided the column had intersected a tree root, possibly a dead tree root which had decomposed enough to leave a space for water, and the coring device was slipping off the side of the root. Alternatively, given our experience at the first sampling location, there may be a W horizon – a water layer – within the sediment column. Had there not been a tree root and if the sediments are similar to those at sampling location #1, we may have been able to collect another 40cm or so of sediment samples before terminating at gravel. At this third sampling location, we obtained 17 samples in total, 9 tubed samples and 8 bagged samples. We discarded what would have been the ninth bagged sample as it was likely contaminated by recent botanical material from the tree root. At this point we felt we had sufficient material from the sample columns and switched to taking some modern surface samples for comparison.

4.1.2 Modern surface composite samples

Modern surface samples are important because they provide phytolith assemblages from known vegetation communities to which we can compare the fossil assemblages from the sampling columns (Pearsall 2015). We took seven modern surface samples (Figure 2.9) from the topographic locations and vegetation communities described in section 2.7 above. Following Pearsall (2015), to collect each modern surface sample, we collected small amounts of surface sediment at random within an area approximately 10m x 10m square until we had a composite sample of approximately 200ml from the location. The sediment was collected with pointing trowels cleaned with alcohol solution before each sample and placed into labeled paper bags. In hindsight, it would have been preferable to use plastic bags rather than paper. But the risk of contamination is low as the bags are made from wood, which produces few phytoliths, and the

Kraft process used to make the paper employs highly alkaline solutions, which would dissolve any phytoliths present or at least reduce them to fragments.

4.1.3 Vegetation samples

The third and final trip to the field site was taken in order to consult with Dr. Cathy Linowski, a botanist who had previously visited the area with Kennedy and Reeves. As described in section 2.7 above, Linowski identified the vegetation communities at our core and modern surface sampling locations. She also showed me several areas with vegetation that is unusual for the area. I collected living samples of several important taxa Linowski identified with the intention of beginning a phytolith reference collection for this project. I later discarded the samples when I decided to abandon this task and leave it for some future researcher or researchers, as I realized such a collection would be the work of years and well beyond the scope of a master's thesis project.

4.2 Phytolith extraction

"No single procedure can be used as a 'recipe' for successful extractions in all types of soils or sediments." (Pearsall 2015:282).

After obtaining the field samples, I brought them back to the laboratory at the University of Saskatchewan to extract the phytoliths. My extraction methodology is based largely on those of Lentfer and Boyd (1998, 1999), Zhao and Pearsall (1998), and Pearsall (2015) and with considerable input from fellow University of Saskatchewan graduate student, Kathryn Burdeyney (personal communication 2017).

The extraction process involves the following basic steps:

1. creating a subsample suitable for phytolith extraction
2. removing the carbonates
3. removing the organic material
4. deflocculating (chemically debonding) the sediment particles
5. removing the sand fraction
6. removing the clay fraction
7. colloids removal with KOH (if necessary)

8. separating the phytoliths from the silt fraction by flotation in a heavy liquid with a specific gravity higher than 2.3 (having a density of 2.3g/cm^3)
9. drying the phytolith fraction
10. storing the phytoliths for slide mounting

Given Burdeyney's (2019) similar successful phytolith extraction process from soil samples at Wanuskewin Heritage Park in Saskatoon, Saskatchewan, a somewhat similar environment to my site in southeastern Alberta, I decided to proceed with my extraction using the above order of operations. It is important to note that steps 2-7 can be accomplished in a different order depending on the composition of the studied sediments.

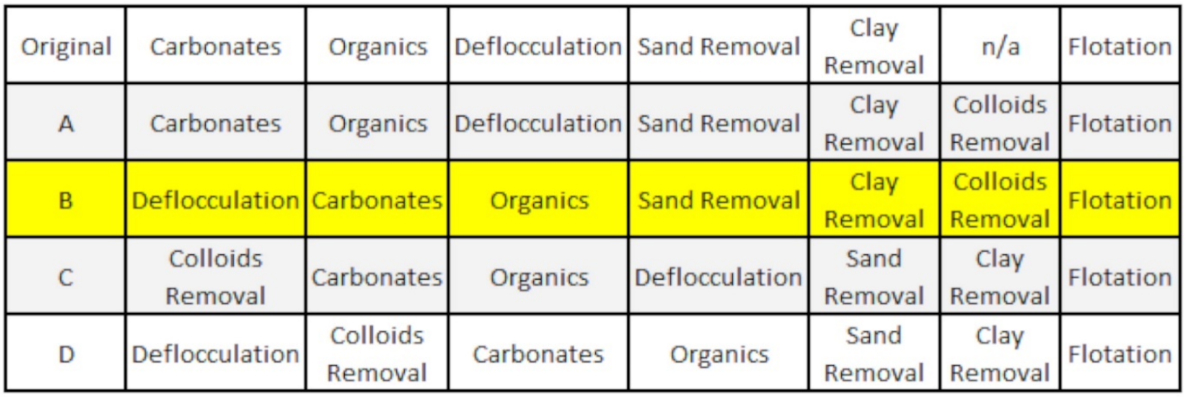
For all steps involving chemicals I performed the treatments under a fume hood using personal protective equipment (PPE) appropriate to the chemicals involved. For the novice phytolitharian, especially archaeologists who may have a limited background in chemistry, it is vitally important to be aware of the dangers of the chemicals used, how they react with each other and the vessels and tools used, and what measures are needed to protect oneself. One very dramatic example is that when nitrile gloves come in contact with high concentration nitric acid, the gloves burst into flames!

The order of operations and the amounts, concentrations, and types of chemicals used should be determined through systematic experimentation with a representative sample of the studied sediments. The results of each test extraction can then be compared under the microscope to see which provides the highest concentration of phytoliths and the best clarity. This process also allows the novice phytolitharian to streamline their workflow for speed and efficiency once they begin the extraction process on their research samples. For both these reasons, it is vitally important not to overlook this step.

I, foolishly, did not experiment with my methods before beginning my original extraction process in earnest. I compounded that error by deciding the most efficient method to process 51 samples was to finish one step on all my samples before moving to the next step. When I finally was able to mount extract onto slides, I found my extract was primarily silt particles. I was forced to return to square one and experiment on my sediments until I found the best combination of chemicals applied in the best order of operations.

When I experimented with the extraction process, I created several trial processes (Table 4.1), in which I systematically changed the order of operations from my original methodology. I knew my original methodology failed to remove colloids and failed to deflocculate the sediments properly, so those are the two variables I focused on.

Table 4.1: Experimental extraction processes. Process B (highlighted) worked best, and I improved it further by removing colloids before removing the clay fraction.



Original	Carbonates	Organics	Deflocculation	Sand Removal	Clay Removal	n/a	Flotation
A	Carbonates	Organics	Deflocculation	Sand Removal	Clay Removal	Colloids Removal	Flotation
B	Deflocculation	Carbonates	Organics	Sand Removal	Clay Removal	Colloids Removal	Flotation
C	Colloids Removal	Carbonates	Organics	Deflocculation	Sand Removal	Clay Removal	Flotation
D	Deflocculation	Colloids Removal	Carbonates	Organics	Sand Removal	Clay Removal	Flotation

In two of the trial processes (A and C) I deflocculated just before separating the sediment fractions and in the other two trial processes (B and D) I deflocculated as a first step. I found no appreciable difference regarding deflocculation timing, but deflocculation worked much better than before because I used laboratory grade sodium hexametaphosphate.

I did not originally plan to use KOH to remove colloids out of concern for damaging the phytoliths. I ran two trial processes (A and B) in which I removed the colloids just before flotation. Following Piperno (2006), I ran one trial process (C) with colloid removal as the first step. Following Lentfer and Boyd (1998), I ran one trial process (D), in which I removed colloids after deflocculation but before all other steps. During colloid removal in trial processes A and B, I found the colloids had trapped the clay particles preventing clay removal. Treating the sediment with KOH just before the clay removal step, instead of after, allowed the colloids and clay particles to separate and allowed for the best colloid removal and clay removal.

Once I completed all four trial processes, I examined extract from each under the microscope. I found processes A and B provided the most clarity and abundance of phytoliths. I decided to use process B because deflocculation required using a shaker in a geology lab across campus. Deflocculating first allowed me to maximize my time and deflocculate all my samples at once, thereby saving me numerous trips. I also streamlined my process by recycling the SPT in the background while I performed the chemical treatments. By the time I developed the second, successful extraction process, time constraints unfortunately necessitated I pare back my sample count from 51 to 35 total samples. Working in batches of four samples, I was able to fully process a batch in 2.5 days and I completed the extraction process on 34 samples in 21 days. The 35th, or rather the 1st, sample was my experimental sample from which I kept the best extract.

I will detail my final extraction methods below, including some of the changes I made between extractions to streamline my process.

4.2.1 Core samples

4.2.1.1 Creating a subsample

At the outset of lab work, I had fifteen tube/bag field samples from sampling columns 2 and 3, each of which corresponded to 18cm of depth, as well as ten field samples from sampling column 1. I also had seven modern surface composite field samples in paper bags, each containing approximately 200ml of sediment. I decided that the samples from sampling column 1 would not be useful to the project due to the aforementioned inconsistencies in their collection. I did use the tubed samples from sampling column 1 to practice my methodology for obtaining a usable laboratory subsample to submit to the phytolith extraction process.

First, I defined a longitudinal plane on the tubes and split the plastic tubes in half along that plane with a hooked utility blade. Next, I used a wire commonly used for cutting modeling clay to split the sample into two equal halves and placed each half into a jig I had created to hold the half-tubes steady. In order to minimize any contamination from the cutting process and to maximize the clarity of the sediment layers, I then cleaned the exposed surface of the sample with a modeling clay scraper by scraping across the surface from one side to the other, cleaning the scraper between passes. I then photographed the sample using a tripod of set height. I also drew a profile illustration, and recorded colour observations using a Munsell chart. I then wrapped one half of each sample in plastic wrap for archival storage.

On the remaining half, I then used a ruler, a straight-edge, and a probe to incise shallow lines dividing the sample into 1cm segments and photographed the sample again. I then divided the sample into 1cm segments and placed each segment in a plastic weighboat labeled with its provenience to dry. I did this to try to find preserved botanicals, preferably seeds, for ^{14}C dating.

When there were no suitable botanicals, I scraped sediment samples, a minimum of 500g each, from the interior of a desired 1cm segment for dating. I stored these botanicals and sediment samples in labeled 5mL polypropylene centrifuge tubes.

Based on the depths of the sampling columns and the number of samples I could realistically examine for this project, I decided to create subsamples from 6cm segments of the sampling columns. Each tube/bag field sample became three lab subsamples. Because all soil phytolith assemblages are an average of the phytoliths accrued over an unknown period of time, an effect referred to as inheritance, (Fredlund and Tieszen 1994; Kerns et al. 2001; Strömberg 2004) and because there was only one distinct layer that may be a buried Ahb horizon, I decided each subsample would be a composite sample of a 6cm segment. I split the top sample of each sampling column into two 3cm thick samples. I did this to use the 0-3cmbs sample as a surface sample to compare with the modern surface composite samples. I also split sample 3.6 into two 3cm thick samples, 3.6A and 3.6B. Sample 3.6A is the possible Ahb horizon and 3.6B is the remaining 3cm of the 6cm segment.

Several of the sample tubes were not full of sediment and had gaps between the end of the tube and the sample. Some of this is due to compression or loss during extraction of the column in the field and some is settling of sediments during storage. I did not make an attempt to account for these gaps in sampling column 2 because we did not stop short on any sample in the field. In sampling column 3, we encountered an obstruction and stopped at 153cmbs but, with the gaps and settling in storage, the sediments as photographed extend to 158cm. I accounted for this during subsampling by measuring back from the base in the last sample tube, so the sediment column ends at 153cmbs. Best practice would have been to use the column measurements as laid out in the lab, as I did with sampling column 2.

Following the methodology of Zhao and Pearsall (1998), I manually disaggregated the six dried 1cm segments of each subsample by grinding them in a mortar and pestle. I sifted the sediments through a #16 sieve (Pearsall 2015), which has a mesh spacing of 1.19mm, to remove any pebbles, coarse sand, and large macrobotanicals. I recorded the mass and volume of the disaggregated sediments before creating the final subsample for extraction.

I used a cone-and-quartering technique to minimize systematic bias in my subsample (Powers and Gilbertson 1987). To do this I poured the entire sample through a funnel onto a flat surface to create a cone of sediment. I then used a large flat-bottomed beaker to flatten the cone into a disk of uniform thickness. I then divided the disk into four equal wedges: collecting the sediment from two opposing wedges and placing the other two wedges into a 50mL centrifuge tube for archival storage. I repeated this process on the collected sediment until I obtained a 10g subsample to submit to phytolith extraction. I recorded the mass and volume of each of these subsamples as well. I collected a maximum of 50mL of discard sediment for archival storage and disposed of any remaining sediment. To avoid cross-contamination of samples, I cleaned my tools between each sample and performed the cone-and-quartering on a fresh sheet of aluminium foil for each sample.

I decide not to do any soil science, such as measuring organics through loss-on-ignition, because it was outside the scope of this project. I did note how strongly sediments reacted to chemicals during the removal of carbonates and organics in the extraction process. This is an *ad hoc* method I came up with to at least get an idea of relative differences between sediments in the sampling columns. I thought about measuring the subsample pellet between stages to determine how much of each sediment component was lost, but this would have required me to dry out the pellet between each step and extended the extraction process by weeks.

4.2.1.2 Radiocarbon Samples

Botanical samples are always preferable for radiocarbon dating (Brock, Higham, Ditchfield and Bronk Ramsey 2010) over sediments, which have a low carbon content that has a variety of ages and sources (Brock, Froese, and Roberts 2010). I obtained 39 samples for potential ^{14}C dating. From sampling column 2, I ended up with 11 potential ^{14}C samples, all of which were sediment samples. From sampling column 3, I obtained 8 botanical samples, of which only one was a good candidate for ^{14}C dating, and 20 sediment samples.

I only had the budget for four ^{14}C dates. I chose the best botanical sample, an unidentified woody plant tissue, which came from sample CL3.14, located roughly in the middle of the core 3 sampling column. This tissue was dark and cylindrical, and my hope was that it was a twig fragment and not an intrusive root fragment. I chose the sediment sample from CL3.6A, the only differentiated, darker layer from an otherwise relatively homogeneous sampling column. Finally, I chose the sediment samples closest to the base of each sampling column in order to get a *terminus post quem* date for each column. All ^{14}C samples were dated using standard AMS radiometric dating techniques at A.E. Lalonde AMS Laboratory at the University of Ottawa.

4.2.1.3 Deflocculation

Chemically debonding the sediment particles from each other was the first of the chemical treatments used in the phytolith extraction process. Following Lentfer and Boyd (1999) I made a 5% w/v solution of sodium hexametaphosphate and filled the samples in their tubes to 45mL and mixed them thoroughly using a vortex machine. I then placed them on their sides on a large reciprocating shaker overnight; a minimum of 12 hours. I then removed the sodium hexametaphosphate by centrifuging the samples for two minutes at 3000 RPM and decanting the supernatant with a pipette. I then rinsed the samples twice with reverse osmosis filtered water by adding the water, centrifuging for two minutes at 3000 RPM, and decanting the supernatant (This rinsing procedure is the same for every chemical treatment except after flotation).

I originally used a 0.1% solution of Na_2H_2EDTA as recommended by Zhao and Pearsall (1998) due to the higher alkalinity of sodium hexametaphosphate but found the Na_2H_2EDTA performed poorly in my sediments. I then switched to “Calgon” following Lentfer and Boyd (1999), but this was a misstep. Prior to the early 2000s, many phytolith extraction methodologies (Twiss et al. 1969; Carbone 1977; Zhao and Pearsall 1998; Lentfer and Boyd 1999) used Calgon, a commercial laundry detergent additive, as a suitable deflocculant. Unfortunately (for the phytolitharian), in the early 2000s the manufacturer of Calgon phased out sodium hexametaphosphate for another active ingredient. In my final extraction process, I used laboratory grade sodium hexametaphosphate as the deflocculant rather than “Calgon”.

4.2.1.4 Carbonates Removal

Carbonates in sediments are removed by treating the sediments with acid. Zhao and Pearsall (1998) recommend using a weak or dilute acid, specifically 1M HCl (hydrochloric acid, 2% v/v concentration) to begin with and to move to a strong acid, specifically a mixture of high concentration HCl and HNO_3 (nitric acid) once the reaction diminishes or if the initial reaction is weak. Strong acid also removes iron and aluminium oxides, which inhibit deflocculation in sediments containing high concentrations of them; a situation less common in temperate regions than in tropical regions (Zhao and Pearsall 1998) and therefore not a major concern in sediments of the Canadian Plains. Finally, strong acid also aids in removing some organics in sediments.

I found in my initial extraction attempt that my sediments react weakly to the dilute acid, so I only used strong acid in my final extraction process. It may be a valuable time saver to use weak acid on a small amount of archive sediment from each sediment or stratum to determine the strength of the oxidation reaction and move directly to the strong acid treatment when possible.

My full-strength acids were HCl (24% v/v, 37% w/w, 12.1M) and HNO_3 (50% v/v, 63% w/w, 13.6M) combined in a 1:1 ratio. Using a graduated cylinder and a funnel in a sturdy stand, for each sample I first measured 20mL of HCl and poured it into a 250mL beaker, then I measured 20mL of HNO_3 and combined it with the HCl, stirring the mixture with a plastic stirrer. In practice, I always processed a set of four samples concurrently, so I combined 80mL of each acid.

Having made the strong acid mixture, I carefully and slowly added the acid up to the 25mL mark on the tube (approximately half the acid or 20mL) for each sample at room temperature, then capped and vortexed the tubes until the sample and acid were thoroughly mixed. I then unscrewed the cap only slightly to let any gases escape slowly, then uncapped the tube entirely. I then placed the tubes in a hot water bath maintained at 85°-90°C and monitored with a probe thermometer.

I monitored the reaction and added acid occasionally as the reaction subsided until the full 40mL was added to each sample. In general, my samples reacted to the strong acid by bubbling gently just about up to the rim of the centrifuge tube for about five minutes, then subsided to a low bubble. The samples from the top of each sampling column and the modern surface composite samples had the strongest reaction to the acid, likely due to the higher organic content in these sediments.

After the bubbling subsided and the mixture took on a strong yellow color, indicating the reaction was complete, I removed the samples from the hot water bath. I then added filtered water to each tube to dilute the mixture somewhat, vortexed them to mix thoroughly, and I centrifuged the samples for two minutes at 3000RPM before decanting the supernatant into a beaker containing a little more water to further dilute the decanted supernatant. I then rinsed the samples twice with filtered water.

4.2.1.5 Organics

Removing the organic components from the sediments is a two-step process, as recommended by Zhao and Pearsall (1998). The first step is to expose the sample to household bleach (active ingredient sodium hypochlorite) for five minutes, any longer may begin to damage the phytoliths due to the alkalinity of bleach. The second step is to treat the sample with a high concentration of hydrogen peroxide (H_2O_2).

I added bleach to the tube up to the 40mL mark, then capped and vortexed the sample. I uncapped the tube and placed it in an 80°C hot water bath for five minutes. I removed the tube from the water, recapped and vortexed it, and centrifuged the sample for two minutes at 2000 RPM. I decanted the bleach supernatant and rinsed the sample twice. It is important that the sample is thoroughly rinsed of the bleach because bleach and hydrogen peroxide react violently to each other, but not dangerously, as the reaction creates salt water and oxygen.

I then added 5mL of high concentration H_2O_2 (30% v/v) to each sample tube, capped and vortexed them, uncapped the tubes, and placed them in an 80°C hot water bath. My samples usually reacted quite strongly to the H_2O_2 and I had to monitor this treatment much more closely and actively than the other chemical treatments.

The reaction began with a gray-brown froth of small bubbles that would climb up the tube and threaten to overflow. If the froth got too high, I would remove the tube from the heat for a few moments to slow the reaction and gently tap the tube on a flat surface to pop some of the bubbles. Usually after around 30 minutes the reaction would subside somewhat, the froth would turn white with a looser structure and the bubbles became larger. When the reaction slowed, I would add a little more H_2O_2 to the sample to start it again. If there was too much liquid, I would let it steam off and reduce. The reaction turns H_2O_2 into H_2O, which can weaken the reaction if there is too much water present.

Across all samples, the reaction times ranged from 45 minutes to four hours but usually were finished after around two hours. Interestingly, all surface samples, including from cores 2 and 3, were finished at about one and a half hours (90 minutes). Samples from core 2 had an average reaction duration of two hours (120 minutes) and the median duration was also two hours (120 minutes). Samples from core 3 had an average reaction duration of two and a half hours (150 minutes) and the median duration was three hours and ten minutes (190 minutes).

In my first extraction attempt, I used 250mL beakers in a hot water bath, but this was not as effective as using the 50mL centrifuge tubes, as recommended by Lentfer and Boyd (1998). Using the beakers required much higher amounts of H_2O_2 to keep the reaction going and took much longer for the reactions to subside. Burdeyney (personal communication 2017), using a similar methodology, had samples that required over 8 hours for the reaction to subside.

Once the sample no longer reacted to the addition of H_2O_2, I removed it from the hot water bath. I then added filtered water to the 45mL mark, capped and vortexed it, and centrifuged the sample for two minutes at 2000 RPM. I then decanted the supernatant and rinsed the sample twice with filtered water.

4.2.1.6 Sand Removal

Phytoliths generally range in size from 2µm to 200µm; a range which overlaps the silt fraction in a sediment sample. Accordingly, we must remove the sand fraction (>250µm) and the clay fraction (<2µm). To remove the sand fraction, I followed Piperno's (2006) methodology.

I placed a 250µm (60 mesh) sieve in a funnel secured in a ring-stand with a 500mL beaker underneath. I then rinsed the sample out of the centrifuge tube and through the sieve using filtered water in a rinse bottle. Sieving out the sand fraction required, on average, approximately 200mL filtered water per sample. I poured the sieved sediment from the beaker into multiple 50mL centrifuge tubes, centrifuged them for two minutes at 2000 RPM, decanted the supernatant, and recombined the sediment back into the original tube. I also collected the sand fraction from each sample, let it air dry, and recorded the mass and volume.

4.2.1.7 Colloids Removal

In my first extraction attempt when I was at the clay removal step, I found there would be several milliliters of a gel-like substance resting on top of the sediment. At the heavy liquid flotation step, there was also a layer of the same gel floating at the top of the heavy liquid. The gel-like substance is the humic colloids mentioned in several of the methodologies (Horrocks 2005; Lentfer and Boyd 1998, 1999, 2000; Pearsall 2015; Piperno 1988; Zhao and Pearsall 1998). Colloids are formed when certain clays bond with organic polysaccharide polymers (Emerson 1977) and require a treatment with a base to break down the humic acids in the colloids (Lentfer and Boyd 1999:43). All of the aforementioned methodologies recommend a treatment of KOH (potassium hydroxide, a strong base) to remove the colloids. Exposure of phytoliths to KOH should be limited to less than ten minutes to minimize damage to the phytoliths (Lentfer and Boyd 1999).

During clay removal in my methods experiment prior to my second phytolith extraction, I observed in all my samples that after treating the sample with sodium hexametaphosphate the supernatant was very clear. I then rinsed with filtered water and the supernatant would become cloudy. I treated the sample with water until the cloudiness decreased, then added sodium hexametaphosphate again, at which point the supernatant would be clear again. Then, when I rinsed the sample, the supernatant would be cloudy again. For experimental samples B and D, I performed 33 treatment cycles in total, including two rinses at the end. For experimental samples A and C, I performed 22 treatment cycles in total, including three rinses at the end. In all four the sodium hexametaphosphate was always clear.

As part of my experiment design, I treated two of my samples, C and D, with KOH at the beginning of the extraction process prior to carbonates removal but I did not treat the remaining two samples, A and B, with KOH until after clay removal and immediately before heavy liquid flotation. When I rinsed the samples after treatment with KOH, the supernatant was cloudy. I rinsed the samples numerous times, and the supernatant clarity increased a little every time. I added sodium hexametaphosphate to see what would happen and it too was cloudy. After 15 treatments, mostly with filtered water, the supernatant began to really clarify, and I ended the treatment after 18 cycles in total. This process was much closer to what I was expecting during the clay removal process based on descriptions in Lentfer and Boyd (1999). I believe colloids had bound up the clay particles with the silt particles, which settled together, and which is why my earlier attempt at clay removal resulted in clear supernatant when sodium hexametaphosphate was applied. From this experience I concluded the best time to treat my sediments with KOH was just prior to clay removal, which is the order of operations I followed.

Following the procedure of Lentfer and Boyd (1998), I added 30mL of a 10% w/v solution of KOH to each sample. I then capped and vortexed the sample to thoroughly mix in the KOH. I uncapped the sample and placed it in a hot water bath maintained at 90°C for five minutes. I removed the sample from the heat, diluted the sample with filtered water up to the 50mL mark and centrifuged the sample for two minutes at 3000 RPM. I decanted the supernatant and rinsed the sample twice.

4.2.1.8 Clay Removal

In order to isolate the silt fraction prior to heavy liquid flotation, the clay particles must be removed from the sediment sample. The clay particles, which are 2µm or less in size, cannot be removed by sieving because a mesh with 2µm spacing is unfeasible as such a mesh would be plagued by clogging (Cwynar et al. 1979). Lentfer and Boyd (1999) compared sieving sediments through a 5µm mesh to still-settling and centrifugation techniques.

Settling and centrifugation both rely on gravity sedimentation, the fact that when particles of similar density are suspended in a column of liquid, larger particles will settle before smaller particles. Sediments will therefore sort themselves by size. For clay removal, sediments suspended in a liquid are left for just enough time for the silt fraction to settle, leaving the clay fraction suspended in the liquid. When the liquid is decanted only the silt fraction remains.

Still-settling entails leaving sediments to settle under normal (1G) gravity, whereas centrifugation enhances the gravitational force to speed the sedimentation process. While clay removal by still-settling takes 8 hours, centrifugation can speed the process to around one minute. Compared to sieving through a 5µm mesh, Lentfer and Boyd (1999) found centrifugation to be faster and to have more reliable recovery of phytoliths, including phytoliths down to 2µm.

Removing the clay fraction from the sediment samples proved to be the most time-consuming treatment of the entire extraction process. In Lentfer and Boyd’s (1999) methodology, the treatment involves mixing the sediment with a 5% w/v solution of sodium hexametaphosphate, for maximum deflocculation, and heating it to 70°C in a hot water bath for 20 minutes, centrifuging the samples for two minutes at 2000 RPM, and decanting the supernatant. The treatment is then repeated until the supernatant is clear. Lentfer and Boyd were able to accomplish the treatment on six samples in 6.5 hours after 13 repetitions and noted the still-settling method for those same samples would require nearly five days (pp 42-43). I was able, however, to decrease the treatment time a little more.

Firstly, Lentfer and Boyd added the 5% sodium hexametaphosphate, then heated the sample to 70°C in a hot water bath. They recommended, however, bringing the sodium hexametaphosphate up to temperature in bulk prior to adding it to the sample to save the 20 minutes in the hot water bath. I followed this recommendation.

Secondly, after adding the heated sodium hexametaphosphate, Lentfer and Boyd recommended shaking the sample then letting it sit for 10-15 minutes before centrifugation. They did not state why the sample should be left to sit but presumably this is meant to be a final deflocculation before sedimentation. I experimented by comparing their method of letting the sample sit for 10 minutes to immediately centrifuging the samples and found no discernible difference in outcomes. I decided, therefore, not to let the samples sit after adding the sodium hexametaphosphate.

Lastly, using settling times described by Lentfer et alia (2003:165 Table 4), I was able to reduce the centrifugation time by nearly half. Lentfer et alia discuss various aspects of settling times and viscosity, including for monodispersed suspensions, in which all suspended particles are of one size, and polydispersed suspensions, in which the suspended particles are of various sizes. The smallest phytoliths are 2µm in size (Rovner 1971) and have a specific gravity ranging from 1.5 g/cm^3 to 2.3 g/cm^3 (quartz, a common mineral constituent of sediment particles has a specific gravity of 2.65 g/cm^3) (Carbone 1977). Table 4 in Lentfer et alia (2003:162-167) details the settling times for particles of various sizes and specific gravities in a polydispersed suspension of sediment in a 5% solution of sodium hexametaphosphate (Calgon in the chart) at 20°C, 40°C, 60°C, and 80°C and at 2000 RPM, 2500 RPM, 3000 RPM, and 0 RPM (still-settling). Their centrifuge had an arm radius of 77mm (0.077m) and the centrifuge I used, a Thermo Scientific Sorvall ST8, had an arm radius of 89mm and is capable of up to 4500 RPM. Besides maximizing efficiency, using a higher RPM for a shorter time may also minimize phytolith loss by better separating particles from each other and the walls of the tube (p168).

Using the data from Lentfer et alia (2003:165 Table 4), I was able to extrapolate centrifugation times for my machine at 4000 RPM. For a 5% w/v solution of sodium hexametaphosphate at 60°C this is 1.31 minutes or 1 minute and 19 seconds. I decided to centrifuge my samples for 1 minute and 20 seconds at 4000 RPM, which is a conservative time that allows the maximum amount of phytoliths down to 2µm to settle while minimizing time spent on centrifugation.

As a first time phytolitharian, I was zealous to recover as many phytoliths as possible. When I designed my research, I still entertained the notion that I would be describing phytoliths from living specimens of certain taxa, which would necessitate recovering phytoliths across the entire size range. In hindsight however, as few of the diagnostic phytoliths I finally analysed were less than 10μm and none were less than 5μm, it would have been better to set my lower phytolith size limit at 5μm. If I had done so, the centrifugation time could have been only 22 seconds at 3000 RPM, and I believe I would have obtained a much higher degree of clarity in my extracts. As the largest quartz clay particles require 36 seconds to settle at 3000 RPM, they and most small biogenic silica debris would likely have been almost completely removed.

Having explored the aforementioned efficiency increases, I created the following methodology for removing clay from my samples. I made 1L of 5% w/v solution of sodium hexametaphosphate in a large flask on a hot plate with a magnetic stirring device, allowing the hotplate to heat and stir the solution. I monitored the temperature of the solution with a probe thermometer. Once the temperature reached 70°C, I poured some of the solution into a 250mL beaker and used that beaker to add the sodium hexametaphosphate solution to the 45mL mark on the centrifuge tube. I capped and vortexed the sample and centrifuged the sample for 50 seconds at 3000 RPM. I decanted the supernatant with the clay suspended in it before starting the process again as a new treatment cycle. I found I got the best results when I alternated between treatment cycles with 5% sodium hexametaphosphate and treatment cycles with filtered water. I continued the treatment cycles, alternating between water and sodium hexametaphosphate approximately every third cycle, until the supernatant was clear, at which point I rinsed the sample three times.

The number of treatment cycles required to remove the clay fraction and clarify the supernatant ranged from 9 to 22, with the average being 19 and the median, 20 cycles. Judging when to stop the treatment cycles was somewhat subjective. I deemed a sample to be finished when I could hold the tube with the volume markings facing away from me and easily read those markings through the supernatant and the walls of the tube.

4.2.1.9 Heavy Liquid Flotation

In order to separate the phytolith fraction from the silt fraction it is necessary to float the less dense phytoliths in a heavy liquid. Because phytolith densities range from 1.5 to 2.3 g/cm^3 and silt particles have a density of roughly 2.65 g/cm^3 (Carbone 1977), when the silt fraction of sediments is suspended in a heavy liquid of 2.3 g/cm^3 (specific gravity of 2.3) and centrifuged, the silt will settle to the bottom leaving the phytoliths suspended in the heavy liquid.

Zhao and Pearsall (1998) tested the heavy liquids zinc bromide/hydrogen chloride ($ZnBr_2$/HCl), zinc iodide (ZnI_2), and sodium polytungstate (SPT) to replace cadmium iodide/potassium iodide

(CdI_2KI), which they had been using up to that point in the University of Missouri phytolith lab. They not only compared the efficacy of the chemicals but also safety, ease of handling, and cost (Zhao and Pearsall 1998: 591). They found all four were similarly effective, though only SPT is non-toxic. They did find that SPT reacted with certain soils and "produced a thin to thick sheet of colloidal soil suspended as a 'cover' on the heavy liquid" (p. 593). This reaction did not hinder phytolith recovery but did also capture a large amount of silt debris. I also observed this phenomenon in my first extraction attempt and my samples also had large amounts of silt debris. Despite the reaction of SPT to certain soils, Zhao and Pearsall still recommended it along with ZnI_2 for extractions. Pearsall implemented the use of ZnI_2 at the University of Missouri phytolith lab but later switched to lithium metatungstate (LMT) due to availability issues (Pearsall 2015).

The heavy liquid I chose to use was sodium polytungstate because it is relatively cheap, it is non-toxic (although it can cause eye damage and respiratory irritation in solid powder form), it is easily recycled for reuse, and it had already proved reliable in a previous archaeological phytolith study conducted at the University of Saskatchewan (Burdeyney 2019). The SPT I used (454g, Poly-Gee Brand from Geoliquids, Inc.) is packaged as a powder with a density of 5.47 g/cm^3 and therefore must be dissolved in water to create a solution with a specific gravity of 2.3 (2.3 g/cm^3). I recycled my SPT for reuse after every four samples processed, as described below. My heavy liquid flotation methodology generally followed Zhao and Pearsall (1998). Lentfer and Boyd (1998) performed a secondary flotation, although the heavy liquid they used was a mixture of cadmium iodide and potassium iodide (CdI_2KI). I decided to also perform a secondary flotation to minimize possible contamination with silt debris accidentally decanted with the phytoliths in the primary flotation. My flotation method was as follows.

I added 10mL of 2.3s.g. SPT solution to the sample, vortexed the sample, and centrifuged it for five minutes at 3000 RPM. I carefully decanted the supernatant with a pipette into another 50mL centrifuge tube, being careful not to take any silt with the supernatant. I repeated this process three times for a total of 40mL of supernatant used for each sample. I performed a secondary flotation by vortexing the collected SPT supernatant and centrifuging again for five minutes at 3000 RPM. In order to properly dilute the samples in the next step, I decanted into each of two new 50mL centrifuge tubes not quite 20mL of supernatant with a pipette from the top of the supernatant, again careful not to remove any settled silt into the extract. Because I was avoiding decanting any silt, I always left a little SPT layer just above the settled silt fraction. This meant that at the end of the two flotations I had less than the 40mL of SPT I started with and each of the final two tubes had less than 18mL of decanted SPT in them. To these I added filtered water to the 50mL mark to dilute the SPT below 1.5 s.g., vortexed each, and centrifuged them for 10 minutes at 3000 RPM. I decanted the supernatant from each into an 800mL beaker to collect the SPT for recycling. I rinsed the extract from one tube into the other and added filtered water to rinse the phytolith extract before drying. I rinsed each sample twice for ten minutes at 3000 RPM. Because I wanted to conserve as much SPT as possible, I added water to the 50mL mark in the centrifuge tube remaining from the first flotation, centrifuged for 5 minutes at 3000RPM, and decanted the supernatant into the SPT recycling beaker.

4.2.1.10 Drying the Phytoliths

I had two options for drying the phytolith extract, thermal drying (Pearsall 2015, Zhao and Pearsall 1998) and chemical drying (Lentfer and Boyd 1998, 1999), and I experimented with each. Lentfer and Boyd prefer a two-step process, in which 50% and then 100% ethanol are used to drive out the water from the extract. I tried methanol, which we had on hand in the lab, and found it required quite a long time to dry completely. Zhao and Pearsall prefer to dehydrate the extract in a low temperature oven at 100°C (Zhao and Pearsall 1998) or even as low as 40°C (Pearsall 2015). The oven I had access to was malfunctioning, so I used a hot plate set at a low temperature to dehydrate the samples. I found this thermal method worked perfectly satisfactorily and was faster than the chemical method I tried.

I added 2 or 3 mL of filtered water into the extract tube and vortexed it to mix it well and so the pellet would not stick to the bottom of the tube. I then rinsed the extract into a small aluminium weigh boat labeled with the sample ID and placed it on a hot plate set at a low setting. I monitored the dehydration to assure the phytoliths were not on the hot plate longer than necessary. This was for efficiency rather than out of concern for the phytoliths as phytoliths are extracted from vegetation by dry-ashing the plant material at temperatures of 500°C for six hours or more without damage to the phytoliths (Pearsall 2015, Twiss et al. 1969). Once the water boiled off, the phytolith extract remained as a white film on the bottom of the weigh boat. I used a plastic probe with a flattened end approximately 1cm wide to scrape the dried extract together. I used the probe to bend a small lip into the side of the weigh boat and carefully poured the extract into a 5mL centrifuge tube labeled with the provenience information. I stored the phytolith extract in the 5mL tubes until I was ready for microscopy.

4.2.1.11 SPT Recycling

One of the benefits of using SPT for heavy liquid flotation is that is easily recycled. Although SPT can be fully dehydrated and repulverized, the time and effort involved is completely unnecessary unless the intent is to place the SPT into longer term storage in its dry powder form. Instead, it is much quicker and more efficient to filter the liquid, reduce it, and recalibrate it to a specific gravity of 2.3. I adapted my recycling process from Zhao and Pearsall (1998) and the process described in the safety data sheet provided with the SPT. I then refined this process based on my experience and the equipment available to me.

For this procedure, a glass microfiber filter with a pore size slightly less than 2µm, such as Whatman GF/C, is ideal. I set up a ring-stand under the fume hood with a filter placed in each of two funnels set in sequence draining into an 800mL beaker, marked with the beaker tare weight. I poured the SPT into the top filter, being careful not to let either filter overflow. The SPT filters slowly, so I would pour a little and wait before pouring more. The SPT filters more slowly over time as the filter clogs and this process usually required several hours to complete.

Once the SPT was filtered, I placed the beaker on a Fisher combination hotplate and magnetic stirrer set to 300°C and 60RPM and monitored the evaporation. At these settings, water evaporated from the SPT at a rate of roughly 100mL/hour. After the SPT was reduced enough, I set the beaker aside to cool before weighing the liquid because the water continues to evaporate for a period. If the SPT solution becomes milky, it needs to be filtered again.

Once the SPT was cool, I took weight and volume measurements to calculate the solution density. I poured the SPT into a graduated cylinder on a level surface to obtain the volume within 0.5mL of accuracy and emptied the SPT into the beaker with the marked tare weight. I then weighed the SPT on a .01g balance and calculated the density. The solution was usually in the 2.35 to 2.5 s.g. range and I added filtered water to the SPT solution to achieve a density as close as possible to 2.33 s.g. I poured the calibrated SPT into a squeeze bottle for storage and easy use.

4.2.2 Modern surface composite samples

The modern surface composite samples were processed following the same phytolith extraction procedure detailed above. The only difference being, during disaggregation, I removed coarse sand grains to protect the mortar and pestle and I removed any large botanicals in order to extract a phytolith assemblage originating from within the soil rather than from surficial macrobotanical debris.

4.3 Microscopy

To collect data for analysis, phytoliths are mounted on slides and examined under the microscope. Only certain phytolith shapes, known as morphotypes, are useful to the researcher. All plants that create phytoliths create a multiplicity of morphotypes and many morphotypes are redundant – they are common to a wide variety of plants (Rovner 1971). Due to multiplicity and redundancy, most phytolith morphotypes are created by such a wide variety of plants as to have no analytical value. To winnow the analytically useful morphotypes from the useless phytolith chaff, the researcher must use or create a morphotype reference collection. Standard practice is to count certain morphotypes until a predetermined sum is reached. The morphotypes counted and the sum counted to (the count) both depend on the types of analyses to be performed on the data. The analyses a researcher chooses depend on the question or questions the researcher is investigating.

4.3.1 Slide mounting

To mount the phytolith extract I used standard glass microscope slides and coverslips. I used glycerine (also sold as glycerin or glycerol) to mount the extract. I used a pipette to place just one or two drops of glycerine on a pre-labeled slide. I used a small spatula probe to remove a very small amount of extract, just enough to cover the corner of the spatula, which when weighed was 0.003-0.005g. I dumped the extract into the glycerine and stirred until it appeared to be homogeneously mixed. I placed a 22 x 22mm coverslip on the extract so one edge touched the mixture first, then gently lowered the coverslip into place with a needle probe. If any excess mixture leaked from the sides of the coverslip, I used the edge of a tissue to soak it up. I cleaned my tools with alcohol and let them dry between slides.

I used glycerine because it is cheap, ubiquitous, and completely non-toxic. It has been used in phytolith research (Fredlund et al. 1998) because it allows phytolith rotation by pressing gently on the coverslip with a probe. The downside of using glycerine as a mounting medium is phytoliths can be difficult to discern within it using brightfield microscopy alone. Phytoliths have a refractive index (RI) of 1.43 (Dayanandan et al. 1983). Because glycerine has a RI of 1.44 there is not very much contrast between them. Palynologist often use glycerine because the refractive index of pollen ranges from 1.55 to 1.60 and glycerine provides good contrast (Twiss 1987). Pearsall (2015:369) provides a chart of the RI of various mounting media and recommends choosing a medium that provides a high contrast. Her lab uses Canada Balsam, which has a RI of 1.541-1.547.

4.3.2 Equipment

I used a Seiler Microlux IV compound microscope to conduct the phytolith identification and count. The microscope came equipped with a 10x eyepiece and 10x, 20x, 40x, and 100x objectives. I replaced the 100x objective with a 60x objective. Thus, the microscope was capable of 100x, 200x, 400x, and 600x magnification. This microscope was also equipped with phase contrast annulars for the 10x, 20x, and 40x objectives. I further equipped the microscope with polarizing filters, one inserted in between the objective and the eyepiece and the other placed over the field diaphragm, which I could rotate to manipulate the light polarization effect. I replaced the binocular head with a Seidentopf trinocular head with a CCD adaptor to allow the attachment of a DSLR camera, a Canon EOS Rebel T3. I used a mini-USB to USB cable to connect the camera to my laptop, an HP Pavilion 13 x360.

I used Canon's proprietary EOS Utility v.2 to adjust the camera settings and take photographs. For bright field microscopy (Figure 4.1) the camera settings at 100x were ISO 800, 1/1250, F0 0, with a fluorescent white balance, at 200x were ISO1200, 1/250, F0 0, and at 400x were ISO 6400, 1/160, F0 0, with a fluorescent white balance. I found these same settings for each magnification worked well when I used phase contrast.

The microscope FOV was not the same as the FOV using the DSLR and a laptop. The microscope FOV is a circle with a radius of 1000µm (1mm) at 100x, 500µm at 200x, 250µm at 400x, and 166.665µm at 600x. The DSLR FOV is a rectangle centred in the microscope FOV but with an area 46.75% of the microscope FOV (Figure 4.1). That rectangle is 1000µm x 1468µm at

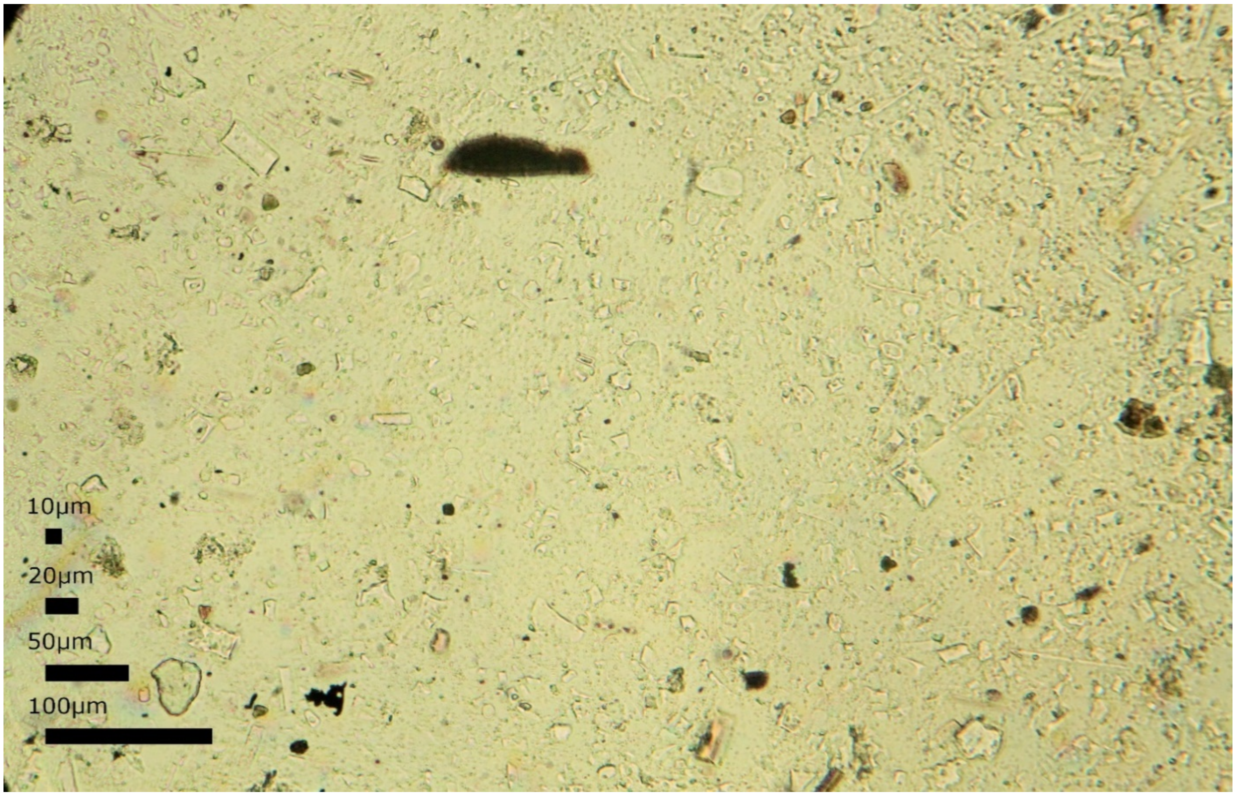


Figure 4.1: Typical field of view at 200x magnification using bright field illumination; scales added for context.

100x, 500µm x 734µm at 200x, 250µm x 367µm at 400x, and 166.665µm x 244.664µm at 600x. When I scanned the slides, I used the DSLR FOV rather than the microscope FOV for all purposes, and all descriptions of FOVs from this point forward refer to the DSLR FOV.

As described above, the similar refractive indices of the glycerine mounting medium and the phytoliths rendered the phytoliths very difficult to see. Parry and Smithson (1958) recommended the addition of both phase contrast and polarization equipment on a microscope used for phytolith investigations. Both of these functions enhance contrast and helped me distinguish between phytoliths and other objects, such as quartz crystals.

Phase contrast (Figure 4.2) provides contrast where there is none or very little under brightfield illumination. As described by Murphy et alia (2020), phase contrast uses a special lens called an annulus to create phase-shifts in the light waves as they pass through the specimen. The phase-shifts are translated into changes in light amplitude creating visible contrast. I used phase contrast most of the time when scanning a FOV because I could see objects much more easily than with brightfield illumination only. I always shifted back to brightfield to briefly do a last check before moving to the next FOV. Phase contrast allowed me to overcome the limitations of the glycerine mounting medium.

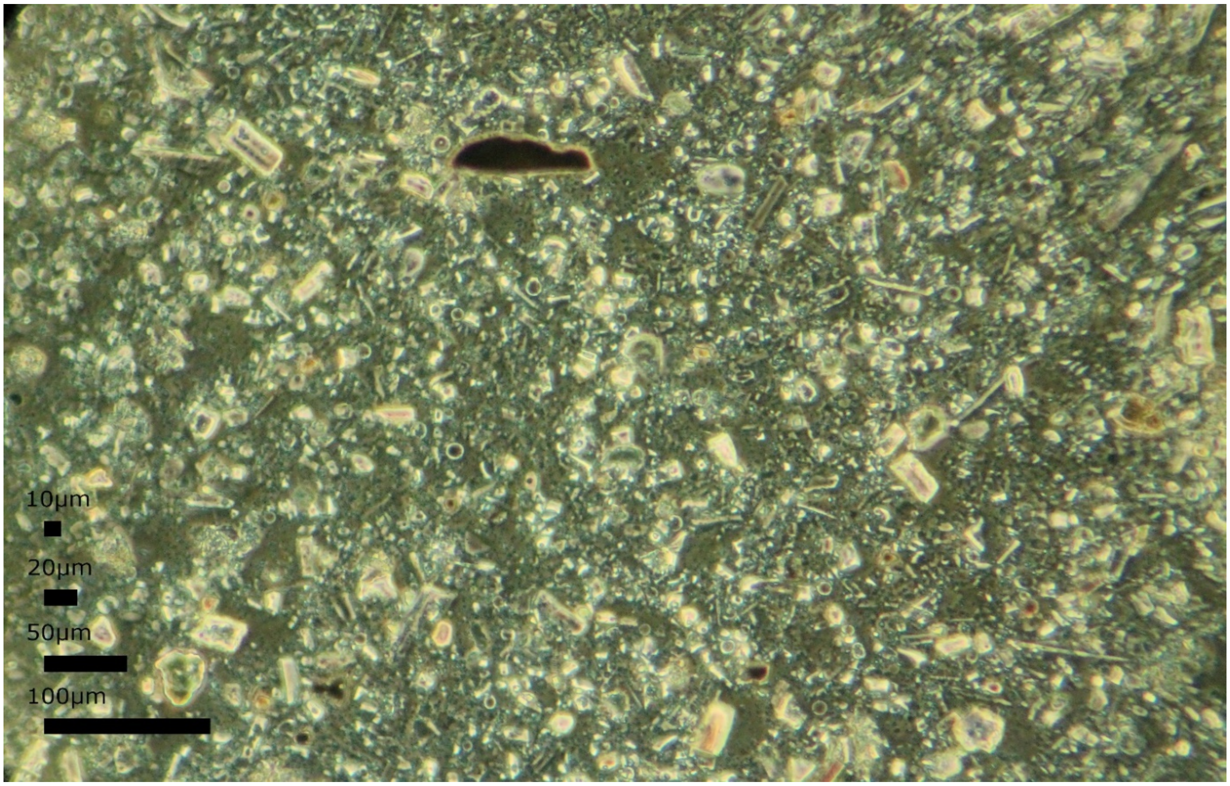


Figure 4.2: Same field of view as in Figure 4.1 above illuminated using phase contrast filters.

Polarized light is useful in distinguishing between materials. To use polarized light, I inserted a polarized filter in a slot between the objective and the eyepiece, and placed another polarized filter, the polarizer, on top of the field diaphragm. When the two filters are aligned in parallel, light waves pass through easily. When the polarizer is rotated the light-waves shift out of alignment until, when the filters are perpendicular, the light is cross-polarized and no light passes through the second filter. According to Robinson et alia (2020), isotropic materials, such as the glass slide, are only visible as long as the polarized light is visible. When the filters are perpendicular, and the light is cross-polarized, isotropic materials are completely obscured. Anisotropic materials, such as quartz crystals, disrupt the polarization effect and these objects remain visible when the polarized filters are perpendicular. Indeed, these objects become more visible, as they glow in an otherwise black field. Furthermore, birefringent materials can be identified based on how their colors change under polarization at different angles. Phytoliths are composed of amorphous silica, an isotropic material, and become invisible under cross-polarized light (Parry and Smithson 1958). Phytoliths can occasionally exhibit some birefringence, but this is due to materials trapped within the silica rather than the silica itself, which is not birefringent (Dayanandan et al. 1983). Several morphotypes I included in this study, such as irregular polyhedron psilate, are easily confused with quartz objects (Bozarth 1993) but under polarized light it is immediately apparent which is which. Parry and Smithson (1958:547) also noted polarization can be used to provide contrast and make phytoliths stand out from the background if the polarizer is only shifted slightly – just 5º or 10º.

Before I close this section with a discussion of issues I experienced with my equipment, I would like to mention www.microscopyu.com is an excellent resource for anyone wishing to further their knowledge on all aspects of microscopy in a manner easily accessible to the neophyte. I experienced some equipment issues that slowed my progress or forced me to slightly change my research design. Most importantly, I was unable to use the 60x objective I received to replace the 100x objective because the lens would touch the slide cover before I could focus in on the phytoliths. I do not know if the fault lay in the objective or the stage but, in either case, I was limited to a maximum magnification of 400x for both observing and photographing phytoliths. This limited my ability to discern internal structures and laminations in the silicified cells but did not generally hinder me from identifying morphotypes. I also highly recommend a DSLR with a power cable. I did not have one for my DSLR, so I would frequently have to swap out the battery. Losing power to the camera shut down the Canon EOS Utility and restarted the photo file names. This was an annoyance and slowed my pace, but vigilance kept it from causing any major complications in my photolog.

4.3.3 Morphotypes

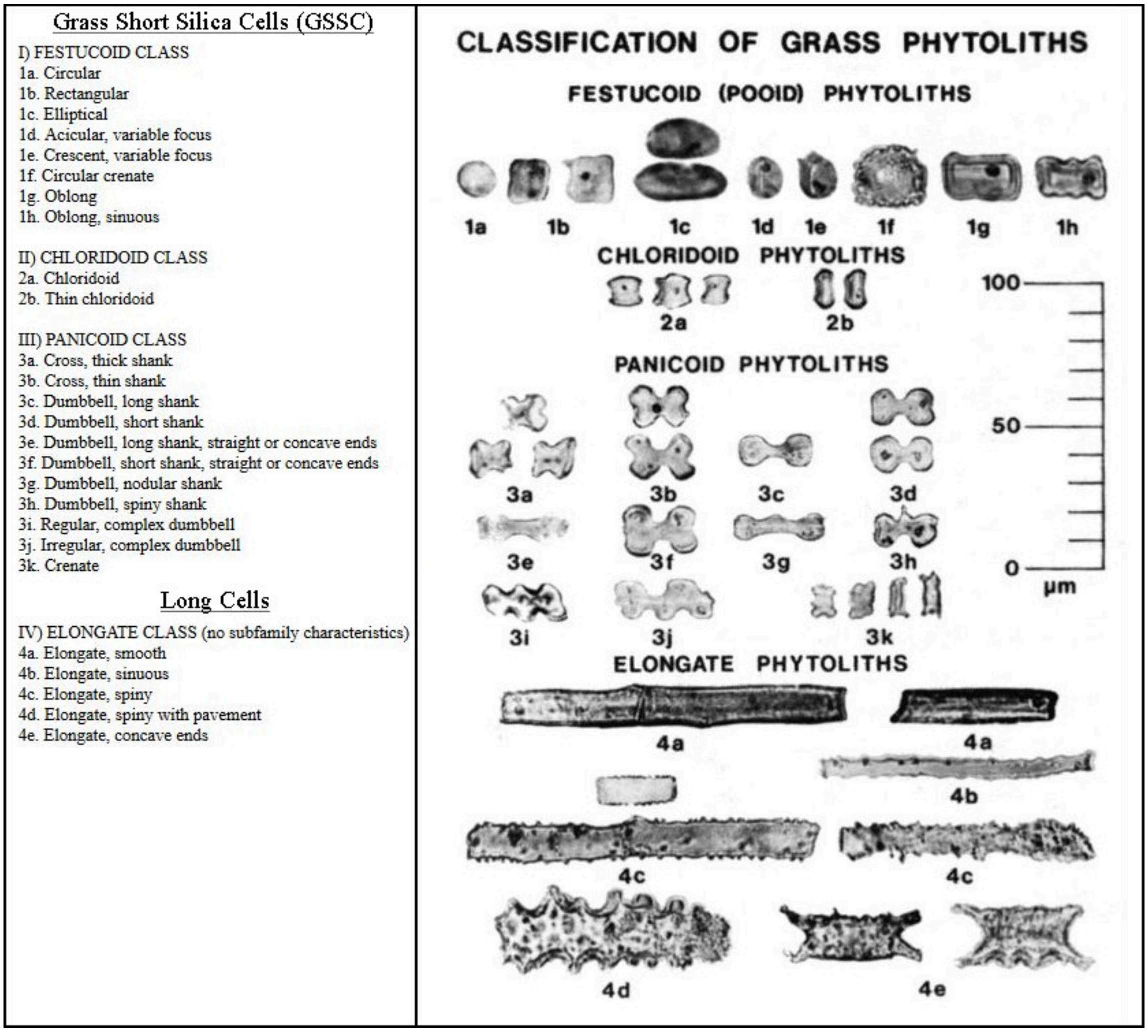
Before scanning the slides for phytoliths, I needed to create a phytolith morphotype reference set and determine which morphotypes to include and count in the study. Because there is no available existing reference set for the study area and since I am not extracting phytoliths from plant tissue, I conducted a literature review of phytolith studies potentially relevant to the study area and created a reference set of morphotypes successfully used in those studies.

4.3.3.1 Literature review of relevant morphotype studies

In this section, I present a brief literature review of relevant phytolith studies on the North American Great Plains and adjacent areas from which I drew the morphotypes for my reference collection and the classification system for this study.

In any investigations into the phytolith record of unstudied or understudied ecological regions, the best practice for a paleovegetation or paleoenvironmental reconstruction is to first examine phytoliths extracted from modern vegetation to identify characteristic and diagnostic morphotypes and create a morphotype reference collection (e.g., Kerns 2001; Blinnikov 2005). Once characteristic and diagnostic phytolith morphotypes have been identified, modern surface soil samples from a range of vegetation community types are examined for these morphotypes to understand the composition of the soil phytolith assemblage from each vegetation community and to assess which types preserve (e.g., Twiss et al. 1969; Wilding and Drees 1971; Bozarth 1993). In well-studied areas, in which a wide range of characteristic and diagnostic morphotypes are known and classified, many researchers opt to use published morphologies as a reference collection rather than expend major time and effort to create one (e.g., Kurmann 1985; Strömberg 2004; Boyd 2005).

The morphotype classification system most commonly used on the North American Great Plains was originated by Twiss et alia (1969). In this system, Twiss et alia identified 26 morphotypes divided among four classes, festucoid, chloridoid, panicoid, and elongates (Figure 4.3). The first three classes consist of morphotypes characteristic of the festucoid, chloridoid, and panicoid grass sub-families. The fourth class, elongates, are produced by all grasses. The festucoid class consists of eight morphotypes, circular, rectangular, elliptical, acicular, crescent, circular crenate, oblong, and oblong sinuous. The chloridoid class has two morphotypes, chloridoid and thin chloridoid. The panicoid class has eleven morphotypes, cross thick shank, cross thin shank, dumbbell long shank, dumbbell short shank, dumbbell long shank straight or concave ends, dumbbell short shank straight or concave ends, dumbbell nodular shank, dumbbell spiny shank, regular complex dumbbell, irregular complex dumbbell, and crenate. The elongate class has five morphotypes, elongate smooth, elongate sinuous, elongate spiny with pavement, and elongate concave ends.



Grass Short Silica Cells (GSSC)

I) FESTUCOID CLASS
1a. Circular
1b. Rectangular
1c. Elliptical
1d. Acicular, variable focus
1e. Crescent, variable focus
1f. Circular crenate
1g. Oblong
1h. Oblong, sinuous

II) CHLORIDOID CLASS
2a. Chloridoid
2b. Thin chloridoid

III) PANICOID CLASS
3a. Cross, thick shank
3b. Cross, thin shank
3c. Dumbbell, long shank
3d. Dumbbell, short shank
3e. Dumbbell, long shank, straight or concave ends
3f. Dumbbell, short shank, straight or concave ends
3g. Dumbbell, nodular shank
3h. Dumbbell, spiny shank
3i. Regular, complex dumbbell
3j. Irregular, complex dumbbell
3k. Crenate

Long Cells

IV) ELONGATE CLASS (no subfamily characteristics)
4a. Elongate, smooth
4b. Elongate, sinuous
4c. Elongate, spiny
4d. Elongate, spiny with pavement
4e. Elongate, concave ends

Figure 4.3: Grass phytoliths of Twiss (adapted from Twiss 1987:Figure 2).

The phytoliths used in this study were extracted from leaf samples of 17 different species across the Central and Southern Great Plains from Kansas to Texas. This classification system was tested against sediment samples from atmospheric dust, modern soils, and fossil sediments. Twiss et alia were able to describe the modern vegetation composition reasonably well and the presence of phytoliths in fossil sediments and paleosols indicated the system would also be useful in paleoenvironmental and archaeological investigations.

Brown (1984) expanded on this work when he created a comparison reference collection of morphotypes extracted from 112 grass species, encompassing 4 sub-families, 16 tribes, and 52 genera. From this he created a detailed and lengthy classification system (Brown 1984 Table 1:347-350) of eight classes, each with several sub-classes and each sub-class with several types: 133 types in all. The eight classes are plates, trichomes, double outline, saddles, trapezoids, bilobates, polylobates, and crosses He renamed Twiss et alia's (1969) chloridoid type as saddles, dumbbells as bilobates and polylobates and also identified trapezoid morphology as important. He examined 12 non-grass species of the region as well, to determine whether their phytoliths are readily distinguishable from grass morphotypes (they are) but he neither described nor classified these phytoliths.

Mulholland (1989) used Twiss et alia (1969) and Brown (1984), along with her own previous work (Mulholland 1987) as a foundation to create a simplified morphotype classification system. Mulholland retained the three grass sub-family classes of Twiss et alia (1969) and recognized eight morphotypes, (1) rectangles, (2) sinuates, (3) rondels, (4) triangles, (5) pentagons, (6) crosses, (7) dumb-bells, and (8) saddles. The first five types are festucoid types, crosses and dumb-bells are panicoid types and saddles are chloridoid types. Rondel means "small circle" (Mulholland 1989:494), a descriptor which appears to have been coined by Mulholland, and this morphotype incorporates phytoliths that are variations on a truncated cone or cylinder.

Mulholland (1989) presents a study of shape frequencies in grasses that complicates the three-class system. She found many morphotypes are produced by more than one sub-family and the class to which a morphotype belongs is the sub-family that produces it most abundantly. All three sub-families produce rondels, but most rondels correlate to festucoids and most festucoids produce rondels. All three sub-families produce dumb-bells but they are mostly produced by panicoids. Stipeae, a tribe of the festucoid sub-family, is a major producer of dumb-bells but Mulholland observed *Stipa*-type dumb-bells have plateau tops, analogous to Brown's (1984) trapezoid morphology, while panicoid dumb-bells have a tabular shape.

Fredlund and Tieszen (1994) created the last major morphotype classification system on the North American Great Plains. This system continues the three grass sub-family class system of Twiss et alia (1969), now ubiquitous in grassland phytolith studies. Fredlund and Tieszen attempt to create a simple classification system that synthesizes the three previously discussed systems of Twiss et alia (1969), Brown (1984), and Mulholland (1989). As Fredlund and Tieszen describe (pp. 324-327), their classification is a 10+1 morphotype system of only Grass Short Silica Cells (GSSC). The conical morphotype is analogous to Mulholland's rondel. The keeled type is a conical variant incorporating Mulholland's ridged rondel, and Twiss et alia's elliptical and acicular types. The pyramidal type is Mulholland's rectangular, Brown's trapezoid, and

Twiss et alia’s rectangular and oblong types. The crenate type incorporates Mulholland’s rectangular, Twiss et alia’s rectangular and oblong, Brown’s sinuous trapezoid and Piperno’s (1988) elongated sinuous. The *Stipa*-type is one of Twiss et alia’s panicoid dumbbells but with the specific morphology of Brown’s trapezoidal bilobate with the flat plateau top described by Mulholland. The simple lobate is another dumbbell type with a more pronounced shank and rounded ends and it is more likely to be produced by non-panicoids. The panicoid-type is the same as the simple lobate but with indented or sculpted ends. The cross is preserved unchanged. Other lobates are not described but must be all other panicoid types of Twiss et alia not in the above categories. The last of the ten types is the saddle. The eleventh type is “irregular” and is the catch-all for any phytolith that does not fit into the other ten types. This classification system was used by Fredlund and Tieszen to reliably differentiate among surface sediment samples collected from 15 modern grassland locations with different species compositions ranging from the Texas Gulf Coast Plains to nearly the Foothills of Alberta.

Fredlund and Tieszen (1994) also marks the beginning of a shift away from researchers extracting phytoliths from plant tissue for comparison and instead using published morphologies as references and applying them to sediments, whether modern or fossil. These “sediment only” studies (e.g., Kurmann 1985; Cummings 1990; Fredlund and Tieszen 1994, 1997; Fredlund et al. 1998; Baker et al. 2000; Strömberg 2002, 2004, 2005; Boyd 2005; Klassen 2004; Robertson 2006; Cordova et al. 2011; Lints 2012) usually create modern analog assemblages from surface soil samples of a range of modern vegetation community types. Phytolith assemblages of fossil sediments can then be compared to the modern assemblages to find the closest modern analog vegetation community.

Beginning in the early 1990s, researchers generally only extract phytoliths from vegetation samples in order to create comparison reference collections for previously unstudied or understudied grassland regions (Bozarth 1993; Kerns 2001; Gallego and Distel 2004; Blinnikov 2005; Silantyeva et al. 2018), for understudied taxa (Bozarth 1992; Hodson et al. 1997), or for ethnobotanical research (Dersch 2005). Fredlund et alia (1998) recognized that the success of the morphological classification system of Twiss et alia (1969) entrenched a bias towards grass-based studies on the North American Great Plains at the expense of phytolith morphology and assemblage studies of non-grass species.

Early studies of non-grass species, herbaceous dicots, woody dicots, deciduous trees, and conifers proceeded alongside grass monocot studies (Rovner 1971; Wilding and Drees 1971; Geis 1973; Klein and Geis 1978). These investigations confirmed non-grass phytolith opal silica had the same properties as grass phytolith opal silica (Wilding and Drees 1971; Rovner 1971), identified silicification potential of various tissues (Geis 1973), and confirmed silicified cells can be distinguished from those of grasses (Wilding and Drees 1968; Rovner 1971). Rovner (1971) also prognosticated phytolith research would be of most value to archaeology.

Wilding and Drees' (1971) study of deciduous trees in the eastern edge of the Prairie Peninsula in western Ohio identified three morphotypes they could link to four species. A cup-shaped honeycomb morphotype is produced by *Quercus alba* (white oak), a jigsaw-shaped honeycomb morphotype is produced by both *Acer saccharum* (sugar maple) and *Fraxinus americana* (white ash), and a morphotype described as "aggregates of thin, fragile, plate-shaped scales or incrustations" is produced by *Fagus grandifolia* (American beech). They found that the complicated structure of these morphotypes gave them more surface area than grass short cells, which made them more susceptible to dissolution and hence are rare in soil assemblages.

Geis (1973) examined phytoliths in samples from deciduous angiosperm trees and shrubs collected in New York and Illinois. They found differences in silica deposition between families and between tissues in the same specimen. Leaf epidermal cells were the most likely to be silicified, while stomata, bundle sheath parenchyma, vascular elements, and mesophyll cells all silicified to varying degrees. Geis observed silicified epidermal cells of *A. negundo*, which is present in my study area, but these phytoliths do not appear to be morphologically distinct.

Klein and Geis (1978) moved away from deciduous angiosperms to study gymnosperms, conifers, the previous investigations of which Rovner (1971) described as "disappointing" and "weak". Klein and Geis investigated samples of 15 taxa across six genera collected from SUNY research plots in New York. While not a fully-fledged classification system, Klein and Geis did identify six categories of phytoliths. Epidermal cells were the most abundant types observed and were mostly long cells or spherical vesicular infillings, very similar to those produced by grasses and deciduous angiosperm trees respectively. Vascular elements identified consisted of parenchyma, tracheids with helical ridges, which are produced by several plants, and tracheids with bordered pits, which now appear to be diagnostic of Pinaceae (Bozarth 1993; Hodson et al.

1997; Dersch 2005). Fibers were uncommon in all the studied taxa, except *Pinus banksiana* (jack pine), in which they were abundant. Asterosclereids were observed solely in the leaves of *Pseudotsuga menziesii* (Douglas fir). Mesophyll was rarely silicified and was deemed to have no taxonomic value. Endodermal cells were abundant in the three examined species of *Picea – P. rubens* (red spruce), *P. mariana* (black spruce), and *P. glauca* (white spruce) – but not observed anywhere else. This type is elsewhere described as polyhedron (Rovner 1971; Bozarth 1993) and Geis and Klein note their similarity to grass bulliform cells. Geis and Klein also observe that most silica extracted from coniferous and deciduous trees is fragments and particles unlike grasses which are more often intact, indicating silicification is more often incidental to water transport within trees than a function of specialized tissues.

Bozarth (1993) appears to be the first to study phytoliths of the boreal forest and aspen-parkland ecoregions of Canada. It is also one of the only studies of non-grass phytoliths up to that point to take phytolith morphological data from plant tissues and apply it to sediment phytolith assemblages. Bozarth corroborates Wilding and Drees' (1971) findings that potentially diagnostic or characteristic morphotypes of non-grass species with complex morphologies often dissolve quickly in soils. Alexandre, Meunier, Colin, and Koud (1997) found 92% of biogenic silica is dissolved leaving only 8% remaining in the soil as phytoliths in an African equatorial rainforest setting. Bozarth observed in his sediment samples five morphotypes characteristic of different tree species, thin plate with wavy margins on all four sides (*Picea glauca*), tracheids with bordered pits (*Pinus banksiana*), blocky polyhedrons with grainy surfaces (*Picea mariana*), thin elongate plate with smooth parallel sides and pointed end (*Larix larciana*), and blocky smooth polyhedrons (abundantly produced in *Picea glauca* but also produced in other conifers and some grasses). Bozarth also found his sediment assemblages were completely dominated by grass morphotypes, usually observing only one or several tree phytoliths in assemblages of 200, even in samples collected from dense tree stands in the boreal forest with no grass whatsoever in the understory. Thus, an observation of just one or two of these phytoliths, even among an assemblage overwhelmingly dominated by grass morphotypes, can indicate a forest community. From this he also infers that, in environments adjacent to grasslands, eolian, especially fire-eolian, deposition is the major contributor to soil phytolith assemblages. Fredlund and Tieszen (1994) came to a similar conclusion the following year, finding grassland phytolith assemblages to generally reflect the regional or extra-local vegetation composition, largely due to eolian deposition.

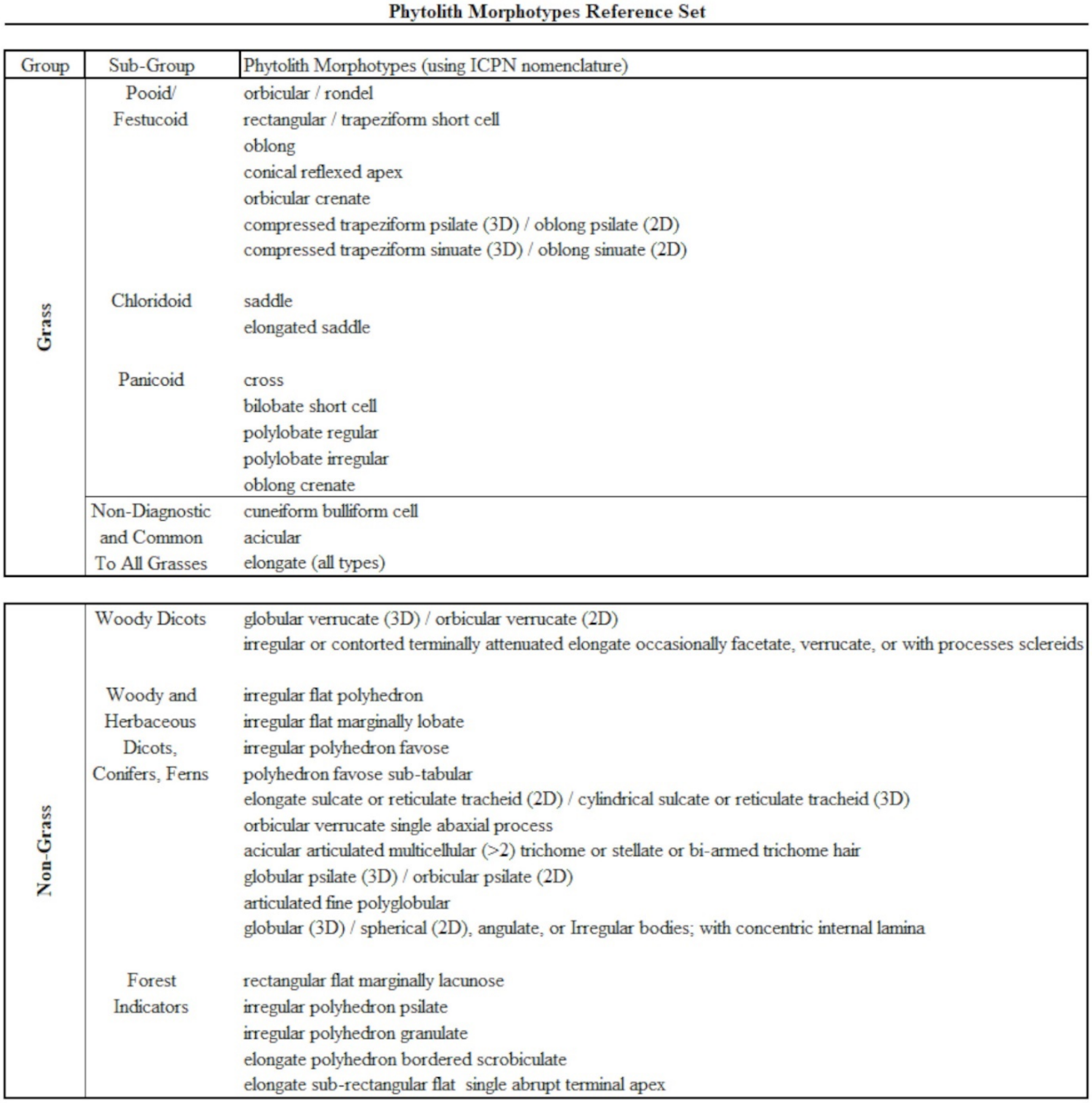
Robertson (2006) provides an excellent overview of the history of phytolith research on the North American Great Plains, especially the Northern Plains of Canada. Strömberg (2002, 2004, 2005) provides clear discussion of numerous phytolith topics from research design, to taphonomy, to biases in the phytolith record. Strömberg (2004) is a particularly excellent resource for researchers new to phytoliths because she brings together a large number of selected phytolith studies from numerous regions and with various analytical approaches (Table1:242-243). She also synthesizes in one place (Table 3:256-257) a comprehensive list of morphotypes, their locations of production, the vegetation that produce them, and the studies that are most relevant to each morphotype, as well as providing clear microphotographs of many morphotypes (pp258-259). Gallego and Distel (2004) is a pilot study of phytoliths extracted from plant specimens to create a reference collection for the La Pampa grasslands of Argentina and, despite the great distance from the prairies of southeastern Alberta, it provides numerous excellent microphotographs of grass morphotypes labeled with the species name and following the classification system of Twiss (1992).

4.3.3.2 Morphotypes included in the reference collection

For the most part, to be useful a phytolith morphotype must be characteristic, defined as a morphotype produced abundantly in a species or other taxonomic level, or diagnostic, a morphotype that unambiguously identifies a species or other taxonomic level (Silantyeva et al. 2018:5). Due to redundancy and multiplicity (Rovner 1971), useful morphotypes are more likely to be characteristic, while only a rare few are diagnostic.

In this study, I created a reference collection of 34 morphotypes (Appendix A). Of these I created a set of 31 diagnostic and characteristic morphotypes to include in the main count and a smaller sub-set of three non-diagnostic grass morphotypes (Table 4.2) used in the environmental index formulae (described below in section 4.4.2). I followed Strömberg's (2004) advice to use a general analytic approach and use many morphotypes, not expecting to observe all of them. I chose these morphotypes to investigate grassland composition and grassland/woodland dynamics, to be incorporated into environmental indices, and to seek key indicators of forest communities (all of which are detailed in section 4.4 below). I felt these morphotypes would be

Table 4.2: Morphotypes in the reference collection, aggregated from Bozarth 1993; Bremond, Alexandre, Peyron, and Guiot 2005; Strömberg 2004; Twiss 1987.

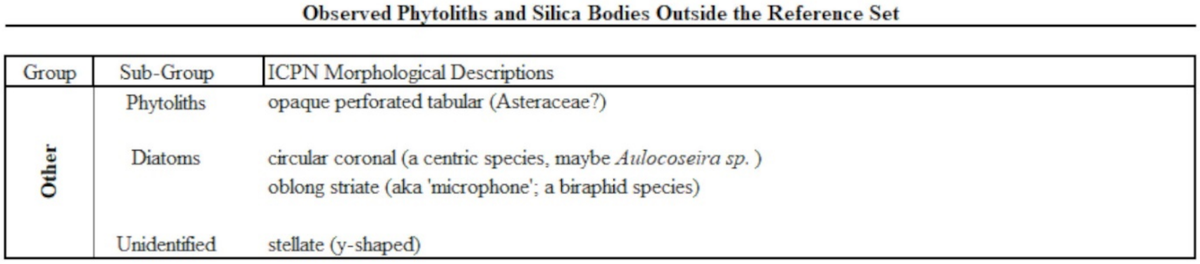


Phytolith Morphotypes Reference Set

Group	Sub-Group	Phytolith Morphotypes (using ICPN nomenclature)
Grass	Pooid/ Festucoid	orbicular / rondel
		rectangular / trapeziform short cell
		oblong
		conical reflexed apex
		orbicular crenate
		compressed trapeziform psilate (3D) / oblong psilate (2D)
		compressed trapeziform sinuate (3D) / oblong sinuate (2D)
	Chloridoid	saddle
		elongated saddle
	Panicoid	cross
		bilobate short cell
		polylobate regular
		polylobate irregular
		oblong crenate
	Non-Diagnostic and Common To All Grasses	cuneiform bulliform cell
		acicular
		elongate (all types)
Non-Grass	Woody Dicots	globular verrucate (3D) / orbicular verrucate (2D)
		irregular or contorted terminally attenuated elongate occasionally facetate, verrucate, or with processes sclereids
	Woody and Herbaceous Dicots, Conifers, Ferns	irregular flat polyhedron
		irregular flat marginally lobate
		irregular polyhedron favose
		polyhedron favose sub-tabular
		elongate sulcate or reticulate tracheid (2D) / cylindrical sulcate or reticulate tracheid (3D)
		orbicular verrucate single abaxial process
		acicular articulated multicellular (>2) trichome or stellate or bi-armed trichome hair
		globular psilate (3D) / orbicular psilate (2D)
		articulated fine polyglobular
		globular (3D) / spherical (2D), angulate, or Irregular bodies; with concentric internal lamina
	Forest Indicators	rectangular flat marginally lacunose
		irregular polyhedron psilate
		irregular polyhedron granulate
		elongate polyhedron bordered scrobiculate
		elongate sub-rectangular flat single abrupt terminal apex

able to provide all necessary data on all potential terminal Pleistocene and Holocene vegetation communities likely to have inhabited the study area. Because I am new to phytolith research I believe creating a pre-defined set of morphotypes helped me focus on the relevant morphotypes and helped me avoid counting morphotypes common to many taxa and without interpretive value. When I encountered phytoliths outside the pre-defined set and other biogenic silica bodies (Table 4.3), which have potential interpretive value, I noted and tabulated my observations of them.

Table 4.3: Observed phytoliths and other silica bodies. Asteraceae phytoliths described by Bozarth (1993). Diatom identification from www.diatoms.com.



Observed Phytoliths and Silica Bodies Outside the Reference Set

Group	Sub-Group	ICPN Morphological Descriptions
Other	Phytoliths	opaque perforated tabular (Asteraceae?)
	Diatoms	circular coronal (a centric species, maybe *Aulocoseira sp.*)
		oblong striate (aka 'microphone'; a biraphid species)
	Unidentified	stellate (y-shaped)

The grass phytoliths follow a simplified version of the classification system of Twiss (1987), in which I combined the festucoid acicular and crescent morphotypes into a single conical irregular base morphotype. I also compressed the panicoid cross and dumbbell categories from multiple types into one type each. The 3D names incorporate Mulholland's (1989) and Fredlund and Tieszen's (1994) descriptions of the morphotypes. I counted elongates, and the point-shaped and fan-shaped morphotypes of Bremond, Alexandre, Peyron, and Guiot (2005) for inclusion in environmental indices (discussed below in section 4.4.2) but not in other analyses, as all three of these morphotypes occur in all grasses and are therefore not useful in differentiating between grass sub-families. As such, I tabulated them separately rather than including them in the main count.

The non-grass morphotypes follow Strömberg (2004) in a slightly modified version. I retained her major plant group classifications of "woody dicotyledons" and "woody or herbaceous dicotyledons, ferns, conifers" but removed certain types as irrelevant to this study. Strömberg included morphotypes of southerly, subtropical, and tropical plants, such as palms, bamboos, and members of the Costaceae family, because she was investigating pre-Pleistocene vegetation. I rejected these from my morphotype set because they are extremely unlikely to occur on the Canadian Plains in the Holocene. The non-grass grouping also includes the forest key indicators of Bozarth (1993), from which I removed two morphotypes, one of which is easily misidentified and the other is too fragile to persist in soils.

4.3.3.3 A note on nomenclature

As we can see from even this brief overview, a single phytolith morphotype can have several names, depending on the researcher and which classification system they prefer. This lack of standardization sows confusion among later researchers who must first find all the names for the same morphotype and decipher whether the names all, in fact, signify the same morphotype. In order to remedy this, the International Code for Phytolith Nomenclature (ICPN) 1.0 was published in 2005 (Madella et al. 2005).

The ICPN attempts to standardize morphotype nomenclature by creating a standard protocol for naming a type and a glossary of descriptors to use in the name. Every phytolith is described with three descriptors in a precise order: shape (2D or 3D), texture and ornamentation, and anatomical origin. Anatomical origin is only used when there is no doubt. Each descriptor does not have to be a single word but can include several terms from the glossary. Certain morphotypes are so well known and a single name is so commonly used that changing it would do more harm than good. These morphotypes fall under the *nomina conservanda* rule (Madella et al. 2005:254) by which the old moniker remains. Currently, the only morphotypes on this list are the bulliform, papillae, dendritic, cross, saddle, and rondel types. Although the ICPN has been in effect for 15 years as of this writing, it is not always used. Furthermore, phytoliths do not always fall neatly into the descriptors. For example, a phytolith that tapers to a point may be described as acute by one researcher and acuminate by another. A useful adjunct to the ICPN would be a central database of all morphotypes (currently there are multiple), which would allow researchers to ensure their morphotype is not redundant and also provide ICPN names for morphotypes used in frequently cited pre-ICPN studies. These issues aside, I believe it behooves all phytolith researchers to use ICPN terminology to try to unmuddy the waters for our own benefit and that of future researchers. To that end, I translated into ICPN all the original names of the morphotypes I use in this study and from this point forward all morphotype names adhere to ICPN terminology.

4.3.4 The count

Once I decided upon a set of morphotypes, I needed to decide how many of these phytoliths to count to ensure an adequate overview of the phytolith assemblage on each slide. Following several studies (Alexandre, Meunier, Lézine, Vincens, and Schwartz 1997; Albert and Weiner 2001; Pearsall 2015) of both grass and woody dicot phytoliths, I decided on a minimum count of 200 diagnostic phytoliths.

Strömberg (2009) identifies two types of phytolith studies, vegetation reconstruction and taxonomic differentiation. She recommends a 200 count of index-specific morphotypes for vegetation reconstruction as a rule of thumb, but bootstrapping can be used to determine best counts within a predetermined confidence interval specific to the index and the expected environment. Furthermore, lower counts can be sufficient to differentiate between states in an environmental index (I discuss the environmental indices I used in detail below in section 4.4.2). For example, Strömberg (2009:131) found that, with a confidence interval of 95%, a count of 25 was sufficient when the D/P value (measures ratio of forest to grassland morphotypes) was 0.1 but a 300 count was required when the D/P was 9. On the other hand, index-specific morphotypes may be rare within an assemblage such that achieving a count of 200 index-specific phytoliths may require a total count of several thousand, which is infeasible for most studies (Strömberg 2009:134). Strömberg also found that for the Iph index (measures proportion of arid grasses in the total grass population), low counts of at least 50 are sufficient if the Iph value is near 0% or 100%. For D/P index, sampling errors play a major role. D/P values higher than or lower than 1 have sampling errors that are large enough to create interpretive difficulties.

Taxonomic differentiation studies usually explore diversity within the assemblage and use sampling curves to determine statistically justified counts. Zurro (2017) describes Morphotype Accumulation Curves (MACs) to determine count size. She measures cumulative totals of morphotypes observed in increments of 50 observed phytoliths. The point at which no new morphotypes are observed after two consecutive increments of 50 is the point where diversity plateaus and further counting is redundant. She found counts of 250-300 phytoliths to be sufficient in most of her samples to document sufficient diversity without resorting to excessively high counts.

I decided on a minimum count of 200 phytoliths of my 31 morphotypes. In this study, I am most interested in comparing fossil sediment phytolith assemblages to modern surface assemblages from known vegetation communities to obtain an overview of temporal changes in vegetation at this location. I am also interested in how well non-grass morphotypes, previously recorded in quite different climatic and latitudinal conditions, may apply to the northern end of the Great Plains. Based on the site location, I am expecting extreme values for most, if not all, of the environmental indices described below in section 4.4.2; values which, according to Strömberg (2009), would require extremely high counts, possibly in the several thousands to obtain high confidence intervals. In many ways this is a preliminary study in this region and only meant to achieve coarse resolution and investigate issues and directions for future research. As such and in light of the foregoing factors, a minimum count of 200 phytoliths should be sufficient.

4.3.5 Scanning procedure

I decided to scan only the middle half of the slide because I believed the middle would be the area with the most regular phytolith densities and the least disturbances caused by the slide mounting process. Slide mounting often creates lower densities near the edges of the coverslip, so starting scanning at the edge of the coverslip will yield lower densities of morphotypes per FOV. I wanted to be able to compare morphotype densities between samples, which may relate to vegetation community differences, or preservation differences among samples with very similar phytolith assemblages.

I scanned at 200x, at which magnification there are 44 rows and 30 columns on a 22mm x 22mm cover slip. To find my starting point, I moved the objective to the top left corner of the coverslip then carefully counted down to the 12th row from the top, using convenient phytoliths or objects at the bottom edge of each FOV as guides. I scanned left to right and when I reached the last FOV in the row I skipped down a row (to avoid accidental double-counts) and began anew on the 14th row, scanning from right to left. I continued this procedure down the slide until I reached my 200 count. Because I was scanning for 31 morphotypes and in order not to overlook any, I scanned each FOV for the first three or four morphotypes, then the next three or four morphotypes, and so on until I went through all the morphotypes. I counted all phytoliths in the last FOV to not skew the results in favor of the first few morphotypes.

I created Excel spreadsheets to keep track of my observations, in which the columns were the morphotypes and the rows were the FOVs. The morphotypes in the columns were arranged by vegetation category and in order of expected frequency, therefore the first category was festucoids and the last was forest indicators. In the rows, I kept track of the FOV numbers, image IDs, and short notes, as well as the morphotype counts. The FOV number was row.FOV, so, for example, the first FOV in every slide was 12.1. The image ID was the sample ID and the photo number, e.g., in sample 3.5 the first image was 3.5.01. In the row comprising the cells at the head of each column, I used a function to automatically tally the total observations of each morphotype. I also kept a running tally of all observed diagnostic morphotypes here so I would quickly and easily know when I reached 200 diagnostic phytoliths counted. At the top of each sheet, I kept track of the date, the sample ID, the camera settings, equipment used, and any comments I might have. I created a workbook for each sampling column and one for the modern surface composite samples. Within each workbook, each sample had its own sheet.

The spreadsheet was very efficient for tracking the morphotypes and easily migrating the tallies to other sheets for analysis. It was also easy and quite useful to add new columns at the end of the row to track interesting objects I encountered. I believe constantly shifting my attention to the spreadsheet and typing in numbers and IDs may have made scanning slower and more laborious than paper and pencil methods described in the literature (Piperno 2006; Pearsall 2015; Strömberg 2009) but also probably made my work faster and easier on the back end when I analysed the data.

Initially, I intended to scan the slides with the DSLR attached to the microscope transmitting to a large screen to aid in visibility. In practice, I found it much better to use the binocular eyepiece to scan the slides and switch over to the DSLR to take photos. I was much more easily able to discern three dimensional features of a phytolith with my eyes in the eyepieces while making fine adjustments to the focus than with the large screen to which my laptop was connected. I found the DSLR was only able to properly focus on one small area and the rest of the FOV would blur a little. My procedure was to use the DSLR to find the initial FOV, switch to the eyepiece to scan for phytoliths, switch back to the DSLR to find the best focus for photographs, then use the DSLR to move to the next FOV. The attentive reader will remember the FOVs for the eyepiece and the DSLR are not the same. I noted phytoliths or debris at the corners and along the edges of the DSLR FOV and used them as guides when I scanned through the eyepiece. In this way I maintained consistency and did not count phytoliths outside the DSLR FOV but visible in the eyepiece FOV.

4.4 Data analysis

Analyses can be performed on both cardinal values and relative values. A cardinal number is often referred to as a counting number and, in this work, the cardinal value indicates the number of observations of a morphotype or morphotypes in a category set (e.g., 143 pooid phytoliths or 23 non-grass phytoliths). A relative value denotes the relevant morphotypes as a proportion or percentage of the counted assemblage (e.g., pooid phytoliths are 95% of the grass assemblage or non-grass phytoliths are 1% of the sample assemblage). Several sources noted relative values to be more accurate and reliable than cardinal values (Powers-Jones and Padmore 1993; Kerns et al. 2001; Watling et al. 2016). Cardinal values can be misleading if the total count is not considered. If two samples both have 22 observations of a morphotype, they appear to be the same. If one sample has 220 total observations and the other has 2200 observations, then the morphotype is 10% of the first assemblage but only 1% of the second assemblage. This only applies in studies like mine, which have a minimum count size, i.e., at least 200 phytoliths, but not an exact count, i.e., all samples stop at 200 phytoliths. In the case of an exact count, PCA performed on either relative or cardinal values would yield the same result. On the other hand, relative values can obscure important results if taken out of context and factors such as phytolith production or taphonomy are not taken into account. At face value, a single observation of a phytolith morphotype out of 200 phytoliths is only 0.5% of the assemblage. If that single phytolith is a rare key indicator morphotype, however, it may be more important than the other 99.5% of the assemblage and change the interpretation of the assemblage from a grassland to a stand of black spruce, a situation similar to that encountered by Bozarth (1993).

I analysed the morphotype data I collected in three ways, using indicator species, environmental proxy index formulae, and Principal Components Analysis (PCA). As we see below, relative values are not very important for indicator species. Relative values are better for comparison between samples and therefore most suitable for PCA. The best value to use in an environmental index is dependent on the index.

4.4.1 Indicator species

An indicator species correlates to a specific modern vegetation community (De Cáceres et al. 2010) and can be used to infer the presence of that community when morphotypes diagnostic of the indicator species are observed in a phytolith assemblage. The major post-glacial vegetation dynamic in the study area is the shift from forest to parkland to grassland communities, which settled into modern ranges by 4400 cal BP (Strong and Hills 2005). Pockets of one community can exist or intrude into another on certain landforms, e.g., river valleys or isolated hills (Zoltai 1975). Poaceae species are prolific phytolith producers and Poaceae morphotypes are ubiquitous and pervasive due to eolian, especially fire-eolian, redistribution (Fredlund and Tieszen 1994); present even in samples collected in heavily forested locations lacking a single grass species, as demonstrated by Bozarth (1993). This trait makes them potentially poor indicators of the dominant vegetation community. In the same study, Bozarth described several morphotypes indicative of boreal forest or aspen parkland. Notably, morphotypes of indicator species were less than 2% of the phytolith assemblage even in sample locations where the species is dominant, e.g., within a dense stand of *Picea glauca* (white spruce) with a sedge (rather than grass) understory. Hence, the presence of even one or two phytoliths from one of these indicator species is significant.

Bozarth (1993) conducted phytolith research in the boreal forest and aspen parkland environments of Canada. He sampled locations in western Manitoba, Saskatchewan, and eastern Alberta, collecting phytoliths from living vegetation and from surface soil samples. He identified a small number of diagnostic morphotypes from living vegetation but several of these were too fragile to remain identifiable in the soil samples. Ultimately, Bozarth identified five diagnostic morphotypes within the surface soil samples from four tree species common to the boreal forest: *Picea glauca* (white spruce), *Picea mariana* (black spruce), *Pinus banksiana* (jack pine), and *Larix larciana* (tamarack). I renamed Bozarth's morphotypes following the International Code for Phytolith Nomenclature recommendations (Madella et al. 2005). The *P. glauca* morphotypes are rectangular flat marginally lacunose, and irregular polyhedron psilate. The *P. mariana* morphotype is irregular polyhedron granulate. The *P. banksiana* morphotype is elongate polyhedron bordered scrobiculate. The *L. larciana* morphotype is elongate sub-rectangular flat single abrupt terminal apex.

A special note should be inserted here about the irregular polyhedron psilate morphotype. While the other four morphotypes are strongly characteristic of an individual species, the irregular polyhedron psilate morphotype is only characteristic of conifers generally. Bozarth notes this morphotype is common in *P. glauca* and *Abies balsamea* (balsam fir), less common in *P. banksiana* and *P. mariana*, and present in grasses as well, though at much lower frequencies than in the conifers. This morphotype occurred in 80% of his modern analog assemblages and he found it to be a good indicator of conifers and especially *P. glauca*. Finally, Bozarth noted the similarity of this morphotype to quartz crystals but the two were easily differentiated with polarized light.

The presence of any of these morphotypes could indicate a potential regional or local forestation episode and possibly a mesic interlude within the generally arid climate regime of the last nearly

6,000 years represented in the sampled soil cores. Or it could indicate a single individual or small stand. A single observed phytolith is a poor basis from which to draw conclusions, however, and other techniques based on the assemblage rather than identification of specific taxa are beneficial to identifying past vegetation regimes.

4.4.2 Environmental indices

An environmental index formula allows the researcher to make inferences about a single climatic variable using phytoliths as proxies. Several index formulae have been developed by phytolith researchers to investigate past climates and vegetation regimes. These indices measure aridity (Iph), climate or temperature (Ic), forest/grassland dynamics (D/P), and water stress (Fs).

The Iph aridity index (Diester-Haass et al. 1973; Kurmann 1985; Twiss 1987; Fredlund and Tieszen 1994; Alexandre, Meunier, Lézine, Vincens, and Schwartz 1997) measures the proportion of arid grasses within the grass population. The chloridoid (C) sub-family of grasses are C4 pathway short grasses that thrive in warm and arid conditions. The panicoid (P) sub-family of grasses are C4 pathway tall grasses that thrive in warm and humid conditions. The Iph formula is C/(C+P) and a higher proportion corresponds to more arid conditions. This index has been used successfully in tropical environments but rarely in the colder temperate environments of the northern latitude plains.

Festucoid grasses are a sub-family that uses the C3 pathway and are prevalent in colder latitudes. Twiss (1987) proposed the addition of festucoid morphotypes to the total when the index is used in a location with all three sub-families present, such as the North American Great Plains. The proposed amended Iph formula is C/(F+P+C). It is unclear to me whether this formula will accurately assess aridity when festucoid grasses are added, because they are cool season C3 grasses with an unclear association to aridity. Fredlund and Tieszen (1994) noted that *Stipa* spp. (thread and needle grass) and *Danthonia* spp. (oatgrass) present in Alberta both make bilobate phytoliths very similar to panicoid grasses, which further complicates the index formula somewhat. Using relative or cardinal values does not matter for this index because it is a proportion and both value types return the same result.

The Ic index measures the climate or temperature by measuring C3 pathway grass phytoliths, i.e., festucoid (F) phytoliths as a proportion of the entire grass phytolith assemblage. The formula is F/(F+P+C). This index was first proposed by Twiss (1987) and used by Twiss (1992). Fredlund and Tieszen (1997) also used the Ic index as a temperature proxy but went further, correlating phytolith observations to historical temperature measurements from numerous meteorological stations on the Great Plains of the U.S. and using statistical analysis to estimate past temperature differences from the modern climate. Such a project is far outside the scope of the current analysis, however. Using relative or cardinal values does not matter for this index because it is a proportion and both value types return the same result.

The D/P index, or tree cover index, measures the ratio of woody (ligneous) and herbaceous dicot (D) phytoliths to Poaceae (P) phytoliths, i.e., the ratio of forest to grassland phytoliths. The index was first proposed and used by Alexandre, Meunier, Lézine, Vincens, and Schwartz (1997) in tropical Africa. This study used standard Poaceae morphotypes (Twiss et al. 1969) from three sub-families: Festucoideae, Chloridoideae, and Panicoideae and a single ligneous dicotyledon morphotype, circular rugous. Strömberg (2002), on the other hand, simply used all dicot morphotypes divide by all Poaceae phytoliths. The direct applicability of the D/P index from lowland tropical Africa to other latitudes and elevations has been shown to be problematic (Bozarth 1993; Strömberg 2004; Barboni et al. 2007). Bremond, Alexandre, Hély, and Guiot (2005) correlated the D/P index with a Leaf Area Index (LAI), defined as the leaf cover (m^2)/ground surface (m^2), where the leaf area was measured at 2m above ground surface. It may be the D/P index will require a similar calibration on the northern Great Plains of Canada. I follow Strömberg (2002) and simply divide all non-grass types by all grass types. I use both relative and cardinal values to compare the two, but I believe using relative values will provide a more accurate comparison between samples.

The final index, Fs, measures the proportion of fan-shaped (alternatively bulliform or cuneiform) phytoliths as a proportion of the total assemblage (Bremond, Alexandre, Peyron, and Guiot 2005). As described by Bremond et alia, bulliform cells are produced by grasses and are the motor cells that allow grasses to curl their leaves when undergoing water stress to reduce water loss from transpiration. While the mechanisms are not well understood, bulliform cells appear to become silicified under conditions of water stress. A higher proportion of bulliform cells observed relative to the total phytolith assemblage therefore may indicate a period of higher water stress. Using relative or cardinal values does not matter for this index because it is a proportion and both value types return the same result.

4.4.3 Principal Components Analysis (PCA)

The final analytical method I used was Principal Components Analysis (PCA). PCA has been used successfully in numerous studies and disparate environments to assess relationships between phytolith assemblages (e.g., Prebble et al. 2002; Lu and Liu 2005; Watling et al. 2016; Gao et al. 2017). According to Birks and Birks (1980), PCA is a commonly used technique that compresses multi-variate, multi-dimensional data into only the most important factors, expressed as the principal components, in a two-dimensional format. PCA creates an array of principal components – as many components as there are variables. The first principal component (PC1) expresses the largest degree of variation in the dataset, the second principal component (PC2) expresses the second largest degree of variation in the dataset, and so forth. Observation data points create a scatterplot on a cartesian coordinate plane with PC1 and PC2 as the *x*-axis and the *y*-axis, respectively. The observations, in my case each soil sample, are plotted as points on the scatterplot and correlated observations form point clusters. I tested the quality of each analysis with a scree plot, a bar graph in which each bar shows the amount of variation explained by each principal component.

I analysed the collected morphotype data using Analyse-it, a commercially available statistics add-in for Microsoft Excel. I chose this statistical analysis package because it is easy to use, and I am not running statistical analyses on my dataset more complicated than determining correlations and principal components. I used two datasets in my statistical analyses. The first was the dataset of all non-0 count morphotypes (i.e., a morphotype I observed at least once) in which each morphotype observed under microscopy is a variable in the dataset. The second was a dataset of vegetation types, each variable of which was the total of all the morphotypes within that vegetation category, e.g., the counts of all festucoid morphotypes observed are added together to create the single festucoid variable. These vegetation types were also used in several environmental index formulae used successfully in previous research, as detailed above. I performed PCA on both these datasets using both cardinal and relative values to compare the two, but I believe the relative value analysis will provide the most accurate results.

As I touched on briefly above in section 4.3.3, I am most interested in comparing fossil phytolith assemblages to modern surface assemblages. When a fossil assemblage is very similar to a modern assemblage, we can infer the two may represent similar vegetation communities. In cases where a fossil assemblage is not similar to a modern community, we can use morphotype classes and environmental indices to investigate how the fossil assemblage is different and draw some conclusions about the fossil vegetation community. For example, if a fossil assemblage has more panicoid morphotypes than any modern assemblage, we can infer the environment was likely warmer and wetter in the past at that time. While we must keep taphonomy in mind as well, we can make cautious statements about past vegetation communities, and this can guide future research to test those conclusions. As we refine methods and develop better reference collections, we can become more secure in our hypotheses.

4.5. Summary

In this chapter I described each step in the process of collecting phytolith data from sediments, from field to lab to microscope to computer. I wanted to show both what I did and how I decided what to do – both methods and methodology. In each section I tried to make clear that behind the final methods are a great deal of research, experimentation, adaptation, and learning from trial-and-error. At every step, plans collide with reality and the final research design grows organically from this interplay. I am sure all methods are arrived at in this way, but necessity or convention usually hides the messy process behind a polished and professional presentation.

Chapter 5

Results

In this chapter, I describe the sediments in the sampling columns to understand the edaphic setting. I establish a chronological framework from the obtained radiocarbon dates. I present the phytolith microscopy results for the diagnostic morphotypes in each vegetation category and discuss problems with several morphotypes and the reasoning behind the ultimate removal of several of them from analysis. I also describe observations of three non-diagnostic morphotypes, a non-diagnostic morphotype characteristic of the Asteraceae family, and three other types of biogenic silica bodies. I then move to describe the results of the analyses of these morphotypes and vegetation categories. I discuss whether any of the observed morphotypes are indicative of a particular species or vegetation community. I detail the results of the four environmental indices. Lastly, I describe and interpret the Principal Components Analyses of the dataset, using both cardinal and relative values (defined above in section 4.4), which create a picture of the relationships linking the sampled fossil assemblages to each other and to the modern assemblages.

5.1 Sediments

As described above in section 2.4, the sampling column 1 location soils are described as miscellaneous undifferentiated mineral, the sampling column 2 location soil is officially described as Ronalaine Solonetzic Brown Chernozem and the sampling column 3 location soil is officially described as Verdigris Cumulic Regosol (Agricultural Regions of Alberta Soil Inventory Database [AGRASID] 2020). The sampling columns allowed me to ground-truth these identifications.

During the phytolith extraction process, as described in section 4.2 above, I took measurements to obtain color and an assessment of soil texture, but I undertook no detailed pedological research. I can make some statements on relative amount of carbonates based on reaction strength to hydrochloric acid, HCl, and organics based on reactions to bleach (sodium hypochlorite), and hydrogen peroxide (H_2O_2). I used the reactions I observed in modern surface composite sample 1 (sample MS1) as the baseline reactions because this was the first sample I processed. MS1 required 60 minutes to remove organics and 80 minutes to remove carbonates. All reaction strengths are relative to MS1, but I cannot quantify the organic or carbonate content from the extraction process.

5.1.1 Sampling Column 1

I decided not to use sampling column 1 (Figure 5.1) for this study due to the large gap in the sediment column caused by the watery layer from 20-44cmbs and due to the poor depth control of this first sampling column. Furthermore, because I only had time and resources to process two sampling columns, I chose to use sampling column 3, which is from a similar environment and location, is deeper, and was extracted with more precise depth control. Because I did not extract phytoliths, I was unable to measure the particle fractions or make observations of the carbonate and organics removal reactions. I used sampling column 1 to practice and refine the subsampling, drying, and disaggregation steps before moving on to the sampling columns I wanted to keep. I discarded the sampling column 1 sediments afterwards. During this process I gauged the sediment texture by feel between my fingers but did not take any color readings. It was only much later I decided to present color data as well. I used a Munsell soil color book to take color readings (Table 5.1) but I had to use photos of the sediments. The following discussion, therefore, only provides a general idea of the sediments rather than a precise description. After this section I will no longer comment on sampling column 1.

Table 5.1: Munsell colors of layers in sampling column 1.

Layer Depth (cmbs)	Primary Munsell Color	Secondary Munsell Color(s)
5-8	5Y 4/1 dark gray– 3/1 very dark gray	
8-16	5Y 6/2 light olive gray	2.5Y 5/4 light olive brown
16-20	(GLEY1) N 6/- gray	
44-83	(GLEY1) N 6/- gray	
58-65	(GLEY1) N 6/- gray	5Y 6/2 light olive gray oxidation
83-87	5Y 5/4 olive	

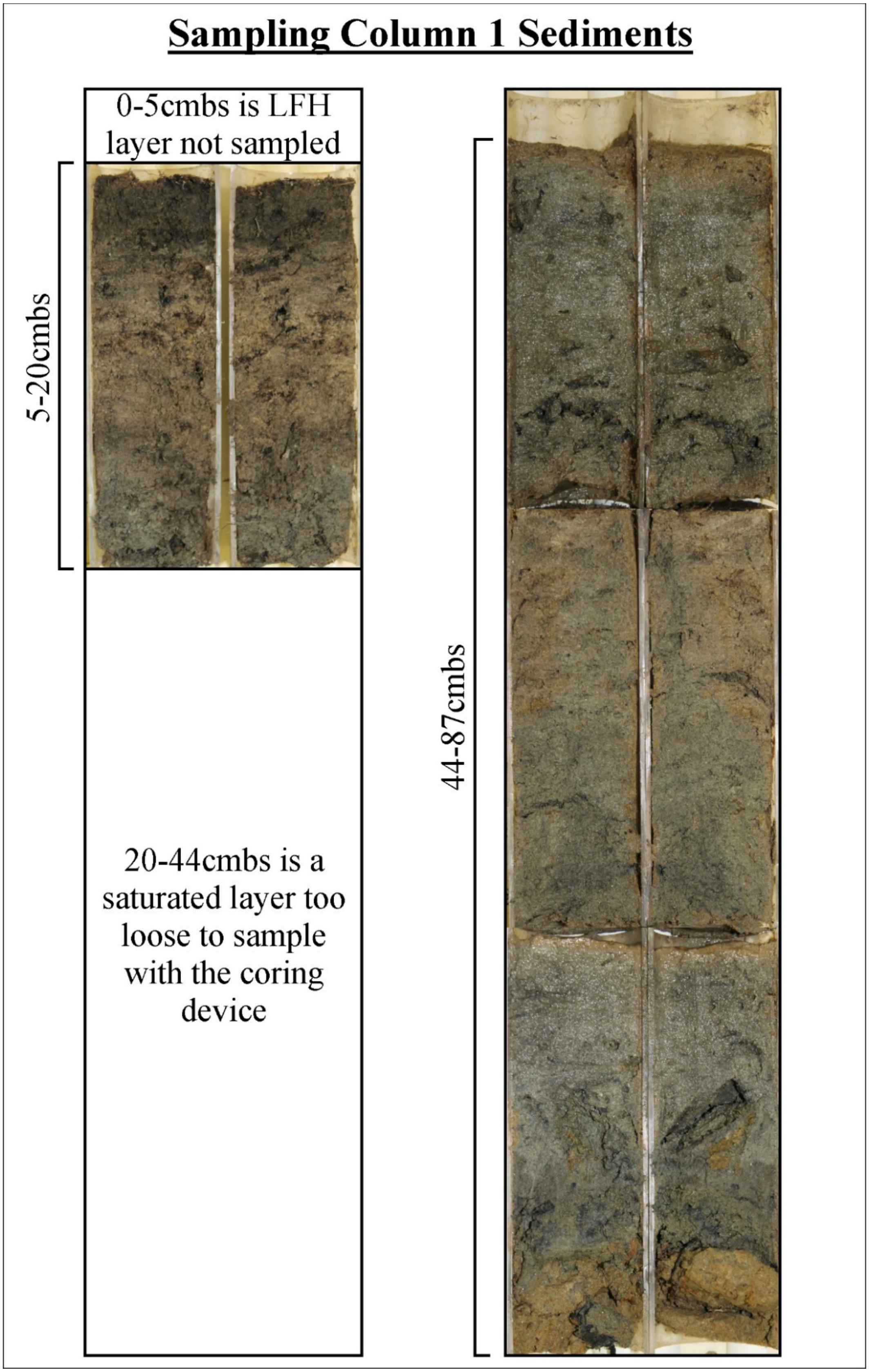


Figure 5.1:Sampling column 1 sediments were highly saturated and gleyed. No subsamples were taken.

The first 5cm of the sampled column was a litter and fibre mat we discarded in the field. The first sample tube collected sediments from 5-20cmbs, which contained many coarse organic inclusions, mostly roots and rootlets. The texture appeared to be a silty loam. There are three layers. The first from 5-8cmbs is dark gray (5Y 4/1) to very dark gray (5Y 3/1) and appears to be a thin Ah horizon. From 8-16cmbs, the sediments are predominately light olive gray (5Y 6/2) with lighter areas of light olive brown (2.5Y 5/4). From 16-20cmbs the color becomes gray ([GLEY1] N 6/-). I believe the gleying of the sediments begins at 16cmbs. From 20-44cmbs the sediments are very loose and too watery to gauge the texture by feel and I neglected to take photos or a color reading. From 44cmbs to 80cmbs the texture becomes finer than above the watery layer and appears to be a silt or silty clay. The dominant color remains the same gleyed gray that began at 16cmbs, though there is a light olive gray (5Y 6/2) coloration where oxidation has occurred from 58-65cmbs and around the edges of the sampling tubes. At 83cmbs there are suddenly gravel inclusions, approximately 3-5cm at the longest point. At 83cmbs there is also an abrupt color change, and the sediments are olive (5Y 5/4) to the termination of the sampling column at 87cmbs. There are very small macrobotanical remains throughout the column and no obvious charcoal inclusions.

5.1.2 Sampling Column 2

Sampling column 2 (Figure 5.2) was a homogenous and uniform brown clay. The top of the column was a 3cm LFH layer above the mineral surface. There was no A horizon though there was some darkening around numerous rootlets, which extended to 30cmbs. There were no mottles or other signs of gleying. The dry sediments Munsell color (Table 5.2) ranged from gray (2.5Y 5/1) to very dark gray (2.5Y 3/1) and the moist sediments ranged from very dark grayish brown (2.5Y 3/2) to very dark gray (5Y 3/1). The only secondary color was a small pocket of 10YR 4/6 dark yellowish brown at 58cmbs. The texture was clay down to 82cmbs, at which point the sediments to the base at 105cmbs become silty clay. Clay has a clay content above 60%, while silty clay has a clay content of 40-60%, a silt content of 40-60%, and a sand content of 0-20%. For all samples in the column, the sand content range was 0-1%, the silt content range was 13-49%, and the clay content range was 52-86%. There is no evidence of lamination or bedding of the sediments. There was almost no macrobotanical material in the sediments below 30cmbs. There were small air pockets in the sediment at 58cmbs and 94cmbs but otherwise no signs of potential bioturbation. The surface sample from 0-3cmbs had a strong reaction to both organics and carbonates removal. The rest of the sediment reacted to carbonates removal in a manner similar to the MS1 baseline and had either baseline or strong reactions to organics removal. Sampling column 2 appears to be an Orthic Vertisol, based on the heavy clay content and lack of A and B horizons.

Table 5.2: Munsell colors of layers in sampling column 2.

Layer Depth (cmbs)	Primary Munsell Color	Secondary Munsell Color(s)
0-3 (modern surface)	not taken, too heterogenous	
3-6.5	2.5Y 3/2 very dark grayish brown	
6.5-15	2.5Y 3/1 very dark gray	
15-18	2.5 Y 5/1 gray (dry)	
18-25 empty space		
25-33	5Y 3/1 very dark gray	
33-35	2.5Y 3/1 very dark gray (dry)	
35-38 empty space		
38-41 disturbed material		
41-50	5Y 3/1 very dark gray	
50-52	5Y 3/1 very dark gray (dry)	
52-67	5Y 3/1 very dark gray	10YR 4/6 dark yellowish brown, in pocket at 58cmbs
67-70	5Y 5/1 gray (dry)	
70-75 empty space		
75-85	5Y 3/1 very dark gray	
85-88	5Y 3/1 very dark gray (dry)	
88-96.5	between, but closer to, 5y 3/1 very dark gray and 5y 4/1 dark gray	
96.5-103	between 5y 3/1 very dark gray and 5y 4/1 dark gray, but closer to 5y 4/1	
103-105	5Y 3/1 very dark gray (dry)	

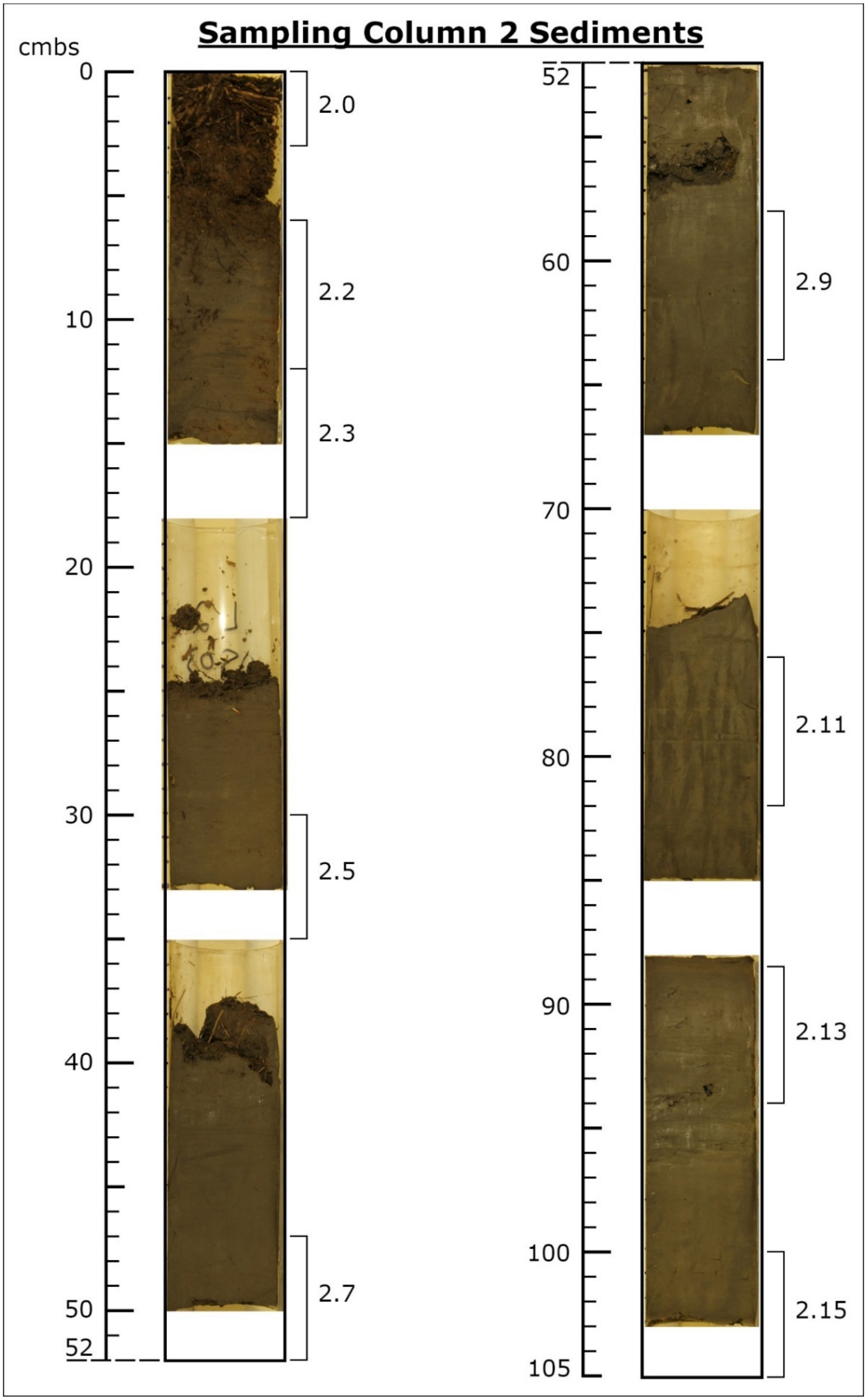


Figure 5.2: Sampling column 2 sediments. Blank spaces between sampling tubes indicate material collected from the end of the coring device and bagged. Dark striations at 7-15cmbs are from scraping clean the face of the split column surface.

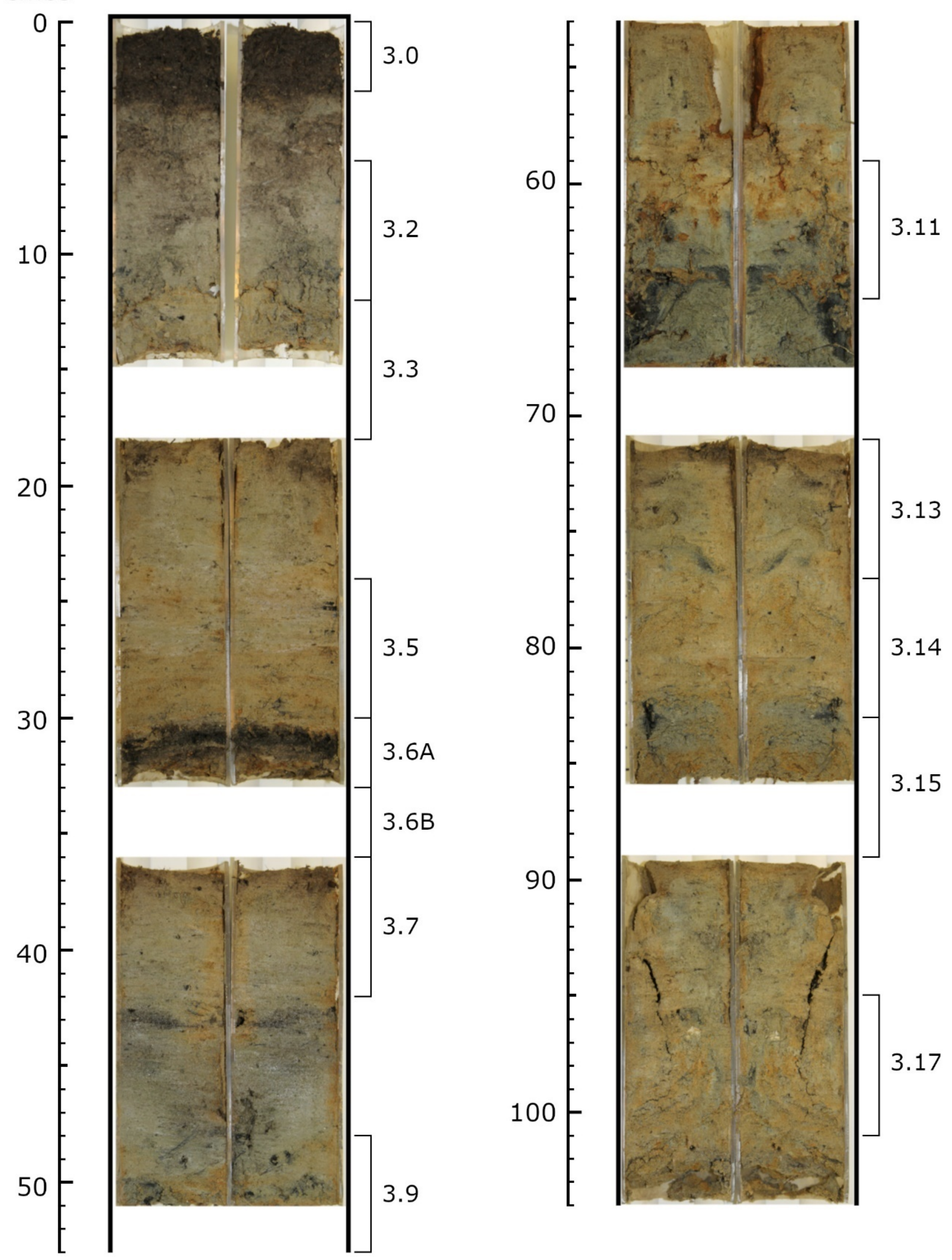
5.1.3 Sampling Column 3

Sampling column 3 (Figure 5.3) was very wet, layered clay with strong gleying and mottles. The soil in this location is identified as Verdigris Cumulic Regosol, which, in the ideal profile, has a surface Ahk horizon (0-7cmbs) and three buried Ahkb horizons, at 20-30cmbs, 45-47cmbs, and 66-69cmbs, separated by Ck horizons.

I differentiated 16 layers (Appendix B) in sampling column 3 based on color and texture changes. There is an Ah horizon (layer 1 or L1) from 0-3cmbs and a possible Ahb horizon (L5) at 30-33cmbs. While there are no other distinct possible Ahb horizons, there are two darker layers, L7 (42.5-51cmbs) and L9 (61-68cmbs). L9 had a large root fragment, and this area may just be darker due to bioturbation. Another layer, L14 at 130-131cmbs, is a narrow band of sediment slightly darker than the neighboring layers and may have been the beginnings of an A horizon before being buried.

Underlying the Ah horizon is a layer of 2.5Y 4/1 dark gray clay which, based on the formation process of cumulic regosols, is likely a C horizon. The boundary between these two layers is abrupt, though there is some organic staining at the top of L2. All sediments below 11cmbs show redoximorphic features – concentrations and reductions in iron – indicating water saturation. From 0-24cmbs, the sediments are clay. At 24cmbs, roughly the base of L3, the sediments become silty clay for the rest of the column. The sand fraction range is 0%-8.1%, the silt fraction range is 7.3%-60.5%, and the clay fraction range is 38.3%-92%. The sand fraction above 59cmbs is usually less than 1%. Between 59cmbs and 95cmbs, the sand fraction averages about 2% but below 95cmbs it increases to approximately 4% on average. This coincides with the observation of a sandstone pebble at 97cmbs. The largest sand fraction is 8.1%, which occurs in the lowest 4cm of the sampling column just before column termination at a large tree root. The sediments below this depth were extremely saturated with water and too loose to be sampled.

Sampling Column 3 Sediments



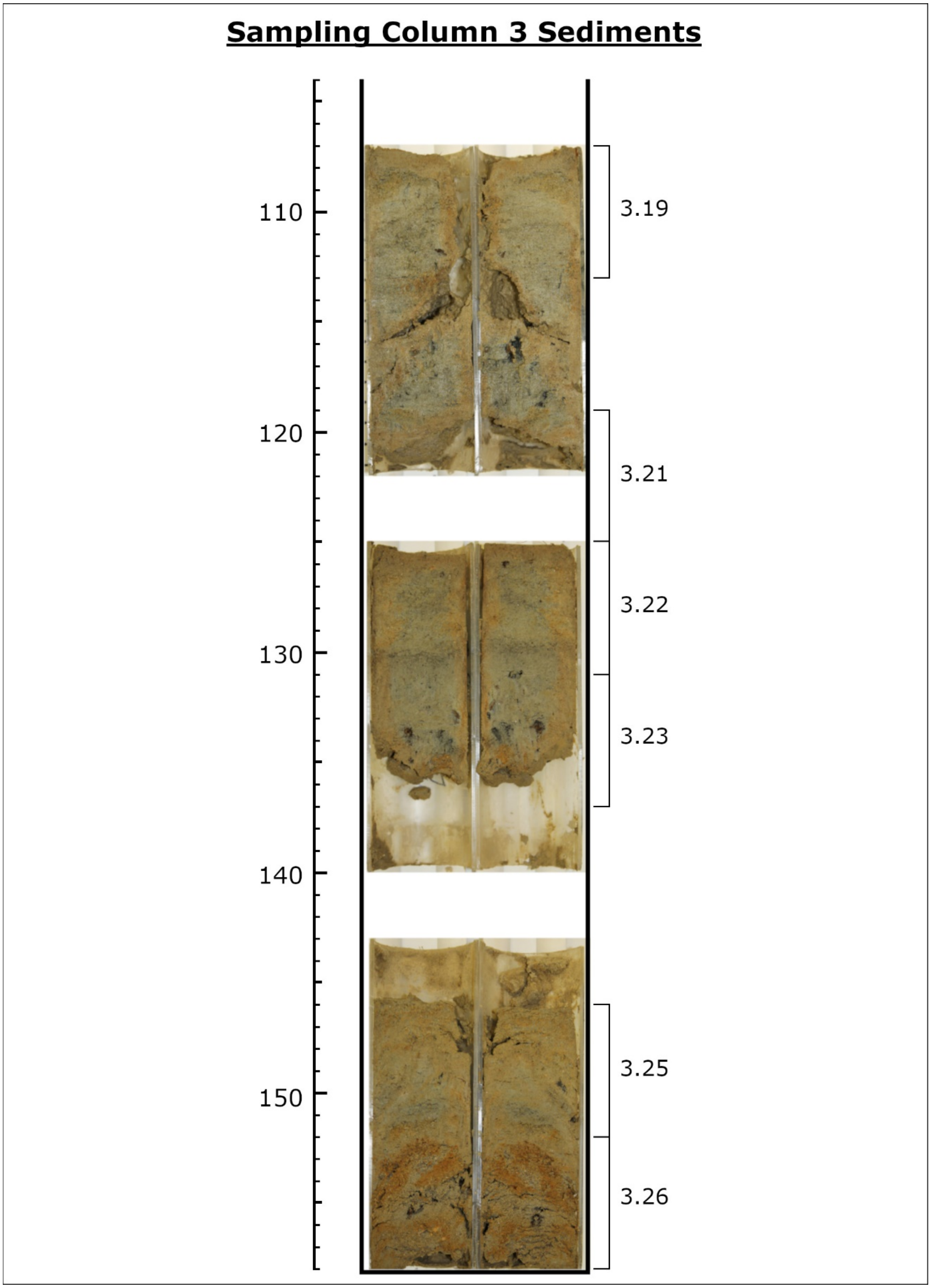


Figure 5.3: Sampling column 3 sediments. Subsamples are noted to the right of the column. Blank spaces correspond to bagged material from the end of the coring device. Samples 3.25 and 3.26 were shifted up to correspond to field measurements.

In sampling column 3, the major colors of the moist sediments were typically grayish brown (2.5Y 5/2) but ranged from dark gray (2.5Y 4/1) to gray (2.5Y 6/1), with common secondary colors of olive brown (2.5Y 4/4) and dark yellowish brown (10YR 4/6). Table 5.3 provides a detailed description of sediment colors. Because the 3cm sediments taken from between the end of the sample tube and the coring device (as described in section 4.1.1) were disturbed and dried

Table 5.3: Munsell colors of layers in sampling column 3.

Layer Depth (cmbs)	Primary Munsell Color	Secondary Munsell Color(s)
0-3.5 (modern surface)	2.5y 2.5/1 black	
3.5-12	2.5y 4/1 dark gray	2.5y 3/1 very dark gray; turbation running diagonally across the layer
12-15	2.5y 4/1 dark gray to 2.5y 4/2 dark grayish brown	2.5y 4/4 olive brown; particles diffused throughout and running in diffuse small streaks throughout layer
15-18 (dry)	2.5y 6/2 light brownish gray	2.5y 5/4 light olive brown particles
18-31	2.5y 4/2 dark grayish brown	2.5y 3/1 very dark grey diagonal coloration possibly bioturbation 2.5y 4/4 olive brown mottling and streaks
31-32	2.5y 2.5/1 black	
32-33	2.5y 5/2 grayish brown	
33-36 (dry)	2.5y 6/2 light brownish gray	2.5y 5/4 light olive brown mottling
36-51	between 2.5y 5/2 grayish brown and 2.5y 4/2 dark grayish brown	2.5y 4/1 dark gray patches at top of core and at 45-48 cm 2.5y 4/4 olive brown mottling and streaks
51-53 (dry)	2.5y 6/2 light brownish gray	2.5y 6/4 light yellowish brown mottling/sediments 2.5y 6/1 gray mottling/sediments
53-68	between 5y 5/1 gray and 5y 5/2 olive gray	2.5y 4/1 dark gray coloration 1-2cm thick following top contour of core

		10yr 3/6 dark yellowish brown mottling, mostly between 60-63cm
68-71 (dry)	2.5y 6/2 light brownish gray	2.5y 6/1 gray mottling 10yr 5/6 yellowish brown mottling
71-86	between 2.5y 5/1 gray and 2.5y 5/2 grayish brown	2.5y 3/1 very dark gray patches at top 1-2 cm of core 2.5y 4/2 dark grayish brown at top 1cm edge of core, likely oxidation or drying 2.5y gray patch of sediment or mottling at 83-85 cm mottling and particles ranging 2.5y 5/4 light olive brown to 2.5y 4/4 olive brown
86-89 (dry)	2.5y 6/2 light brownish gray	2.5y 6/4 light yellowish brown mottling 2/5y 6/1 gray mottling
89-103	2.5y 5/2 grayish brown	2.5y dark grayish brown patch at top of core, likely oxidation or drying 2.5y 5/1 gray mottling/patches mostly between 97-103cm range from 2.5y 5/4 light olive brown to 10yr 4/6 dark yellowish brown mottling/patches
103-104 (empty space)		
104-107 (dry)	2.5y 6/2 light brownish gray	2.5y 6/1 gray mottling (sandier sediment) range from 10yr 4/6 dark yellowish brown to 10yr 5/6 yellowish brown mottling
107-121	between 2.5y 6/1 gray and 2.5y 5/2 grayish brown	2.5y 6/1 gray mottling (sandier sediment) range from 2.5y 5/4 light olive brown to 2.5y 4/4 olive brown mottling
121-122 (empty space)		

122-125 (dry)	2.5y 6/2 light brownish gray	2.5y 6/1 gray mottling (sandier sediment) range from 2.5y 5/4 light olive brown to 10yr 4/6 dark yellowish brown mottling
125-135	between 2.5y 4/2 dark grayish brown and 2.5y 5/2 grayish brown	2.5y 4/2 dark grayish brown 1cm strip at top of core and 1cm strip at 130-131cm, neither looks like a strat but oxidation or drying range from 10yr 5/8 yellowish brown to 10yr 4/6 dark yellowish brown mottling
135-140 (empty space)		
140-143	2.5y 6/3 light yellowish brown very mixed and dried very platy	
143-146 (empty space)		
146-158	2.5y 5/2 grayish brown	2.5y 5/1 gray sandier sediment as diagonal banding between 152-156cm range from 10yr 7/6 yellow to 10yr 4/6 dark yellowish brown as diagonal banding with gray sediment between 152-156cm and as transverse band at 156cm; yellow color appears as small cluster of large specks within this band

out as an unavoidable effect of the sampling process, they provided an average dry color of the sediments, which was always 2.5Y 6/2 light brownish gray.

There was little evidence of major bioturbation within the sampling column. Most bioturbation appears to be related to roots and rootlets. The largest root fragment I observed was at 66cmbs and appeared to be a fragment of a living root. I observed sparse small macrobotanical fragments throughout the sampling column, none of which weighed more than 50mg. Based on the botanical sample I sent for radiocarbon dating (described in section 5.2 below), I believe most or all of these are fragments of rootlets. The samples of and near the Ah horizons had strong or very strong reactions to bleach and H_2O_2 during organics removal, while all other samples had a weak reaction. The strongest reactions to HCl during carbonates removal occurred in the samples within 40cm of the surface and 30cm of the base of the column. The samples between had either weak or baseline reactions. This seems to indicate higher carbonate concentrations in samples closer to water at the surface and underground. Sampling column 3 is a gleyed cumulic regosol, which matches the official soil description for this locality.

5.2 Radiocarbon dates

An accurate chronological framework is of paramount importance for any investigation of the past. Ideally, this framework is crafted from numerous dates taken from high quality botanical specimens, such as seeds, which are produced annually (Brock, Higham, Ditchfield, and Bronk Ramsey 2010). The reality is that local conditions and luck often determine what material is both preserved and collected, and financial resources determine how many samples can be dated. In this case, I was limited to four dates, three of which are on sediments and only one of which is on botanical remains. Appendix C contains the full report from A.E. Lalonde AMS laboratory.

It is unfortunate but not unexpected that I was unable to recover more macrobotanicals suitable for radiocarbon dating from my sampling columns. The area has poor conditions for preservation of organic remains, with variable soil moisture and temperature extremes from -40°C in the winter to 40°C in the summer (Alberta Climate Information Service 2020). Given the serious limitations of sediment samples for radiocarbon dating (Brock, Froese, and Roberts 2010), the following results (Table 5.4) should be interpreted as a very coarse resolution timeframe for the changes observed in the vegetation communities and climate proxies described below. To maintain consistency throughout this thesis, I will use calibrated radiocarbon dates. Because the submitted samples return an age range, for ease of reference and comparison I created a simplified cal BP date. This date is the middle point between the high and low ends of the calibrated age range with the highest degree of confidence, rounded to the nearest decade. For example, sample CL3.6A returned a range of 461-347 cal BP with 75.2% confidence, so the middle point is 404 cal BP, which I rounded to 400 cal BP.

The most important radiocarbon dates are the *terminus post quem* dates from the lowest levels of the two sampling columns. The lowest level (CL2.15, sampled at 101-102cmbs) of sampling column 2 from the upland depression had the oldest dated sediments with an age of 5700 cal BP. Deposition vectors here are eolian, colluvial, and alluvial. The second lowest level (CL.3.25, sampled at 145-146cmbs) of sampling column 3 from the coulee bottom returned an age of 3440 cal BP. Deposition vectors here are predominately alluvial and colluvial, though both fluvial and eolian deposition are also possible minor vectors.

Table 5.4: Radiocarbon results calibrated with OxCal v4.3 (Bronk Ramsey 2009) and the IntCal13 calibration curve (Reimer et al. 2013) by A.E. Lalonde AMS Laboratory (Appendix C).

Sample ID	Depth (cmbs)	Material	^{14}C BP	Cal BP ranges and confidence (2 sigma)	Simplified date
CL3.6A	31-32	Sediment	321 ± 22	461-347 (75.2%) 339-307 (20.2%)	400 cal BP
CL3.14	80	Botanical	177 ± 22	222-140 (56.8%) 25-0 (20.6%) 288-260 (18.1%)	Within last 300 calendar years*
CL3.25	145-146	Sediment	3222 ± 34	3510-3374 (88.5%) 3557-3531 (6.9%)	3440 cal BP
CL2.15	101-102	Sediment	4996 ± 24	5753-5654 (83.2%) 5864-5827 (11.7%) 5873-5870 (0.5%)	5700 cal BP
*Suess effect from fossil fuel burning causes dates calibrated between 1700-1950 to range across most of the period.					

Having determined *terminus post quem* ages for both sampling columns, I was able to obtain two more dates, both from sampling column 3. The sediment sample from CL3.6A (sampled at 31-32cmbs) is from the only differentiated layer within either sampling column – a darker layer that is the only potential paleosol – and returned a radiocarbon date of 400 cal BP. The botanical material recovered from CL3.14 (sample at 80cmbs) returned an age of 177 radiocarbon years before present, which can only be calibrated to within the last 300 years, unfortunately, due to a flattening of the calibration curve caused by a consequence of burning fossil fuels known as the Suess effect. Because fossil fuels lack ^{14}C, the radioactive isotope of carbon (because it has long since decayed into ^{14}N), the Suess effect simply states that burning fossil fuels dilutes atmospheric ^{14}C, which diminishes biological ^{14}C and creates problems for calibrating radiocarbon dates against global signatures found in marine isotopes and tree rings (Keeling 1979).

As we can see, the botanical sample returned a younger age than the sediment sample 48cm above it in the sampling column. There are two possible explanations for this fact. Either the botanical sample age is accurate, and the sediment age is unreliable, or both the botanical age and the sediment age are relatively reliable, and the botanical is intrusive into the older sediments. Based on appearance, my opinion is that the botanical is an intrusive root, but I cannot make any more reliable determination. Because of this age discrepancy and the Suess effect, I will ignore the botanical ^{14}C date and use only the sediment dates.

5.3 Morphotypes

As detailed in section 4.3.3 in Methodology above, I decided upon 31 different diagnostic phytolith morphotypes and a minimum count of 200 diagnostic phytoliths per sample to achieve an adequate overview of the phytolith assemblage in each sample. Of these 31 morphotypes, I recorded observations of 23 morphotypes in my samples. As is portrayed in Table 5.5 (relative values) and Appendix D (cardinal values), I recorded observations of 8,992 objects of which 7,994 were diagnostic phytoliths. I also observed 968 non-diagnostic but useful morphotypes and 22 phytoliths of a morphotype described by Bozarth (1993) as indicative of the Asteraceae family of herbaceous dicots. I also observed eight non-phytolith biogenic silica bodies. I ultimately removed several morphotypes from the dataset because they were problematic and each of these will be discussed below. After removing these morphotypes, I was left with 6,347 observations of useful diagnostic phytoliths.

What is immediately apparent is the vast majority, 6,306 or 99% of the 6,347 diagnostic phytoliths, are grass phytoliths. Of the grass phytoliths the vast majority are festucoid morphotypes; 6,235 or 99% of the grass phytolith total and 98% of all diagnostic phytoliths. Fifty phytoliths are chloridoid morphotypes representing 0.787% of the total assemblage and 0.792% of the grass assemblage. With only 21 observations, panicoid morphotypes are 0.330% of the total assemblage and 0.333% of the grass assemblage. There are only 41 observations of all non-grass morphotypes or 0.646% of the total assemblage. Focusing on only the non-grass

Table 5.5: Relative values for all morphotypes observed at least once. The Total column is the number of observations of each morphotype. When a morphotype has a value in the Total column but no relative values are presented, it is because this morphotype was not included in analyses. For cardinal values see Appendix D.

			MS1	MS2	MS3	MS4	MS5	MS6	MS7	Total	Mean	Median	sd
Grass	Pooid/Festucoid	Orbicular / Rondel	13.5%	15.2%	15.0%	10.7%	13.8%	16.3%	11.4%	230	13.7%	13.8%	2.0%
		Rectangular / Trapeziform short cell	79.0%	77.2%	77.5%	83.3%	77.9%	77.5%	81.4%	1334	79.1%	77.9%	2.3%
		Oblong	5.6%	6.5%	7.0%	5.2%	7.5%	4.4%	6.4%	102	6.1%	6.4%	1.1%
		Conical irregular base								118			
		Orbicular crenate											
		Compressed trapeziform psilate (3D) / Oblong psilate (2D)											
		Compressed trapeziform sinuate (3D) / Oblong sinuate (2D)											
		Total	98.1%	98.9%	99.5%	99.2%	99.2%	98.2%	99.2%	1666	98.9%	99.2%	0.5%
	Chloridoid	Saddle	1.9%	1.1%	0.5%	0.4%	0.8%	0.4%	0.8%	15	0.9%	0.8%	0.5%
		Elongated saddle						0.4%		1	0.1%		0.2%
		Total	1.9%	1.1%	0.5%	0.4%	0.8%	0.9%	0.8%	16	0.9%	0.8%	0.5%
	Panicoid	Bilobate short cell											
		Polylobate regular											
		Polylobate irregular											
		Oblong crenate											
		Total											
Non-Grass	Woody Dicots	Globular verrucate (3D) / Orbicular verrucate (2D)				0.4%		0.9%		3	0.2%		0.3%
		Irregular or contorted terminally attenuated elongate occasionally facetate, verrucate, or with processes sclereids											
		Total				0.4%		0.9%		3	0.2%		0.3%
	Woody and Herbaceous Dicots, Conifers, Ferns	Irregular flat polyhedron											
		Irregular polyhedron favose											
		Polyhedron favose sub-tabular											
		Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)											
		Globular psilate (3D) / Orbicular psilate (2D)											
		Globular (3D) / Spherical (2D), Angulate, or Irregular bodies; with concentric internal lamina											
		Total											
	Forest Indicators	Irregular polyhedron psilate											
		Irregular polyhedron granulate											
		Total											

Table 5.5 (cont.): Relative values for all morphotypes observed at least once. The Total column is the number of observations of each morphotype. When a morphotype has a value in the Total column but no relative values are presented, it is because this morphotype was not included in analyses. For cardinal values see Appendix D.

			2.0	2.2	2.3	2.5	2.7	2.9	2.11	2.13	2.15	Total	Mean	Median	sd
Grass	Pooid/Festucoid	Orbicular / Rondel	23.8%	28.4%	18.6%	21.6%	19.8%	30.2%	21.0%	23.7%	26.2%	431	23.71%	23.7%	3.9%
		Rectangular / Trapeziform short cell	60.9%	67.1%	76.9%	71.4%	77.0%	62.6%	73.2%	70.4%	70.6%	1306	70.01%	70.6%	5.6%
		Oblong	11.9%	4.5%	4.1%	6.9%	3.2%	7.1%	5.4%	5.1%	2.1%	101	5.61%	5.1%	2.9%
		Conical irregular base										223			
		Orbicular crenate	1.3%									2	0.15%		0.4%
		Compressed trapeziform psilate (3D) / Oblong psilate (2D)													
		Compressed trapeziform sinuate (3D) / Oblong sinuate (2D)	0.7%									1	0.07%		0.2%
		Total	98.7%	100.0%	99.6%	100.0%	100.0%	100.0%	99.6%	99.2%	98.9%	1841	99.56%	99.6%	0.5%
	Chloridoid	Saddle	0.7%							0.4%		2	0.12%		0.2%
		Elongated saddle			0.4%							1	0.05%		0.1%
		Total	0.7%		0.4%					0.4%		3	0.16%		0.3%
	Panicoid	Bilobate short cell										5			
		Polylobate regular													
		Polylobate irregular													
		Oblong crenate	0.7%									1	0.07%		0.2%
		Total	0.7%									1	0.07%		0.2%
Non-Grass	Woody Dicots	Globular verrucate (3D) / Orbicular verrucate (2D)							0.4%	0.4%	1.1%	4	0.21%		0.4%
		Irregular or contorted terminally attenuated elongate occasionally facetate, verrucate, or with processes sclereids													
		Total							0.4%	0.4%	1.1%	4	0.21%		0.4%
	Woody and Herbaceous Dicots, Conifers, Ferns	Irregular flat polyhedron													
		Irregular polyhedron favose													
		Polyhedron favose sub-tabular													
		Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)													
		Globular psilate (3D) / Orbicular psilate (2D)										201			
		Globular (3D) / Spherical (2D), Angulate, or Irregular bodies; with concentric internal lamina													
		Total													
	Forest Indicators	Irregular polyhedron psilate													
		Irregular polyhedron granulate													
		Total													

Table 5.5 (cont.): Relative values for all morphotypes observed at least once. The Total column is the number of observations of each morphotype. When a morphotype has a value in the Total column but no relative values are presented, it is because this morphotype was not included in analyses. For cardinal values see Appendix D.

			3.0	3.2	3.3	3.5	3.6A	3.6B	3.7	3.9	3.11	3.13	3.14
Grass	Pooid/Festucoid	Orbicular / Rondel	16.8%	20.9%	22.4%	16.3%	17.2%	29.5%	27.3%	8.6%	20.1%	11.3%	20.2%
		Rectangular / Trapeziform short cell	45.4%	64.1%	67.2%	74.8%	79.9%	66.7%	70.5%	86.0%	75.8%	86.5%	78.2%
		Oblong	15.7%	3.9%	6.0%	1.4%	1.5%	0.8%	0.7%	2.2%	3.4%	0.7%	0.8%
		Conical irregular base											
		Orbicular crenate	1.1%										
		Compressed trapeziform psilate (3D) / Oblong psilate (2D)	1.1%	0.7%									
		Compressed trapeziform sinuate (3D) / Oblong sinuate (2D)	3.2%										
		Total	83.2%	89.5%	95.5%	92.5%	98.5%	97.0%	98.6%	96.8%	99.3%	98.6%	99.2%
	Chloridoid	Saddle	3.2%	6.5%	1.5%	2.0%	1.5%	1.5%	0.7%		0.7%	0.7%	
		Elongated saddle							0.7%				
		Total	3.2%	6.5%	1.5%	2.0%	1.5%	1.5%	1.4%		0.7%	0.7%	
	Panicoid	Bilobate short cell											
		Polylobate regular	2.7%	0.7%									
		Polylobate irregular	1.1%		1.5%								
		Oblong crenate	4.3%			1.4%							
		Total	8.1%	0.7%	1.5%	1.4%							
Non-Grass	Woody Dicots	Globular verrucate (3D) / Orbicular verrucate (2D)	4.3%	0.7%	0.7%	1.4%		1.5%		3.2%		0.7%	0.8%
		Irregular or contorted terminally attenuated elongate occasionally facetate, verrucate, or with processes sclereids											
		Total	4.3%	0.7%	0.7%	1.4%		1.5%		3.2%		0.7%	0.8%
	Woody and Herbaceous Dicots, Conifers, Ferns	Irregular flat polyhedron	0.5%	0.7%									
		Irregular polyhedron favose		0.7%		0.7%							
		Polyhedron favose sub-tabular											
		Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)		0.7%		0.7%							
		Globular psilate (3D) / Orbicular psilate (2D)											
		Globular (3D) / Spherical (2D), Angulate, or Irregular bodies; with concentric internal lamina											
		Total	0.5%	2.0%		1.4%							
	Forest Indicators	Irregular polyhedron psilate	0.5%	0.7%	0.7%	1.4%							
		Irregular polyhedron granulate											
		Total	0.5%	0.7%	0.7%	1.4%							

Table 5.5 (cont.): Relative values for all morphotypes observed at least once. The Total column is the number of observations of each morphotype. When a morphotype has a value in the Total column but no relative values are presented, it is because this morphotype was not included in analyses. For cardinal values see Appendix D.

			3.15	3.17	3.19	3.21	3.22	3.23	3.25	3.26	Totals	Mean	Median	sd
Grass	Pooid/Festucoid	Orbicular / Rondel	21.8%	18.1%	18.0%	26.2%	22.2%	30.3%	29.3%	28.8%	611	21.33%	20.9%	6.1%
		Rectangular / Trapeziform short cell	74.4%	80.6%	74.9%	69.0%	71.0%	66.5%	68.4%	67.8%	2001	71.98%	71.0%	9.2%
		Oblong	3.0%		4.8%	4.2%	6.2%	3.2%	2.3%	3.4%	102	3.37%	3.0%	3.5%
		Conical irregular base									1015			
		Orbicular crenate				0.6%					3	0.09%		0.3%
		Compressed trapeziform psilate (3D) / Oblong psilate (2D)			1.2%						5	0.15%		0.4%
		Compressed trapeziform sinuate (3D) / Oblong sinuate (2D)									6	0.17%		0.7%
		Total	99.2%	98.6%	98.8%	100.0%	99.4%	100.0%	100.0%	100.0%	2728	97.09%	98.6%	4.3%
	Chloridoid	Saddle		0.7%	0.6%						30	1.04%	0.7%	1.6%
		Elongated saddle									1	0.04%		0.2%
		Total		0.7%	0.6%						31	1.08%	0.7%	1.6%
	Panicoid	Bilobate short cell									3			
		Polylobate regular									6	0.18%		0.6%
		Polylobate irregular									4	0.14%		0.4%
		Oblong crenate									10	0.30%		1.0%
		Total									20	0.61%		1.9%
Non-Grass	Woody Dicots	Globular verrucate (3D) / Orbicular verrucate (2D)	0.8%	0.7%	0.6%		0.6%				23	0.84%	0.7%	1.1%
		Irregular or contorted terminally attenuated elongate occasionally facetate, verrucate, or with processes sclereids									1			
		Total	0.8%	0.7%	0.6%		0.6%				23	0.84%	0.7%	1.1%
	Woody and Herbaceous Dicots, Conifers, Ferns	Irregular flat polyhedron									2	0.06%		0.2%
		Irregular polyhedron favose									2	0.07%		0.2%
		Polyhedron favose sub-tabular									1			
		Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)									2	0.07%		0.2%
		Globular psilate (3D) / Orbicular psilate (2D)									54			
		Globular (3D) / Spherical (2D), Angulate, or Irregular bodies; with concentric internal lamina									1			
		Total									6	0.20%		0.5%
	Forest Indicators	Irregular polyhedron psilate									5	0.17%		0.4%
		Irregular polyhedron granulate									3			
		Total									5	0.17%		0.4%

morphotypes, 30 (73.2%) are in the woody category, 6 (14.6%) are in the woody and herbaceous dicots, conifers, and ferns category, and 5 (12.2%) are in the forest indicator category.

5.3.1 Festucoids

Sampling column 2 averaged 229.33 festucoid phytoliths per sample, with a standard deviation (sd) of 47.41, indicating a relatively wide range of fluctuation. Sampling column 3 averaged 197 festucoid phytoliths per sample with a sd of 11.95, indicating a relatively narrow range of fluctuation. I observed each festucoid phytolith morphotype in at least two samples.

I should note, one reason for the narrow range of fluctuation in sampling column 3 is the relatively low density of phytoliths per field of view (pFOV), which I discuss further below. Because I counted all phytoliths in the last FOV for each sample (i.e., the FOV in which I counted the 200th phytolith), samples with a higher density of phytoliths were more likely to have a total count much higher than low density samples.

The rectangular/trapeziform short cell morphotype was the most commonly observed type overall and of the festucoid morphotypes, with 4,641 total observations. The mean observation rate was 132.60 per sample and with a sd of 40.55; it is the type with the highest fluctuation. In sampling column 2 there were 1,306 observations of the type, with a mean observation rate of 145.11 per sample and a sd of 36.82. In sampling column 3 there were 2001 observations of the type, with a mean observation rate of 105.32 per sample and a sd of 14.01.

The conical irregular base (CIB) morphotype was the second most commonly observed type with 1,356 total observations. The mean observation rate was 38.74 per sample with a sd of 23.25. In sampling column 2 there were 223 observations of the type, with a mean observation rate of 24.78 per sample and a sd of 9.92. In sampling column 3 there were 1,015 observations of the type, with a mean observation rate of 53.42 per sample and a sd of 21.23.

While testing the interrelationships of grass morphotypes to investigate the viability of bilobates on the Northern Great Plains, as described below in section 5.3.3, the CIB morphotype of the festucoid sub-family revealed itself to be a problematic morphotype. This morphotype showed a strong and statistically significant ($p < 0.05$) negative relationship to the festucoid category but no significant correlation to any other vegetation category.

When looking into why this is the case, I found conical morphotypes are also produced abundantly in the sedge family (Cyperaceae), most commonly found in wetland locations (Murungi and Bamford 2020; Ollendorf 1992; Ollendorf et al. 1987). While festucoid conical morphotypes can be differentiated from sedge conical morphotypes (Ollendorf 1992), I did not discriminate between them in my analysis because I was unaware of the issue. I believe the CIB morphotype is probably a mix of observations of both sedge and festucoid conicals. It may even be mostly sedge conicals but, without certainty, I decided to remove the CIB morphotype from the principal components analyses. I discuss this issue and the interpretive ramifications further below in section 6.2.2.2.

The orbicular/rondel morphotype was the third most commonly observed type and the second most commonly observed festucoid type, with 1,272 total observations. The mean observation rate was 36.34 per sample with a sd of 11.80. In sampling column 2 there were 431 observations of the type, with a mean observation rate of 47.89 per sample and a sd of 8.28. In sampling column 3 there were 611 observations of the type, with a mean observation rate of 36.34 per sample and a sd of 11.58.

The oblong morphotype was the fourth most commonly observed type and the third most commonly observed festucoid type, with 305 total observations. The mean observation rate was 8.71 per sample with a sd of 6.58. In sampling column 2 there were 101 observations of the type, with a mean observation rate of 11.22 per sample and a sd of 4.76. In sampling column 3 there were 102 observations of the type, with a mean observation rate of 5.37 per sample and a sd of 6.41. Sample 3.0 had a strong effect on the numbers in this column as it contained nearly triple as many oblongs (29) as the next highest sample (10).

After the four most commonly observed morphotypes, all other morphotypes were rarely observed. With such low counts it is no longer useful to speak of mean observation rates or standard deviation. The orbicular crenate morphotype is the first of these less commonly observed morphotypes, having only 5 total observations. In sampling column 2 there were two observations of the type, both in surface sample 2.0. In sampling column 3 there were three observations of the type, two in surface sample 3.0 and one in sample 3.21. There were no observations of this type in the MS samples.

There were five total observations of the compressed trapeziform/oblong psilate morphotype, all in sampling column 3. There were two observations in surface sample 3.0, one observation in sample 3.2, and two observations in sample 3.19.

There were seven total observations of the last festucoid type, the compressed trapeziform/oblong sinuate morphotype. Six observations were recorded in surface sample 3.0, one observation in surface sample 2.0, and no observations in the MS samples.

To summarize, the orbicular/rondel, rectangular/trapeziform short cell, oblong, and conical irregular base morphotypes dominated not only the festucoid assemblage (99.8%) but the total assemblage (94.7%) of diagnostic morphotypes. I removed the conical irregular base morphotype from the festucoid category due to uncertainty as to whether the observations are festucoid or sedge phytoliths. With the removal of the problematic morphotypes, the orbicular/rondel, rectangular/trapeziform short cell, and oblong morphotypes are 99.7% of the festucoid assemblage and 98.0% of the total diagnostic assemblage. The remaining three morphotypes have very low observation counts and mostly occur in the surface samples of the sampling columns but are not observed in the modern surface composite samples.

5.3.2 Chloridoids

Chloridoid morphotypes, predominately the saddle morphotype, were the next most common grass morphotypes. In general, the highest number of chloridoid phytoliths were recorded in surface or near surface samples. Sampling column 2 only had single observations of the morphotypes; occurring in only 33% of the samples. Sampling column 3 had chloridoid phytoliths in 69% of the samples, including the highest number of recorded chloridoid phytoliths in samples 3.0 (10 phytoliths) and 3.2 (6 phytoliths). Every modern surface sample had at least one observed chloridoid with the highest counts from the upland prairie samples MS1 (5 phytoliths) and MS2 (3 phytoliths).

There were 47 recorded saddle morphotypes in total. Every modern surface composite sample had one or two recorded observations of this type. Sampling column 2 only had two observations of this type, one phytolith in the surface sample 2.0 and one in sample 2.13. There were 30 observations of this type in sampling column 3 in eleven of the nineteen samples, mostly one or two phytoliths in each sample but sample 3.2 had ten, the highest number recorded in any sample, followed by the surface sample 3.0 with six saddle phytoliths.

There were only three observations of the elongated saddle morphotype. One phytolith was observed in MS6, the modern composite surface sample from the coulee bottom. In sampling column 2, there was one elongated saddle morphotype in sample 2.3. In sampling column 3, there was one observation of this type in sample 3.7.

5.3.3 Panicoids

Panicoid phytoliths were the least observed of the three grass subfamilies. There were approximately twice as many chloridoid phytoliths as panicoids and 300 times more festucoid phytoliths than panicoids. Of the observed panicoid phytoliths, 13 of the 34 are of the bilobate morphotype. Of the remaining 21 observed panicoid phytoliths of the other morphotypes, 20 were from samples 3.0-3.5 only. In the modern surface composite samples, the bilobate type was the only observed Panicoid morphotype. The same is true of sampling column 2, with the exception of a single observation of another morphotype in the surface sample 2.0. Sampling column 3 had a wider variety of observed morphotypes but, with the exception of the bilobate short cell type, these were confined to samples 3.0, 3.2, 3.3, and 3.5. Only one morphotype, the cross type, was not observed in any sample.

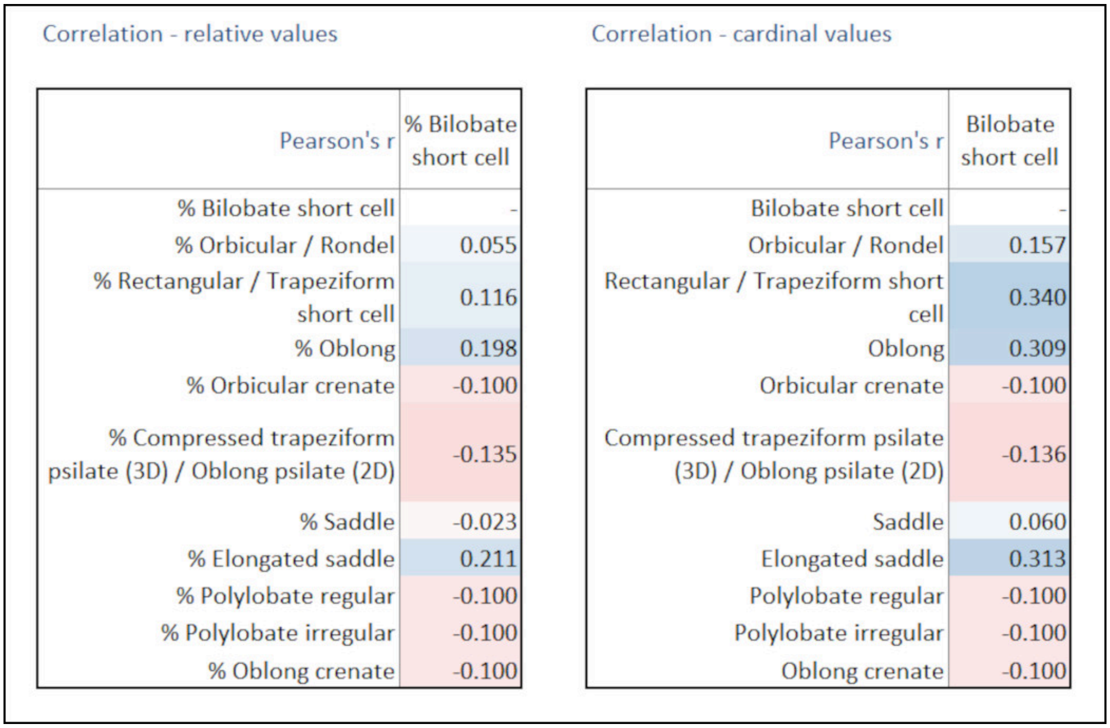
The bilobate short cell morphotype was the most commonly observed panicoid type. In the modern surface composite samples, there were two observations of the type in MS1, and one observation in each of samples MS5, MS6, and MS7. In sampling column 2 there were also five observations of the type, two each in samples 2.2 and 2.3 and one observation in sample 2.5. There were only three observations of the morphotype in sampling column 3, one in surface sample 3.0, one in sample 3.6B, and one in sample 3.26.

Fredlund and Tieszen (1994) noted that the panicoid bilobate morphotype is problematic on the Northern Great Plains (tested site at Stavely, AB) because there are a high percentage of *Stipa* spp. (sub-family Festucoideae [Pooideae]) and *Danthonia* spp. (sub-family Danthonioideae) grasses which also produce bilobate short cell phytoliths. *Stipa* spp. have been observed to produce bilobate morphotypes in several studies (Brown 1984; Mulholland 1989; Kerns 2001), typically accounting for less than 5% of a species' total phytolith assemblage. Of the seven

Danthonia species native to North America, five are present in Alberta: *Danthonia californica* (California oatgrass), *D. intermedia* (timber oatgrass), *D. parryi* (Parry's oatgrass), *D. spicata* (poverty oatgrass), and *D. unispicata* (onespike oatgrass) (USDA 2020). All five of these species produce bilobate short cell phytoliths (Reimer 2006; Reimer and Cota-Sánchez 2007)

When I tested relationships among all grass phytolith morphotypes recorded in the dataset (Table 5.6), I found bilobates negatively correlated with other panicoid morphotypes and positively correlated to chloridoid and festucoid morphotypes. Though these relationships are weak, and none are statistically significant ($p < 0.05$), they lend credence to Fredlund and Tieszen's (1994) findings. I removed bilobates from the panicoid morphotype set in subsequent analyses.

Table 5.6: Correlations between bilobates and all other grass morphotypes.



Correlation - relative values

Pearson's r	% Bilobate short cell
% Bilobate short cell	-
% Orbicular / Rondel	0.055
% Rectangular / Trapeziform short cell	0.116
% Oblong	0.198
% Orbicular crenate	-0.100
% Compressed trapeziform psilate (3D) / Oblong psilate (2D)	-0.135
% Saddle	-0.023
% Elongated saddle	0.211
% Polylobate regular	-0.100
% Polylobate irregular	-0.100
% Oblong crenate	-0.100

Correlation - cardinal values

Pearson's r	Bilobate short cell
Bilobate short cell	-
Orbicular / Rondel	0.157
Rectangular / Trapeziform short cell	0.340
Oblong	0.309
Orbicular crenate	-0.100
Compressed trapeziform psilate (3D) / Oblong psilate (2D)	-0.136
Saddle	0.060
Elongated saddle	0.313
Polylobate regular	-0.100
Polylobate irregular	-0.100
Oblong crenate	-0.100

There were six observations of the polylobate regular morphotype, five of which were in the surface sample 3.0 and the remaining observation occurred in sample 3.2.

There were four observations of the polylobate irregular morphotype, two in the surface sample 3.0 and two in sample 3.3.

There were eleven observations of the oblong crenate morphotype. In sampling column 2, the sole observation of this type occurred in surface sample 2.0. In sampling column 3, there were eight observations of the type in surface sample 3.0 and two observations in sample 3.5.

5.3.4 Non-Grass

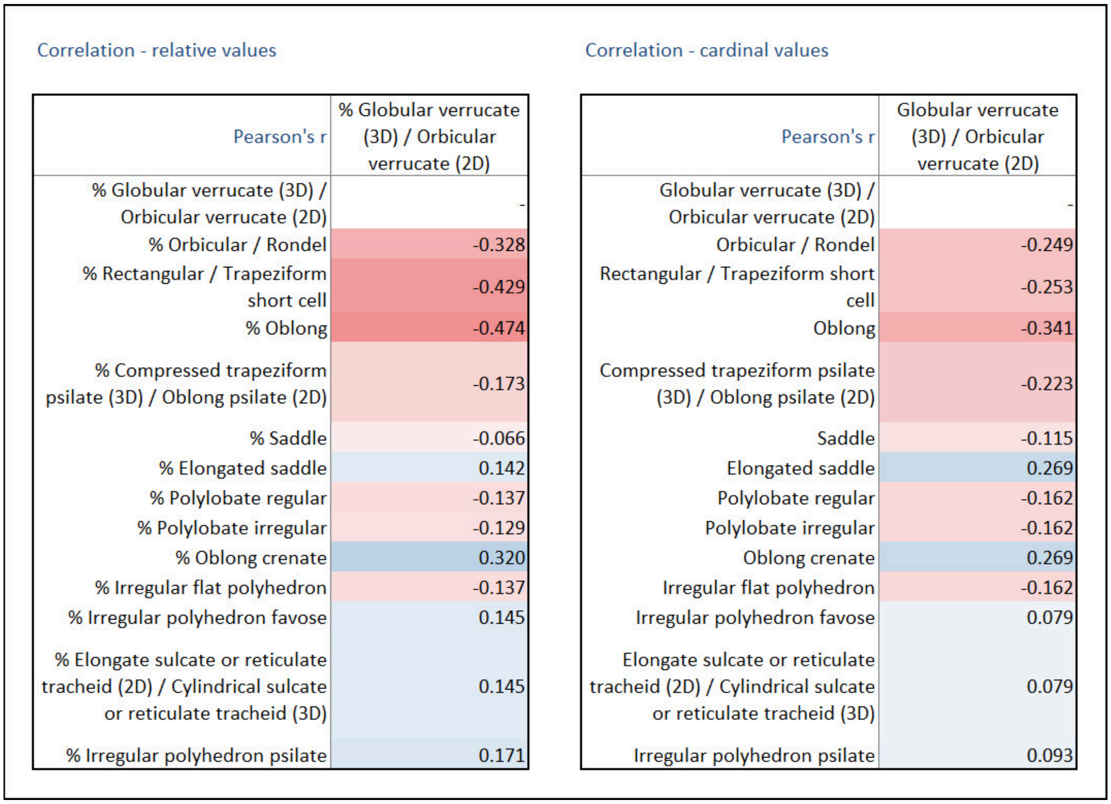
Non-grass phytolith morphotype observations were very few in comparison to the grass morphotypes, 319 in total, or 4% of all diagnostic phytoliths. Of these, globular/orbicular psilates constituted the vast majority at 272, or 85% of all non-grass diagnostic phytoliths. The remaining 47 recorded non-grass diagnostic phytoliths, therefore, are 15% of the non-grass total and 0.59% of all recorded diagnostic phytoliths. After removing the problematic morphotypes, as described below, I was left with only 41 non-grass phytoliths in the dataset. After removal, the non-grass category contained 0.65% of all recorded diagnostic phytoliths.

5.3.4.1 Woody Dicots

With only two morphotypes in the woody dicots category, it is the smallest of the three non-grass categories. I observed 30 phytoliths of the globular/orbicular verrucate morphotype, the second highest number of observed non-grass phytoliths. Once I removed the globular/orbicular psilate morphotype from the dataset used for analyses (described below), the globular/orbicular verrucate type became the most observed non-grass morphotype. This type is also the sole remaining woody vegetation morphotype observed outside of samples 3.0, 3.2, 3.3, and 3.5. Of the 30 observed phytoliths of the globular/orbicular verrucate morphotype, only three were observed in the modern surface composite samples; one in MS4 and two in MS6. In sampling column 2, there were only four observations of the morphotype, one each in sample 2.11 and sample 2.13, and two in sample 2.15. In sampling column 3, there were 23 observations of this morphotype, which was present in 12 of the 19 samples. Most samples in this column had only one, two, or three phytoliths of this type but surface sample 3.0 had eight.

Because the globular/orbicular verrucate morphotype is the sole recorded phytolith morphotype diagnostic of woody vegetation for most of the samples in the dataset, it was especially important to ensure it was functioning in this role. As we see in Table 5.7, the globular/orbicular verrucate morphotype is positively correlated to most other recorded woodlands morphotypes and negatively correlated to most grass morphotypes. Interestingly, it is positively correlated to the oblong crenate panicoid morphotype, which is similar in form and size. No correlations are statistically significant ($p < 0.05$) but the fact that this morphotype was only observed in locations with woody vegetation, or in the case of MS4, within a few meters of woody vegetation, bolsters the case that it is probably a good indicator of woody vegetation on the Canadian prairies.

Table 5.7: Correlations between the woody globular/orbicular verrucate morphotype and all other morphotypes.



Correlation - relative values

Pearson's r	% Globular verrucate (3D) / Orbicular verrucate (2D)
% Globular verrucate (3D) / Orbicular verrucate (2D)	-
% Orbicular / Rondel	-0.328
% Rectangular / Trapeziform short cell	-0.429
% Oblong	-0.474
% Compressed trapeziform psilate (3D) / Oblong psilate (2D)	-0.173
% Saddle	-0.066
% Elongated saddle	0.142
% Polylobate regular	-0.137
% Polylobate irregular	-0.129
% Oblong crenate	0.320
% Irregular flat polyhedron	-0.137
% Irregular polyhedron favose	0.145
% Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)	0.145
% Irregular polyhedron psilate	0.171

Correlation - cardinal values

Pearson's r	Globular verrucate (3D) / Orbicular verrucate (2D)
Globular verrucate (3D) / Orbicular verrucate (2D)	-
Orbicular / Rondel	-0.249
Rectangular / Trapeziform short cell	-0.253
Oblong	-0.341
Compressed trapeziform psilate (3D) / Oblong psilate (2D)	-0.223
Saddle	-0.115
Elongated saddle	0.269
Polylobate regular	-0.162
Polylobate irregular	-0.162
Oblong crenate	0.269
Irregular flat polyhedron	-0.162
Irregular polyhedron favose	0.079
Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)	0.079
Irregular polyhedron psilate	0.093

I only observed one phytolith of the second woody dicot morphotype – irregular or contorted terminally attenuated elongate occasionally facetate, verrucate, or with processes sclereids – in surface sample 3.0. This morphotype is one of the three unique outlier morphotypes I removed from the analysis dataset, following Howe and Webb (1983).

5.3.4.2 Woody and Herbaceous Dicots, Conifers, and Ferns

Most of the non-grass phytoliths fall into the woody and herbaceous dicots, conifers, and ferns category. I recorded 280 total observations of six of the ten morphotypes in this sub-category of non-grass phytoliths. 272 of the observations (97.1%) were of the globular/orbicular psilate morphotype. This morphotype and two other morphotypes with outlier observations (just one observation in only one sample) in this category were removed from the dataset, as discussed below, leaving a mere six total observations, confined to only three morphotypes, which were only observed in samples 3.0, 3.2, and 3.5. There were no observations of four of the morphotypes: irregular flat marginally lobate; orbicular verrucate single abaxial process; acicular articulated multicellular (>2) trichome or stellate or bi-armed trichome hair; and articulated fine polyglobular.

There were two observed phytoliths of the irregular flat polyhedron morphotype, one in surface sample 3.0 and one in sample 3.2.

There were two observed phytoliths of the irregular polyhedron favose morphotype, one in sample 3.2 and one in sample 3.5.

There was one phytolith of the polyhedron favose sub-tabular morphotype observed in sample 3.5. This morphotype is one of three unique outlier morphotypes removed from the analysis dataset.

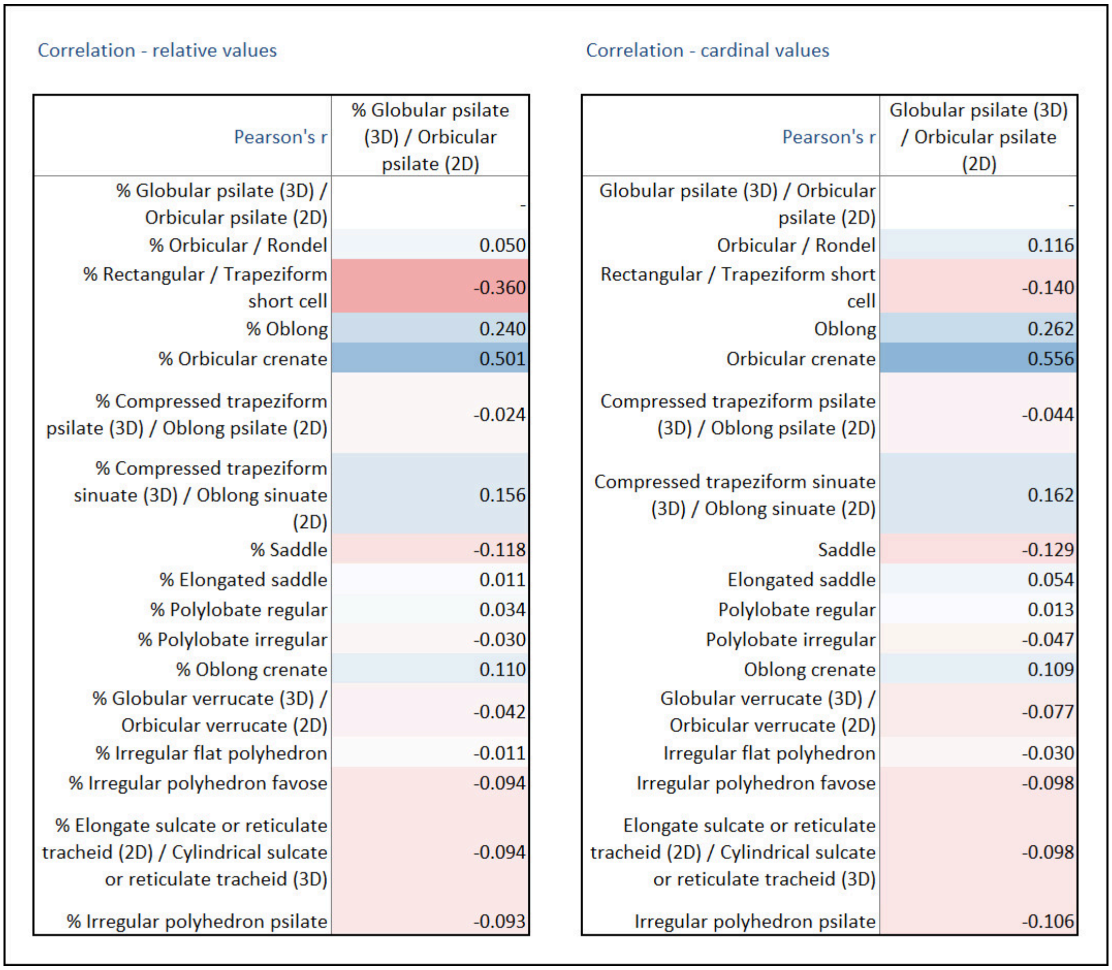
There were two observed phytoliths of the cylindrical/elongate sulcate or reticulate tracheid morphotype, one in sample 3.2 and one in sample 3.5.

I recorded 272 total observations of the globular/orbicular psilate morphotype in all samples but five, making it the fifth most commonly observed morphotype overall. In the modern surface composite samples there were typically one, two, or three observations of the type in each sample, though MS7 had six phytoliths of this type. Sampling column 2 had the most observations of the globular/orbicular psilate morphotype, accounting for 201 of the 272 observations. The three highest counts of this morphotype occurred in the top three samples of this column, decreasing with depth. In the surface sample 2.0 there were 77 observations of the type, in sample 2.2 there were 44 observations, and in sample 2.3 there were 24 observations. There was an average of 22.33 observations per sample, with an sd of 23.79 and the median sample had 12 observations of the type. In sampling column 3, I observed a total of 54 globular/orbicular psilate phytoliths, with an average of 2.84 observations per sample and an sd of 3.52. In this column, I counted the most phytoliths of this type in sample 3.9 with 13 observations, followed by sample 3.0 with 10 observations.

It has been noted that while globular/orbicular psilate phytoliths have been used to identify low and mid-elevation woodlands in the African tropics, they may be problematic in higher elevations and latitudes (Strömberg 2004; Barboni et al. 2007). Furthermore, this type is also produced in smaller amounts by some grasses (Strömberg 2004). The high proportion of these phytoliths relative to all other woody and herbaceous phytoliths (272/313 or 86.9%) may corroborate this.

To investigate the suitability of the orbicular/globular psilate morphotype in northern latitudes, I tested correlations between it and other types. I first tested its correlations with all other morphotypes (Table 5.8). I then tested how well the woody and herbaceous dicot vegetation category, which contains the orbicular/globular psilate morphotype, correlated to the other two woodland categories, woody dicots, and forest indicators (without the irregular polyhedron granulate morphotype).

Table 5.8: Correlations of the globular/orbicular psilate morphotype to all morphotypes.



Correlation - relative values

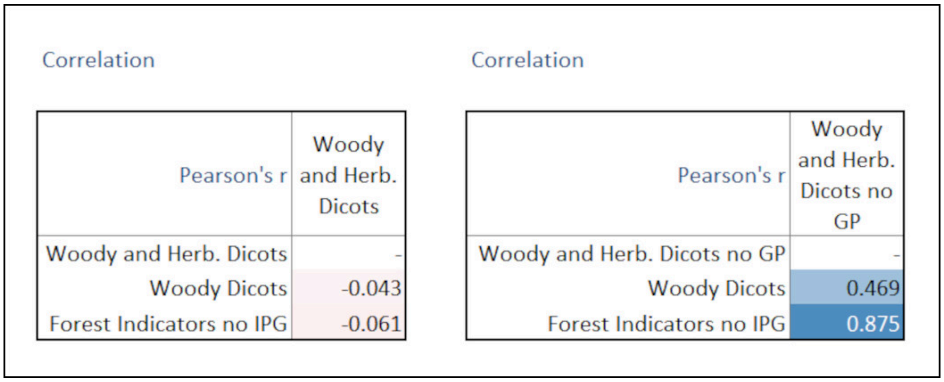
Pearson's r	% Globular psilate (3D) / Orbicular psilate (2D)
% Globular psilate (3D) / Orbicular psilate (2D)	-
% Orbicular / Rondel	0.050
% Rectangular / Trapeziform short cell	-0.360
% Oblong	0.240
% Orbicular crenate	0.501
% Compressed trapeziform psilate (3D) / Oblong psilate (2D)	-0.024
% Compressed trapeziform sinuate (3D) / Oblong sinuate (2D)	0.156
% Saddle	-0.118
% Elongated saddle	0.011
% Polylobate regular	0.034
% Polylobate irregular	-0.030
% Oblong crenate	0.110
% Globular verrucate (3D) / Orbicular verrucate (2D)	-0.042
% Irregular flat polyhedron	-0.011
% Irregular polyhedron favose	-0.094
% Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)	-0.094
% Irregular polyhedron psilate	-0.093

Correlation - cardinal values

Pearson's r	Globular psilate (3D) / Orbicular psilate (2D)
Globular psilate (3D) / Orbicular psilate (2D)	-
Orbicular / Rondel	0.116
Rectangular / Trapeziform short cell	-0.140
Oblong	0.262
Orbicular crenate	0.556
Compressed trapeziform psilate (3D) / Oblong psilate (2D)	-0.044
Compressed trapeziform sinuate (3D) / Oblong sinuate (2D)	0.162
Saddle	-0.129
Elongated saddle	0.054
Polylobate regular	0.013
Polylobate irregular	-0.047
Oblong crenate	0.109
Globular verrucate (3D) / Orbicular verrucate (2D)	-0.077
Irregular flat polyhedron	-0.030
Irregular polyhedron favose	-0.098
Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)	-0.098
Irregular polyhedron psilate	-0.106

I ran this test both with and without the orbicular/globular psilate morphotype included (Table 5.9). In the morphotype test, the orbicular/globular psilate morphotype was only weakly or not correlated with most other morphotypes and appeared to have mixed correlations to both grassland and woodland morphotypes. In the vegetation test, the woody and herbaceous dicots category with the orbicular/globular psilate morphotype included showed no correlation to either the woody dicots or to the forest indicators vegetation categories. When I removed the orbicular/globular psilate morphotype there was a strong correlation to the other two woodland vegetation categories. These results appear to confirm the research of Barboni et alia (2007) and Strömberg (2004) that the orbicular/globular psilate morphotype may be a poor indicator of woodland vegetation in the northern latitudes. As a result of this test, I removed the orbicular/globular psilate morphotype from my analyses.

Table 5.9: Correlations between the woody and herbaceous dicots category to the woody and forest indicators categories, with orbicular/globular psilates (left) and without (right).



Correlation

Pearson's r	Woody and Herb. Dicots
Woody and Herb. Dicots	-
Woody Dicots	-0.043
Forest Indicators no IPG	-0.061

Correlation

Pearson's r	Woody and Herb. Dicots no GP
Woody and Herb. Dicots no GP	-
Woody Dicots	0.469
Forest Indicators no IPG	0.875

I observed only one phytolith of the globular/spherical, angulate, or irregular bodies with concentric internal laminae morphotype in surface sample 3.0. This type is the final of the three unique outlier morphotypes I removed from the analysis dataset.

5.3.4.3 Forest Indicators

The forest indicators category are phytoliths that have been shown by Bozarth (1993) to be strongly indicative of stands of several species of conifer, as described above in Methodology. I made no observations of three of the five morphotypes: rectangular flat marginally lacunose (*Picea glauca*), elongate polyhedron bordered scrobiculate (*Pinus banksiana*), and elongate sub-rectangular flat single abrupt terminal apex (*Larix larciana*). Once again, I only observed the remaining two types in samples 3.0, 3.2, 3.3, and 3.5. I observed five phytoliths of the irregular polyhedron psilate morphotype, two in sample 3.5 and one each in samples 3.0, 3.2, and 3.3. I observed three phytoliths of the irregular polyhedron granulate type, one each in samples 3.0, 3.3, and 3.5.

Because the phytoliths in this vegetation category can be used as indicators of an entire vegetation community – for example a stand of white spruce or a stand of jack pine – I decided to double check the integrity of my observations of these types.

The irregular polyhedron granulate morphotype is a forest indicator produced in the needles of *Picea mariana*, black spruce. The irregular polyhedron psilate morphotype is produced most heavily in the needles of *Picea glauca*, white spruce, but is also produced by other conifers and, occasionally, grasses (Bozarth 1993:98). I was especially concerned with the black spruce morphotype because their current range is approximately 300 km away from the sampling site (Viereck and Johnston 1990). Any observation of black spruce, therefore, needs to be of high confidence. I compared the photos of the objects I recorded with the type phytolith photos in Bozarth (1993). The objects I recorded as irregular polyhedron granulate are similar but do not appear to be the same as those in the type-photo (Figure 5.4). The body I observed has a similar surface texture but is amorphous rather than polyhedral. Based on this re-assessment, I removed the irregular polyhedron granulate phytolith observations from the dataset.

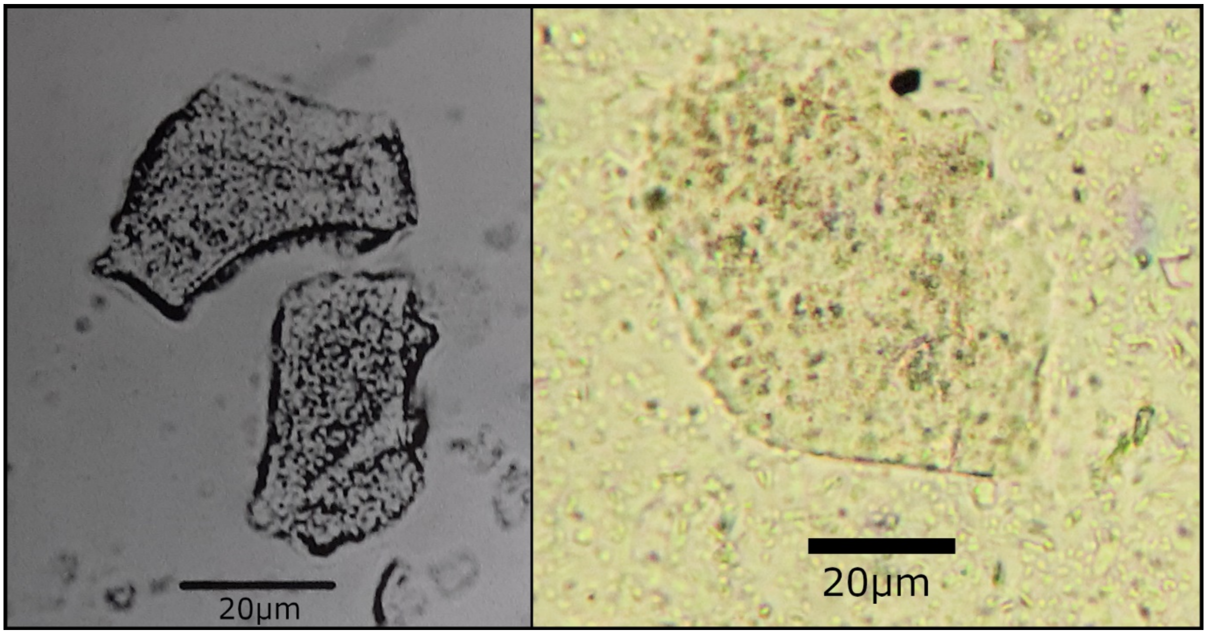


Figure 5.4: (left) The irregular polyhedron granulate morphotype characteristic of Picea mariana *(black spruce) from Bozarth (1993:Figure 2); (right) a similar silica body from this study.*

The objects I recorded as phytoliths of the irregular polyhedron psilate morphotype do match Bozarth’s type photos. I only observed this morphotype in the top 30cmbs of sampling column 3.

This places the samples within the last 400 years cal BP based on the radiocarbon date of the sediments collected from a depth of 31-32cmbs in sample 3.6A.

5.3.5 Other morphotypes

Besides the diagnostic and indicator morphotypes described above, I also tracked three non-diagnostic morphotypes, acicular, elongates of various types, and cuneiform bulliform short cell. These types are not diagnostic to a taxonomic precision better than the family level but are useful in the environmental indices. In addition to these, I created an *ad hoc* category of opaque perforated tabular phytoliths to record observations of this type.

I observed a total of 35 phytoliths of the acicular morphotype. Of the modern surface composite samples there were only two acicular phytoliths observed in sample MS1 and one in MS4. In sampling column 2 there were five observations of the type in surface sample 2.0 and one each in samples 2.5 and 2.15. In sampling column 3 the acicular morphotype was observed in nine of the nineteen samples. I made one, two, or three observations of the type in each sample, except in surface sample 3.0, in which I observed thirteen acicular phytoliths.

I observed a total of 928 phytoliths of the elongate morphotype and they were present in every sample. There were on average fewer elongates per sample among the modern surface samples, which is in stark contrast to the surface samples of each sampling column, 2.0 and 3.0, which had the second highest and highest counts, respectively, of the elongate morphotype. Among the modern surface composite samples, the counts ranged from 7 to 14 per sample; a tight range given the differences in vegetation communities. In sampling column 2, I observed 221 total elongate phytoliths with a range of 9 to 85, an average of 24.56 per sample, and a sd of 23.42. If we exclude sample 2.0, the range is 9 to 29, an average of 17 per sample, and a sd of 6.28. In sampling column 3, I observed 634 total elongate phytoliths with a range of 11 to 167, an average of 33.37 per sample, and a sd of 34.03. If we exclude sample 3.0, the range is 11 to 49, an average of 25.94 per sample, and a sd of 10.83.

I observed only five total phytoliths of the cuneiform bulliform cell morphotype: one in the modern surface composite sample MS4, one each in samples 3.2 and 3.3, and two in sample 3.5.

In several of my samples, I observed objects that matched Bozarth's (1993:96) description of Asteraceae phytoliths as "opaque platelets with systematic perforations" (Figure 5.5) and which I

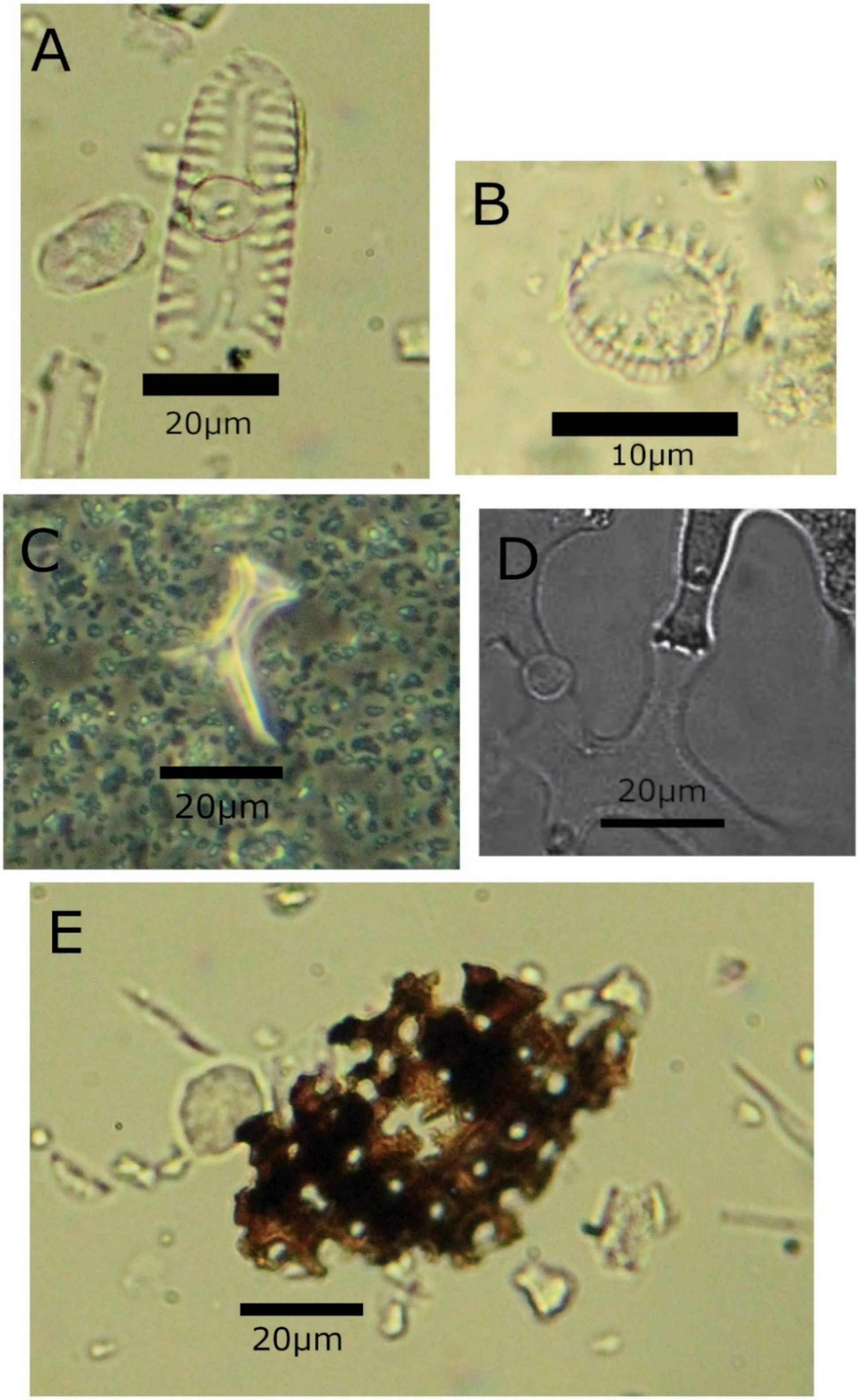


Figure 5.5: Other silica bodies. (A) biraphid diatom; (B) centric diatom; (C) unidentified stellate fragment very similar to sedge aerenchyma phytoliths (from Honaine et al. 2009:Figure3[s]); (E) Asteraceae phytolith fragment.

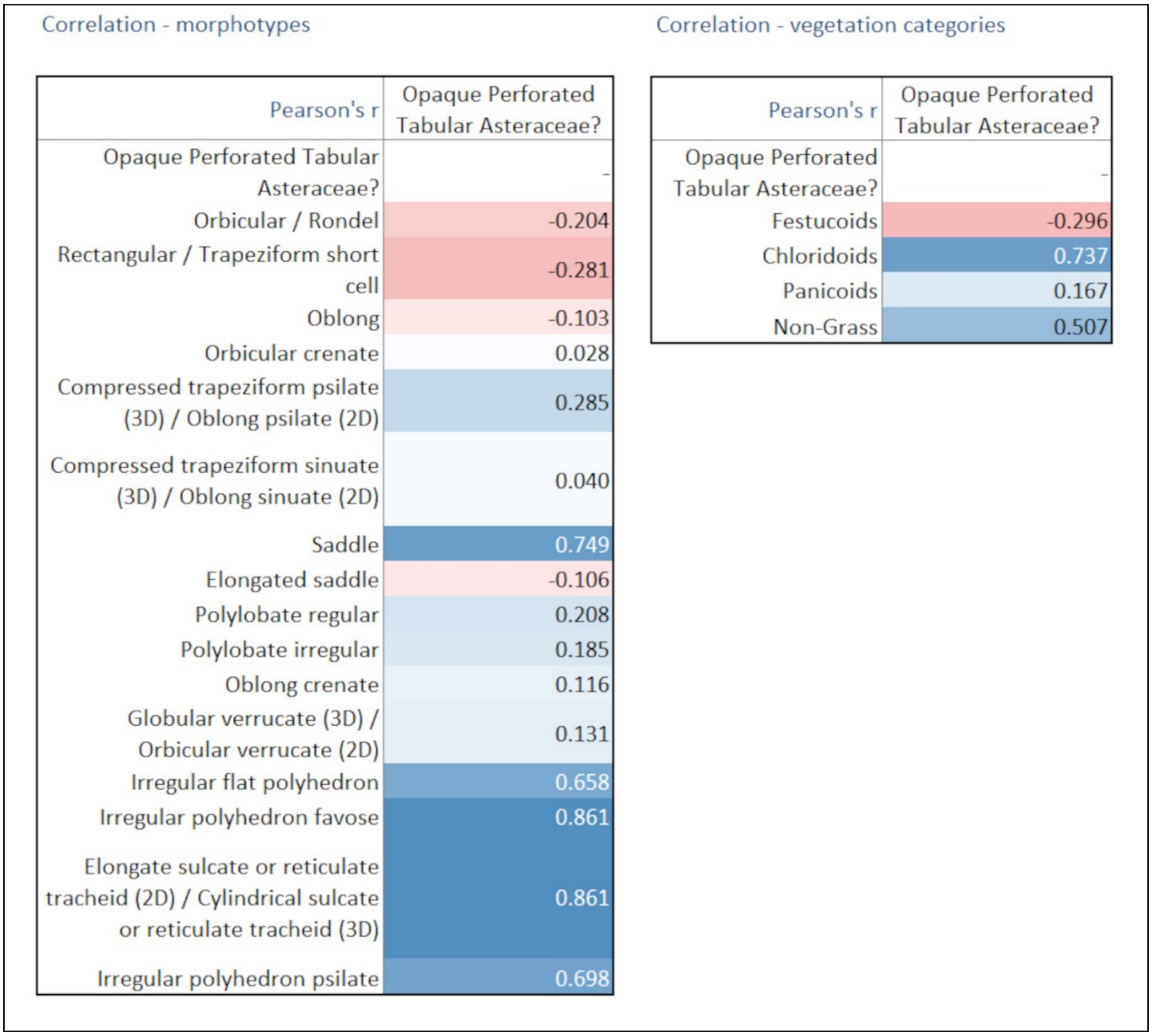
refer to as the opaque perforated tabular morphotype. I observed 22 total phytoliths of this morphotype. I did not observe this morphotype in any modern surface composite sample. In sampling column 2, I observed one phytolith of this type in surface sample 2.0. In sampling column 3, I observed 23 phytoliths of this type: one in surface sample 3.0, ten in sample 3.2, three in sample 3.3, four in sample 3.5 and one each in sample 3.11, sample 3.13, and sample 3.15. These two concentrations of observations of this morphotype occur at or near the surface and near the midpoint of sampling column 3.

I investigated whether these phytoliths might show any correlation to either woodlands or grasslands. I tested correlations of the Asteraceae morphotype to all other morphotypes and to the different vegetation categories (Table 5.10). The Asteraceae morphotypes were negatively correlated with the most numerous festucoid morphotypes but positively correlated to all other morphotypes included in the analysis dataset. When compared to vegetation types, again the Asteraceae morphotypes correlated negatively to the festucoid grass sub-family (and, because festucoids dominate the assemblage, to the grass total as well) but correlated positively to the woodland vegetation categories and to the other two grass sub-families, chloridoid and panicoid.

5.3.6 Other biogenic silica bodies

Finally, I observed other biogenic silica objects (Figure 5.5 above) which are not phytoliths but are of interest. I observed two different types of diatoms and was able to categorize them with the aid of the website www.diatoms.org. In sample 2.0 I observed three diatoms of what appears to be the same biraphid species. Samples 3.2, 3.3, and 3.11 all had one occurrence each of what appear to be the same centric diatom species, possibly in the genus *Aulocoseira*. In sample 3.5 I observed two fragments of the same stellate or y-shaped object. I was unable to identify this object, but it does appear to be composed of biogenic silica and it bears a strong resemblance to phytoliths of sedge aerenchyma (Honaine et al. 2009).

Table 5.10: Correlations between opaque perforated tabular phytoliths of Asteraceae and all other morphotypes (left); and vegetation categories (right).



Correlation - morphotypes

Pearson's r	Opaque Perforated Tabular Asteraceae?
Opaque Perforated Tabular Asteraceae?	-
Orbicular / Rondel	-0.204
Rectangular / Trapeziform short cell	-0.281
Oblong	-0.103
Orbicular crenate	0.028
Compressed trapeziform psilate (3D) / Oblong psilate (2D)	0.285
Compressed trapeziform sinuate (3D) / Oblong sinuate (2D)	0.040
Saddle	0.749
Elongated saddle	-0.106
Polylobate regular	0.208
Polylobate irregular	0.185
Oblong crenate	0.116
Globular verrucate (3D) / Orbicular verrucate (2D)	0.131
Irregular flat polyhedron	0.658
Irregular polyhedron favose	0.861
Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)	0.861
Irregular polyhedron psilate	0.698

Correlation - vegetation categories

Pearson's r	Opaque Perforated Tabular Asteraceae?
Opaque Perforated Tabular Asteraceae?	-
Festucoids	-0.296
Chloridoids	0.737
Panicoids	0.167
Non-Grass	0.507

5.3.7 Morphotypes summary

When analysing my observations, I found sample 3.0 was consistently a distant outlier, with a wider variety of morphotypes observed than in other samples, two of which were unique to 3.0. Sample 3.0 was the first slide I scanned for phytoliths, and it is easily possible I was overenthusiastic in my observations. It is also possible that it is just an especially rich sample from a location and position where there are both many phytolith types and more intact types. I might have resolved this question more satisfactorily if I had scanned the slide again, but I no longer had access to the microscope by the time I began analysing the data. In either case and in order to avoid skewing the data, I decided to amend sample 3.0. In order to include it in the PCA, I removed from the dataset the two morphotypes unique to this sample, “Irregular or contorted terminally attenuated elongate occasionally facetate, verrucate, or with processes sclereids” and “Globular (3D) / Spherical (2D), Angulate, or Irregular bodies; with concentric internal lamina”. There was also a single observation of the polyhedron favose sub-tabular morphotype unique to sample 3.5, hence I removed this morphotype from the dataset as well. The seven morphotypes I observed but excluded from the dataset were these three unique outliers, one non-viable type (globular/orbicular psilate), two insufficiently discriminated morphotypes (conical irregular base and bilobate), and one false positive (irregular polyhedron granulate). There are a further eight morphotypes I did not observe in my samples. Of the 31 morphotypes I included in my reference collection, I observed 16 I was able to include in my analyses.

There were seven morphotypes I only observed in samples 3.2, 3.3, and 3.5. I decided not to discard any observed morphotypes confined to these four samples because, while rare within the dataset, these types were not outliers, i.e., unique to a single observation in a single sample.

As discussed in chapter 4, Methodology, I included morphotypes such as panicoid bilobates and woody orbicular/globular psilates in my diagnostic morphotypes set in order to investigate their viability on the Northern Great Plains. But I failed to account for their potential removal from the dataset when I decided on a minimum count of 200 phytoliths per sample. Removing outlying and problematic morphotypes from the dataset should be taken into account when determining the minimum count and which morphotypes to include in the count, especially when a researcher is investigating phytoliths in an area with little previous work done. I should have counted the morphotypes I thought might be problematic separately from the main count, which would have allowed me to include them in analyses at my discretion. Increasing the count would also have given me a buffer. These measures would have allowed me more flexibility when analysing the data without jeopardizing the statistical robustness of the results by having too low a count. This was a great oversight on my part, which was, luckily, somewhat buffered by my decision to count all the phytoliths in the last FOV, at least in samples with higher phytolith densities.

I measured the density of the phytoliths as the number of phytoliths observed in a single field of view at 200x magnification (pFOV). The modern surface composite samples had the highest density, averaging 131 pFOV and ranging from 63 pFOV in MS6 to 214 pFOV in MS3, which was also the highest density in the entire dataset. The median sample, MS5, had 136 pFOV. The sd was 48 pFOV, which is 37% of the average. Sampling column 2 had a similar but slightly lower density than the modern surface composite samples. This column had an average density of 112 pFOV and ranged from 34 pFOV in surface sample 2.0 to 148 pFOV in sample 2.11. The median sample was 2.15 with 111 pFOV. The sd was 34 pFOV, which is 31% of the average. Sampling column 3 had a drastically lower density than the other samples, likely due to the fact it is frequently saturated, which, if the water has a high pH, can be deleterious to phytoliths. Samples in this column had an average density of 16 pFOV and densities ranged from 2 pFOV in sample 3.9 to 35 pFOV in sample 3.2. The median is 12 pFOV in sample 3.21. The sd is 10 pFOV which is 61% of the average and indicates a wider relative range of variation in density in sampling column 3 compared to sampling column 2 and the modern surface composite samples. In samples with a low pFOV, my total phytolith counts were much closer to the 200 diagnostic phytolith minimum count than those with high densities. In high density samples, counting all the phytoliths in the final FOV usually meant the total count was very high, e.g., sample MS1 with 145.5 pFOV resulted in a final count of 291. Compare this to sample 3.9 which had a pFOV of 2.1 and a final count of 202. Of course, once the pFOV topped 200, this effect was lost, as in sample MS3, where the pFOV was 214, which, naturally, was also the final count.

Despite count issues and morphotype removals, I was successful in observing phytoliths from all sampled locations. Differences in phytolith density between samples may be indicative of taphonomic processes that affect preservation, or they may indicate vegetation changes. With a dataset of observed morphotypes in hand, we can use various techniques to learn more about the vegetation communities they represent.

5.4 Indicator species

As discussed above in section 4.3.2.1, there has only been sparse research on the Northern Great Plains of Canada into morphotypes indicative of different vegetation communities. Non-grass, woodland communities composed of trees, shrubs, forbs, and even ferns that can be found in pockets throughout the prairies have generally been overlooked. In some cases, even one observation of a morphotype can indicate the presence of one of these communities. Bozarth (1993) identified five morphotypes indicative or typical of certain forest vegetation communities common to the boreal forest and aspen-parkland. I only observed the irregular polyhedron psilate morphotype, which is typical, possibly even strongly indicative, of conifers generally, especially

Picea glauca (white spruce), but which is also produced by some grasses. Without any corroborating evidence, such as the *P. glauca*-specific rectangular flat marginally lacunose morphotype, pollen grains, or macrobotanical remains, it is impossible to confidently assert the presence of *P. glauca* at this site.

5.5 Environmental indices

As described above in section 4.4.2, I used four indices to make environmental inferences from the dataset, the Iph aridity index, the D/P tree cover index, the Ic climate index, and the Fs water stress index. As we can see in Table 5.11, the results of two of these indices, Iph and Fs, are problematic due to insufficient data. The other two indices, D/P and Ic, have sufficient data but return measurements at the extremes of their gradients. Here, I will examine the results of each index more closely.

The Iph index infers aridity by measuring the proportion of chloridoid (C) phytoliths in the total number of chloridoid and panicoid (P) phytoliths (C/C+P). Originally developed for use in the African tropics (Diester-Haass et al. 1973), Twiss (1987) proposed adding festucoid (F) phytoliths to the total (C/C+P+F) when used in the Great Plains, where festucoid grasses are a large part of the grassland community.

In Table 5.11 we can see the results for both the original formula for the tropics (Diester-Haass et al. 1973) and the formula amended for temperate latitudes (Twiss 1987). In the case of the tropical formula, usually there are either no recorded panicoid phytoliths (100% chloridoids) or no observations of phytoliths from either category (0% chloridoids and panicoids). In only 5 samples are there recorded observations of both chloridoids and panicoids and only sample 3.0 has more than one or two panicoid phytoliths. In the temperate formula results, there are either no recorded chloridoids or the chloridoids are vastly overshadowed by the festucoid presence.

Again, there are not enough occurrences of either the warm-humid panicoid or the warm-arid chloridoid types in relation to the cool climate festucoid types to get a clear signal in the data. We can see that there are never panicoids without there also being chloridoids, however, and, in general, chloridoids outnumber panicoids at all levels. In this case, while we cannot properly quantify the aridity, we can make a general statement that the assemblage has more morphotypes from grasses that prefer arid rather than mesic conditions at all sampled locations and times (with the exception of sample 3.0) within the dataset.

Table 5.11: Results of environmental indices.

Sample	Aridity Iph* (Diester-Haass et al. 1973)	Aridity Iph* (Twiss 1987)	Water Stress Fs* (strictly types of Bremond et al. 2005)	Water Stress Fs* (all grass types)	Climate Ic (C3%)	Tree Cover D/P (D%/P%)*	Tree Cover D/P (value x1000)
MS1	100.00%	1.87%			98.13%		
MS2	100.00%	1.14%			98.86%		
MS3	100.00%	0.50%			99.50%		
MS4	100.00%	0.40%	33.33%	0.40%	99.60%	0.0040	4.0
MS5	100.00%	0.83%			99.17%		
MS6	100.00%	0.89%			99.11%	0.0089	8.9
MS7	100.00%	0.85%			99.15%		
2.0	50.00%	0.66%			98.68%		
2.2					100.00%		
2.3	100.00%	0.41%			99.59%		
2.5					100.00%		
2.7					100.00%		
2.9					100.00%		
2.11					100.00%	0.0039	3.9
2.13	100.00%	0.39%			99.61%	0.0039	3.9
2.15					100.00%	0.0108	10.8
3.0	28.57%	3.43%			88.00%	0.0571	57.1
3.2	90.91%	6.76%	7.14%	0.66%	92.57%	0.0338	33.8
3.3	50.00%	1.52%	14.29%	0.74%	96.97%	0.0152	15.2
3.5	60.00%	2.13%	25.00%	1.37%	96.45%	0.0426	42.6
3.6A	100.00%	1.49%			98.51%		
3.6B	100.00%	1.54%			98.46%	0.0154	15.4
3.7	100.00%	1.44%			98.56%		
3.9					100.00%	0.0333	33.3
3.11	100.00%	0.67%			99.33%		
3.13	100.00%	0.71%			99.29%	0.0071	7.1
3.14					100.00%	0.0081	8.1
3.15					100.00%	0.0076	7.6
3.17	100.00%	0.70%			99.30%	0.0070	7.0
3.19	100.00%	0.60%			99.40%	0.0060	6.0
3.21					100.00%		
3.22					100.00%	0.0062	6.2
3.23					100.00%		
3.25					100.00%		
3.26					100.00%		
	*blank = no chloridoids		*blank = no bulliforms			*blank = no dicots	

The water stress index, Fs, is the proportion of fan-shaped phytoliths (cuneiform bulliform morphotype in my dataset) to all grass phytoliths. I only observed 5 total cuneiform bulliform phytoliths in 4 samples. MS4, the modern composite surface sample from a *Bouteloua* dominant lowland mixed grassland, had one cuneiform bulliform phytolith. Samples 3.2 and 3.3 each had one and 3.5 had two cuneiform bulliform phytoliths. I did two analyses, one using only the grass morphotypes used by Bremond, Alexandre, Peyron, and Guiot (2005) and one using all the grass morphotypes I observed in this study. These return quite different values due to the high numbers of festucoids in this study. These results would seem to indicate very low water stress in the sampled areas.

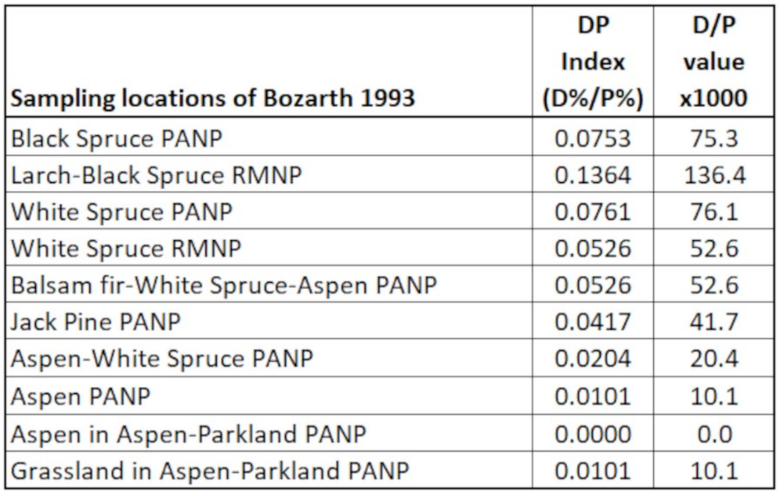
When we move to the climate index, Ic, we see that the cool climate C3 festucoid phytoliths completely dominate the grass family assemblage. Festucoid types never fall below 98% of the assemblage except in the top 30cmbs of sampling column 3. Sample 3.0 has the lowest Ic value of 88%. This may indicate a microclimate at this location and time amenable to a wider variety of flora than at the other sampled locations. Surface samples also appear to slightly favor the presence of non-festucoid, specifically chloridoid types, relative to subsurface samples. This may indicate subsurface preservation differentials between the types.

The tree cover index, D/P, yields more interesting data than at first glance. As we see, about half of the samples have no woodland phytoliths at all and the other half have extremely low ratios (less than 0.1 and often less than 0.01) of woodland to grassland phytoliths. In the first study to use this metric, Alexandre, Meunier, Lézine, Vincens, and Schwartz (1997:218) observed that, in the African tropics, the woodland dicot phytoliths they used range from 0%-6.3% of the total assemblage in the grasslands with D/P values lower than 1.0. In dense rainforest dicot phytoliths composed more than 40% of the assemblage, with grass phytoliths composing less than 7% of the assemblage in locations with D/P values higher than 6.0.

Bozarth (1993) noted in the boreal forest of Canada the hyperabundance of grass phytoliths in surface samples from even thick stands of trees, in which it was a good result if even 1% of the recorded phytoliths were from woodland dicots. Obviously, some sort of local calibration is needed to make the D/P index more accurate, similar to what was undertaken by Bremond, Alexandre, Hély, and Guiot (2005), who measured leaf canopy at 2m in their sampling locations. I did not have the equipment to quantify the leaf canopy, and, in any case, there were trees and leafy canopy in only two sampled locations.

I created a D/P index using both cardinal and relative values (described in section 4.4 above). In both, the values returned in this study were very low, so to make the numbers more intuitive, I multiplied the D/P ratio of each sample by 1000. Thus, a value of 0.001 becomes a value of 1. I use these amended numbers throughout the rest of this work. To put this into perspective, compared to Alexandre, Meunier, Lézine, Vincens, and Schwartz (1997), their African tropical grassland upper value of 1.0 becomes 1000 in my system and their tropical forest lower value of 6.0 becomes 6000. In the Canadian context, Bozarth's (1993) study of boreal forest and aspen-parkland assemblages yield a relative values D/P range (Table 5.12) from 0.1364 (136.4) in a boreal forest larch-black spruce stand in Riding Mountain National Park in Manitoba to 0.0101 (10.1) in both an aspen stand in the boreal forest and a grassland community in the aspen-parkland of Prince Albert National Park, Saskatchewan.

Table 5.12: D/P values calculated from Bozarth (1993). PANP is Prince Albert National Park, Saskatchewan and RMNP is Riding Mountain National Park, Manitoba.



Sampling locations of Bozarth 1993	DP Index (D%/P%)	D/P value x1000
Black Spruce PANP	0.0753	75.3
Larch-Black Spruce RMNP	0.1364	136.4
White Spruce PANP	0.0761	76.1
White Spruce RMNP	0.0526	52.6
Balsam fir-White Spruce-Aspen PANP	0.0526	52.6
Jack Pine PANP	0.0417	41.7
Aspen-White Spruce PANP	0.0204	20.4
Aspen PANP	0.0101	10.1
Aspen in Aspen-Parkland PANP	0.0000	0.0
Grassland in Aspen-Parkland PANP	0.0101	10.1

We can observe the D/P values of surface samples in the dataset to make some basic inferences. Sampling column 3 was taken in a wooded coulee bottom with several large willow trees and an abundance of shrubs in the immediate vicinity. Sample 3.0, the surface sample at the top of sampling column 3, had the highest D/P ratio of 56.2 cardinal and 57.1 relative. MS6, a modern composite surface sample collected in a wooded coulee bottom with several standing and fallen trees and later identified to be subject to frequent flooding, has a D/P index of 8.2 cardinal and 8.9 relative. MS4, a modern composite surface sample collected within 60m of the same wooded coulee, has a D/P of 3.7 cardinal and 4.0 relative. Contrarily, MS5, collected from within 50m of the same coulee and only a few meters upslope from MS4, had no woodland phytoliths. Based on these results, we could make a rough speculation that a D/P above 8.2 cardinal and 8.9

relative may indicate a wooded area with trees and any D/P value below these indicates proximity to a wooded area with at least shrubs and possibly trees. I should note that the MS6 relative value D/P result of 8.9 is very close to Bozarth's lowest values, which lends credence to this hypothesis. As has been indicated, the MS6 location is subject to frequent fluvial disturbances and this may affect the phytolith assemblage in a way that lowers the D/P value, such as washing away tree leaves, seeds, or other botanical materials before they decompose and their phytoliths are incorporated into the soil.

In this case, we see that the upland depression may have had or been proximal to woody vegetation in the past around 5700 cal BP. On the other hand, there are woody shrubs currently present on the outer edges of the depression 50m from sampling column 2 and no dicot morphotypes were observed in the surface sample 2.0. The coulee sampling column location appears to have had woody vegetation for much of the sampled timeframe. There appears to be no woody vegetation around 3400 cal BP followed by a period of uniform low presence of woody vegetation, then an increase in woody vegetation punctuated by periods without woody vegetation as we approach the present.

Unsurprisingly, the environmental indices cannot be lifted from the tropical context and be expected to function perfectly in a high latitude, temperate region. Despite being in need of some adaptation to increase their efficacy and interpretive power, the indices performed well enough to glean some interesting and useful information.

5.6 Principal Components Analysis (PCA)

To briefly recap from section 4.4.3 above, Principal Components Analysis (PCA) compresses a multi-dimensional dataset with multiple observations of multiple variables into the most important two dimensions, the principal components, and creates a scatterplot of the observations with the principal components acting as the *x*- and *y*-axes. For our purposes, the results of a principal components analysis have four important elements, each with its own visual representation. The first element is a table of the correlations, which can be positive (blue) or negative (red) and the closer the value is to 1.0 or -1.0, the stronger the correlation and the darker the color. On the other hand, as the value approaches 0 we can say the variables are negligibly correlated and the colors in the table become whiter. The second element is a test of the statistical significance of the correlations. If the correlation exhibits a less than 5% probability of occurring by chance ($p < 0.05$) it is statistically significant. The third element is a chart of the principal components' amount of variance captured, i.e., the eigenvalue of the eigenvector, ranked from largest to smallest. The chart also shows the proportion of the total variance captured by each component and the cumulative variance captured with the addition of each successive component. The fourth element is the scree plot, which shows the same data as the components chart in bar graph form. The scree plot can help visualize the importance of the components and the quality of the analysis. In a robust analysis, the first two components should capture the majority of the total variance within the data. The final element is the biplot. The biplot is a scatterplot with PC1 as the x-axis and PC2 as the y-axis. Vector arrows radiate from the origin, one for each variable. The vector indicates the direction (eigenvector) as well as the strength of the "pull" of that variable (eigenvalue), which is illustrated by the length of the arrow. The angle between two vectors indicates the character of their correlation. If the two vectors make a 90° angle, they are not correlated. An acute angle indicates a positive correlation, and an obtuse angle indicates a negative correlation. The more acute or obtuse the angle, the stronger the correlation is. The observation points are the individual samples and the closer they are, the more similar they are. Similar observations may form clusters. In this case, the clusters indicate each of their constituent members have vegetation communities with similar compositions of the measured vegetation types.

Multivariate analyses, such as PCA, can be performed on either cardinal or relative values. A cardinal value is the actual number of phytoliths observed in a vegetation category. A relative value is how large the cardinal value of the phytoliths in a vegetation category is as a proportion of the total phytoliths counted in a sample. For example, sample MS1 has a cardinal value of 262 festucoid phytoliths, which translates to a relative value of 98.1% of all the phytoliths counted in MS1. Using relative values creates better comparisons between samples (Powers-Jones and Padmore 1993; Kerns et al. 2001) when total counts differ, as they do in this dataset. If all samples had the same total count (e.g., 200), the cardinal values and relative values would obtain identical comparisons between samples, rendering analyses of relative values redundant. I performed PC analyses on the dataset using both cardinal values and relative values.

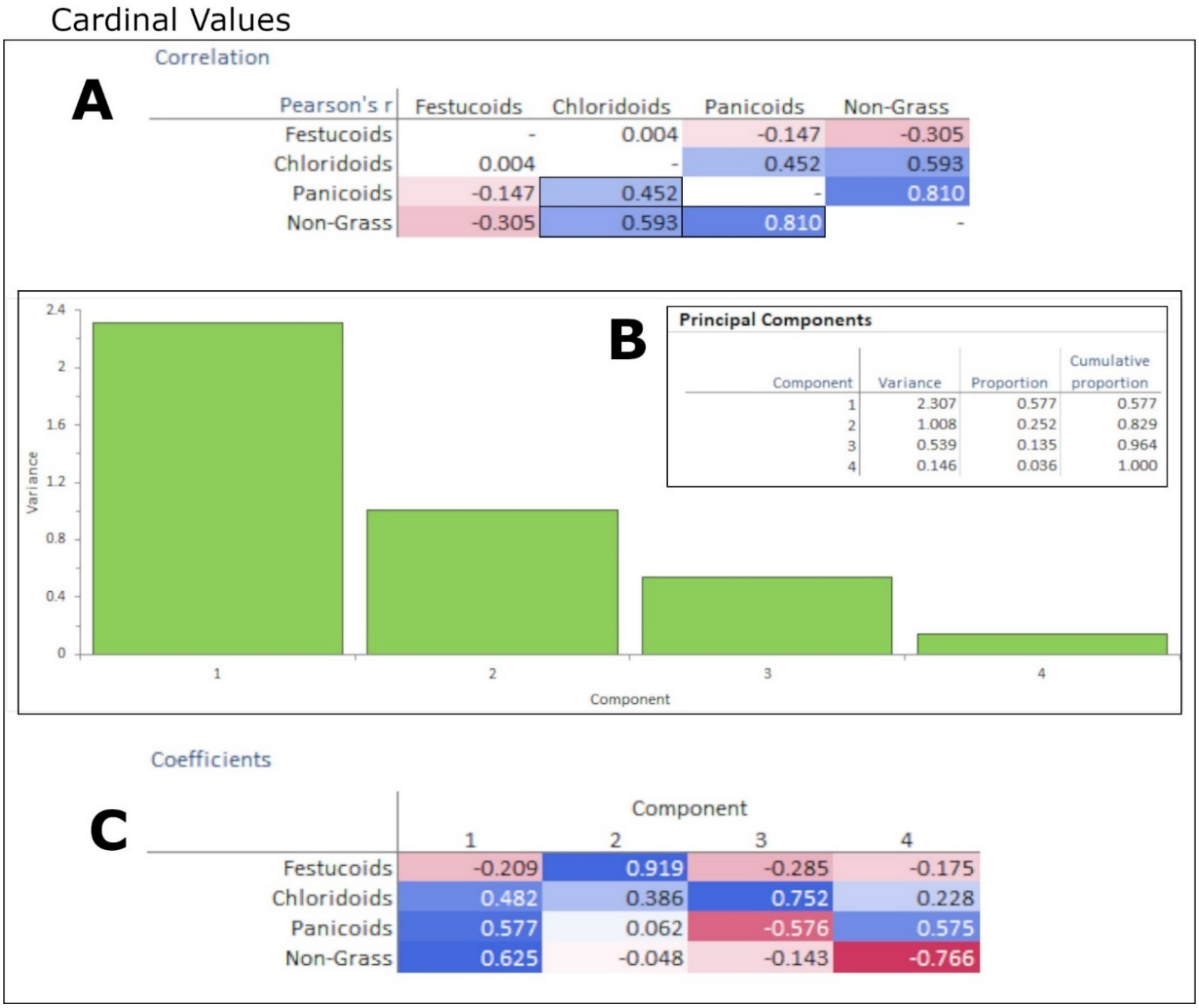
5.6.1 Preparing the data for analysis

Though my dataset consists of morphotype observations, I aggregated these morphotypes into several vegetation type categories. Thus, the dataset can be divided into two datasets, a morphotype set and a vegetation type set. I initially ran PCA on both datasets but came to the realization that, in my particular circumstances, PCA is better confined to the vegetation type dataset rather than the morphotype dataset. When morphotypes can be linked to species or genera, PCA can reveal much about the composition of vegetation communities. As previously discussed, there is just not enough information on the phytoliths of the species of the Canadian Great Plains, especially non-grass species, to currently make anything other than broad statements. I chose the morphotypes specifically to obtain as much information as possible on grassland and woodland, non-grass vegetation communities. The only morphotypes capable of providing data at the species level are those in the forest indicator category. Unfortunately, of these the only morphotype I observed is poorly constrained to a single species and in fact is produced by several species of conifer as well as by some grass species (Bozarth 1993). Faced with this reality, I confined the application of PCA to the vegetation type dataset.

When I came to run the PCA, I needed to optimize the dataset and account for the several problematic morphotypes discussed above. The three non-grass morphotype categories, woody dicots; woody and herbaceous dicots, conifers, and ferns; and forest indicators, all include morphotypes of woody vegetation or woodland-associated vegetation. I combined these categories into a single, new non-grass category. I then removed the bilobate, spherical/globular psilate and the irregular polyhedron granulate morphotypes from their respective vegetation categories. This created four vegetation categories, festucoids, chloridoids, panicoids less bilobates, and optimized non-grass. I initially thought to remove sample 3.0 from the dataset as an outlier but ultimately I decided to amend it (following Howe and Webb 1983) because of its importance as the surface sample for column 3. I amended sample 3.0 by removing the two outlier morphotypes only represented in 3.0, (1) the irregular or contorted terminally attenuated elongate, occasionally facetate, verrucate, or with processes sclereids morphotype and (2) the globular/orbicular, angulate, or irregular bodies with concentric internal laminae morphotype. I then re-integrated sample 3.0 into the dataset for the final analysis. The polyhedron favose sub-tabular morphotype was uniquely observed in sample 3.5, so I removed it from the analysed dataset as well.

5.6.2 Results – cardinal values

Figure 5.6 shows the correlations, principal components, and PC coefficients of this analysis. As we can see, the festucoid category is negatively correlated to the panicoid and non-grass categories and shows no correlation to the chloridoid category. The chloridoid category is positively related to the panicoid and non-grass categories. The panicoid category is strongly positively correlated to the non-grass category. When I tested the significance of the correlations, I found that only half were statistically significant ($p < 0.05$). While the correlations between the chloridoid, panicoid, and non-grass categories were significant, none of the correlations to the



Cardinal Values

Correlation

Pearson's r	Festucoids	Chloridoids	Panicoids	Non-Grass
Festucoids	-	0.004	-0.147	-0.305
Chloridoids	0.004	-	0.452	0.593
Panicoids	-0.147	0.452	-	0.810
Non-Grass	-0.305	0.593	0.810	-

Principal Components

Component	Variance	Proportion	Cumulative proportion
1	2.307	0.577	0.577
2	1.008	0.252	0.829
3	0.539	0.135	0.964
4	0.146	0.036	1.000

Coefficients

	Component			
	1	2	3	4
Festucoids	-0.209	0.919	-0.285	-0.175
Chloridoids	0.482	0.386	0.752	0.228
Panicoids	0.577	0.062	-0.576	0.575
Non-Grass	0.625	-0.048	-0.143	-0.766

Figure 5.6: Correlations, principal components and coefficients of the vegetation categories using cardinal values. (A) shows the correlations between the categories (significant correlations outlined); (B) is a table and scree chart in bar graph form showing the proportion of the variance carried by each principal component 1-4; (C) displays the coefficients of each principal component 1-4.

festucoid category were. This is almost certainly due to a combination of the facts that the assemblage is predominately composed of festucoid phytoliths, and that the cardinal value, the total count, is somewhat determined by the phytolith density in the last field of view. I decided to perform PCA on this data nevertheless, in order to see how such an unstable foundation would affect the analysis.

The principal components and the scree chart describe the amount of variation captured by each principal component. The first two principal components account for 82.4% of the variation in the dataset. The first principal component captures 57.2 % of the variation and the second principal component captures 25.2% of the variation. Each subsequent component captures approximately half the variation of the next higher ranked component. The fact that the first two principal components capture most of the variation signals the analysis is fairly robust.

Figure 5.7 is the PCA biplot. PC1 is the *x*-axis and describes the largest portion of the variation in the dataset. The PC coefficients indicate that the Non-Grass, Panicoid, and Chloridoid vegetation categories all have strong positive coefficients (0.623, 0.576, and 0.484 respectively) and the Festucoid category has a low negative coefficient (-0.212). Along PC1, Non-Grass, Panicoid, and Chloridoid phytoliths all exert a relatively strong and nearly equal positive or rightward influence on a sample's location. Festucoid phytoliths exert a weak negative or leftward influence.

PC2 is the *y*-axis and describes the second largest portion of the variation in the dataset. Here we see the festucoid category has a giant positive coefficient of 0.917 followed by the chloridoid category with a weaker positive coefficient of 0.390 and the panicoid and non-grass categories have negligible coefficients of 0.067 and -0.052 respectively. Along PC2 then, the festucoid phytoliths exert a massive upward or positive influence on a sample's location along the *y*-axis, as do chloridoid phytoliths but to a much lesser extent. Panicoid and Non-Grass phytoliths exert almost no influence on a sample's vertical position. Both festucoid and chloridoid phytoliths

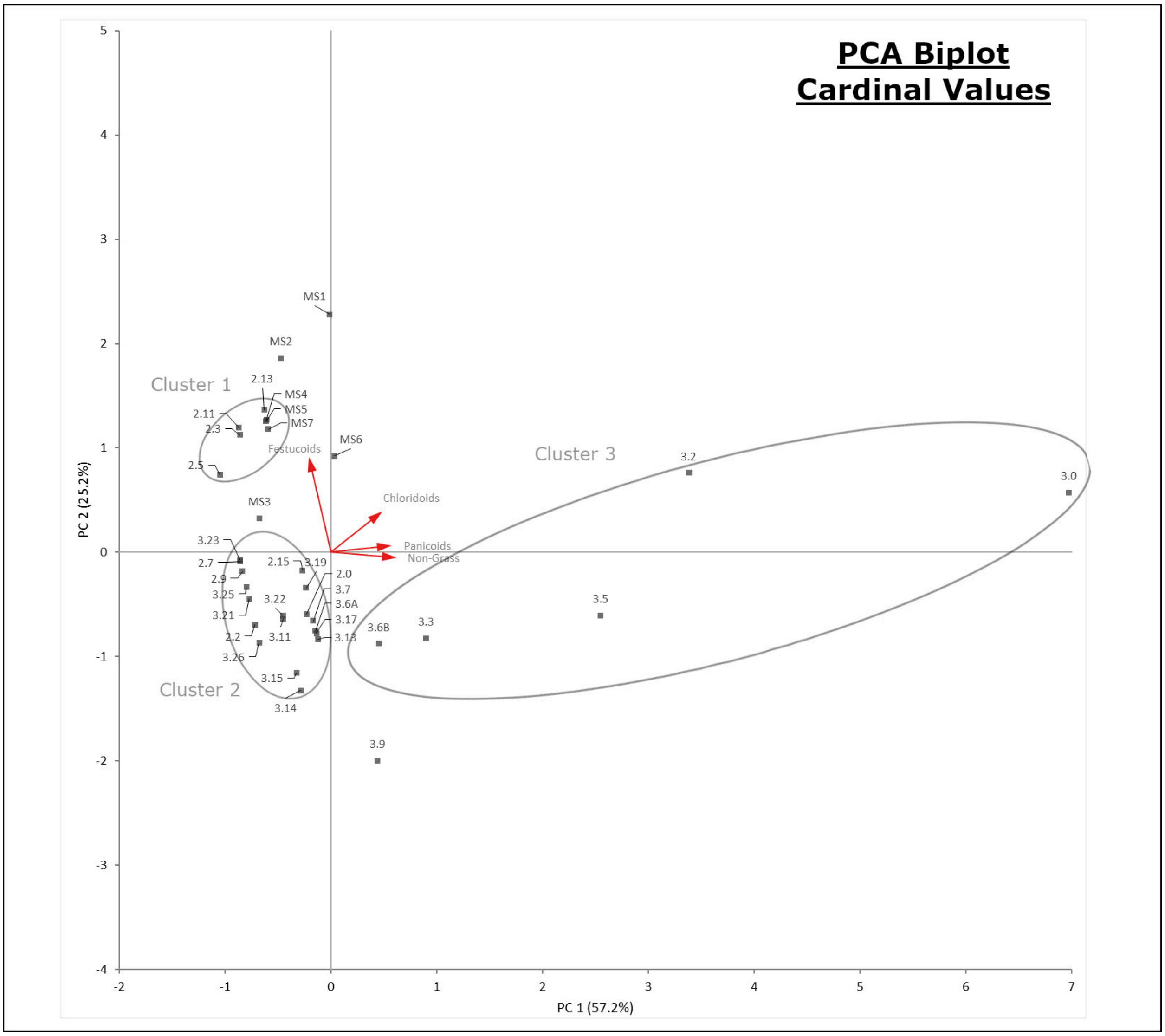


Figure 5.7: PCA biplot using the cardinal values. PC1 is the x*-axis and PC2 is the* y*-axis.*

exert some locational pressure on both PC1 and PC2. Festucoids pull strongly up and somewhat to the left, while chloridoids pull with nearly equal pressure both up and to the right.

Now that we understand the locational forces of each vegetation category we can turn to the observation points, i.e., the samples, themselves. Most of the samples appear to be grouped in three clusters. There are also a few outlier samples that do not conform well to any specific cluster.

Cluster 1 consists of seven observations, which includes the lowland mixed grassland modern surface composite samples MS4, MS5, and MS7; and the upland depression samples 2.3, 2.5, 2.11, and 2.13. Cluster 1 samples have high amounts of festucoid phytoliths; low amounts of chloridoid phytoliths, if any; no panicoid phytoliths; and only one non-grass phytolith, if any. The cardinal D/P index values for these samples are either below 5 or non-existent, if there are no non-grass phytoliths present. All samples have an Ic index value of 99% to 100%, indicating very high levels of C3, cool climate, grasses.

Cluster 2 encompasses the highest number of observations, over half or 18 of 35 samples. Cluster 2 contains no modern composite surface samples but does contain sample 2.0, the surface sample from sampling column 2, taken from an upland depression which intermittently contains water. The other constituent samples of Cluster 2 are 2.2, 2.7, 2.9, and 2.15 from sampling column 2 and 3.6A, 3.7, 3.11, 3.13, 3.14, 3.15, 3.17, 3.19, 3.21, 3.22, 3.23, 3.25, 3.26 from sampling column 3. Cluster 2 samples have lower amounts of festucoid phytoliths; low amounts of chloridoid phytoliths, if any; and no panicoids (sample 2.0 is the outlier here, with one recorded panicoid phytolith). Cluster 2 samples have slightly more variation of non-grass phytolith counts. Eleven samples have no non-grass phytoliths, six samples have one non-grass phytolith, and one sample, 2.15, has two non-grass phytoliths. All non-grass phytoliths are the same woody dicot morphotype, globular/orbicular verrucate. All samples have high Ic values; eleven samples have a value of 100%, four samples have a value in the 99% range, and three samples have a value in the 98% range. All Ic values indicate very high levels of C3, cool climate grasses. The D/P index values (cardinal) are varied but none are high. Eleven samples have no D/P index value, six samples have a value in the 5 to 8 range (in fact five samples have a value of 5.0 and one has a value of 5.2), and one sample, 2.15, has a value of 9.3, which is above the threshold value of 8.2 that may indicate the presence of wooded vegetation and a leafy canopy.

The final cluster, Cluster 3, has no modern surface composite samples but does contain the surface sample from sampling column 3, which was taken from a wooded coulee bottom with water, including near-surface groundwater, commonly persisting through the warm, arid summer months. Cluster 3 is a loose aggregation of five widely dispersed observation points, consisting of samples 3.0, 3.2, 3.3, 3.5, and 3.6B. It is immediately apparent that all samples in Cluster 3 are from the upper levels of sampling column 3. Cluster 3 samples have festucoid counts similar to Cluster 2 and are in the bottom 50% of festucoid amounts in both the entire dataset and sampling column 3 itself. Chloridoid counts in Cluster 3 are relatively high; all samples have more than one chloridoid phytolith and three of the five samples with the highest counts are in this cluster. All the samples in Cluster 3, with the exception of 3.6B, have panicoid phytoliths and, indeed, comprise four of the five total samples in the entire dataset with recorded panicoid phytoliths. All the samples in Cluster 3 have high non-grass phytolith counts, including morphotypes other than the woody dicot globular/orbicular verrucate morphotype. The three samples with the highest counts of non-grass phytoliths are members of Cluster 3. The samples in Cluster 3 have the lowest Ic values in the entire dataset, indicating a higher proportion of warm climate C4 grasses than in any other vegetation community type. The D/P index values (cardinal) of all the samples in Cluster 3 are well above the 8.2 threshold indicating wooded vegetation and leafy canopy.

There are five samples that do not fit well into the three clusters, MS1, MS2, MS3, MS6, and 3.9. MS1, MS2, and MS3 are all modern surface composite samples collected from the upland prairie grassland. MS6 is the modern surface composite sample collected from a wooded coulee bottom with a leafy canopy. Sample 3.9 is from 53-48cmbs, about 2/3 up from the base of sampling column 3.

MS1 and MS2 are very similar to the samples in Cluster 1; they have high festucoid counts and no panicoid morphotypes. They have no non-grass phytolith morphotypes and, hence, no D/P values. On the other hand, MS1 and MS2 have much higher chloridoid counts, which is also reflected in their respective Ic index values of 98.13% and 98.86%.

MS3 is also very similar to the samples in Cluster 1 and to MS1 and MS2 but has lower festucoid phytolith counts than any of them and much lower chloridoid counts than the other upland modern surface composite samples.

MS6 is a modern surface composite sample from a wooded coulee bottom with a leafy canopy, most similar to the setting of sample column 3. MS6 has relatively high chloridoid and non-grass counts comparable to samples 3.3 and 3.6B and lacks any recorded panicoid phytoliths, as does sample 3.6B. MS6 has a much higher festucoid count than any of the Cluster 3 samples, however.

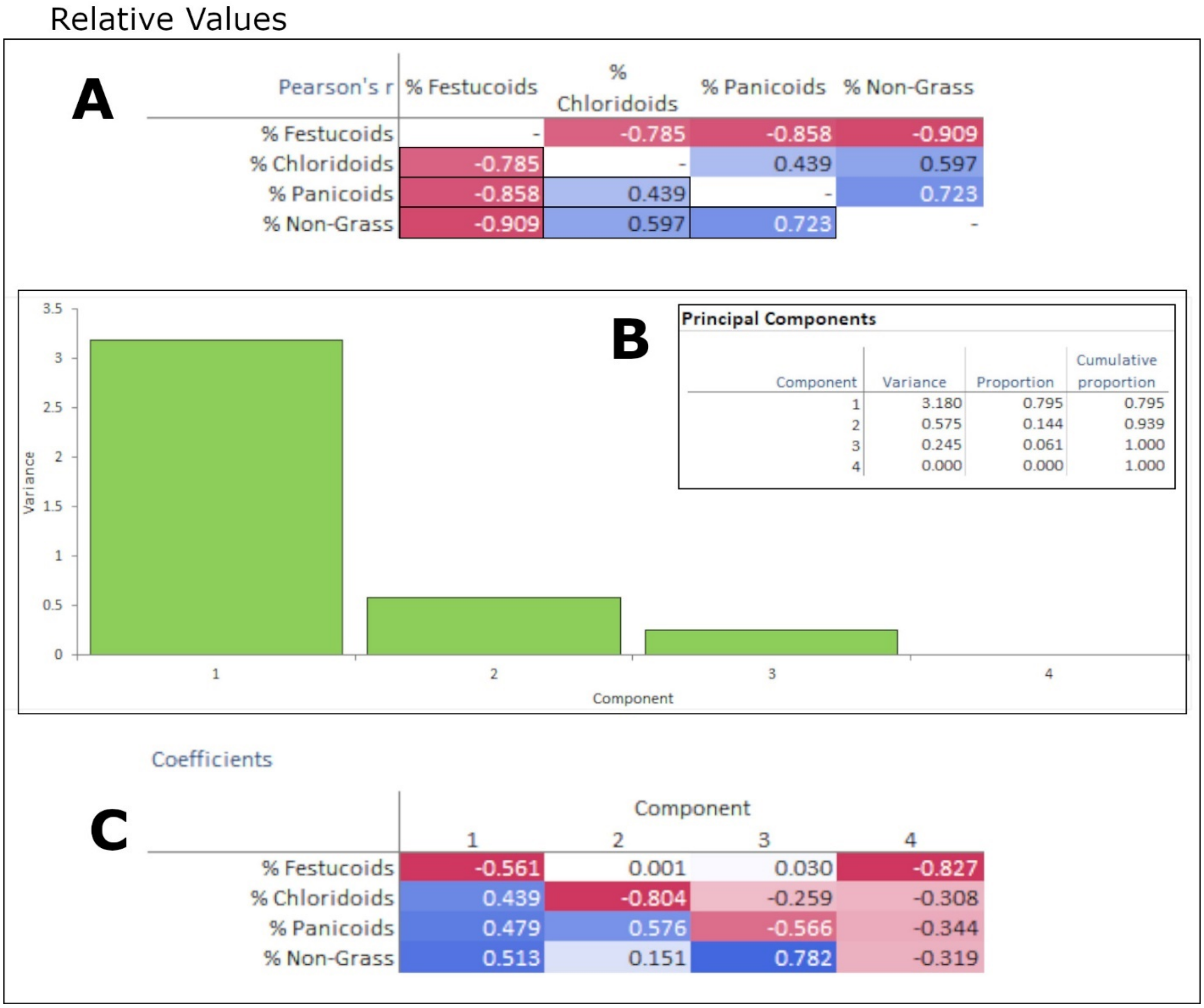
Sample 3.9 has no recorded panicoid or chloridoid phytoliths but has the fourth highest non-grass phytolith count and the lowest festucoid count in the entire dataset. Sample 3.9 is closest in similarity to the samples in Cluster 3 and, in fact, I originally included it in Cluster3 before I decided to remove it based on its position in the biplot.

To summarize the cardinal values PCA results, there appear to be three clusters and five outliers. However, any conclusions drawn from false premises will likewise be false. In order to obtain a significant and robust analysis from cardinal values, a stable constraint is required. This stability is usually provided by constraining the counted phytoliths to an arbitrary number – usually around 200 – consistent across all samples. When each sample contains the same number of counted phytoliths, then comparisons can be made between samples. Without such a constraint, distortions occur and comparisons between samples become vague, if not impossible. In this case, the significance test reveals the correlations between the festucoids, and the other categories are ruled by chance rather than an actual relationship. That is, a rise or fall in the number of festucoid phytoliths observed has nothing to do with a rise or fall in the number of phytoliths observed in any other category. We can observe this distortion in the PCA biplot above. The samples 2.5, 3.23, 2.7, 2.9, 3.25, 3.21, 2.2, and 3.26 create a line parallel to the festucoid vector because their observed assemblages are composed entirely of festucoid morphotypes. If the count was consistent between samples, say 200 counted phytoliths, then this line would become a single point as each sample with only festucoid phytolith observations would all have exactly 200 festucoid phytoliths counted. This distortion affects all the sample assemblages because all samples contain large numbers of festucoid morphotypes. Without a stable foundation no robust conclusions can be drawn from my cardinal values using PCA and any clusters observed within such an analysis become suspect.

5.6.3 Results – relative values

The final Principal Components Analysis uses relative values based on each category's proportion of the total. Because the sum of the relative values of each of the four vegetation categories used in this study will always equal 100%, robust comparisons between samples become possible where they were not in the previous PCA, which used cardinal values without a consistent count total. This analysis of relative values accounts for 93.9% of the variation in the dataset.

Figure 5.8 shows the correlations, principal components, and PC coefficients of this analysis. The correlations chart shows the festucoid category is strongly negatively correlated to all other categories. The other three categories are all positively correlated to each other. A significance test indicates all correlations are statistically significant ($p < 0.05$). The principal components and the scree chart bar graph describe the amount of variation captured by each principal component. The first principal component captures 79.5% of the variation and the second principal component captures 14.4% of the variation. The third principal component accounts for all the



Relative Values

A

Pearson's r	% Festucoids	% Chloridoids	% Panicoids	% Non-Grass
% Festucoids	-	-0.785	-0.858	-0.909
% Chloridoids	-0.785	-	0.439	0.597
% Panicoids	-0.858	0.439	-	0.723
% Non-Grass	-0.909	0.597	0.723	-

B

Principal Components

Component	Variance	Proportion	Cumulative proportion
1	3.180	0.795	0.795
2	0.575	0.144	0.939
3	0.245	0.061	1.000
4	0.000	0.000	1.000

Coefficients

C

	Component 1	2	3	4
% Festucoids	-0.561	0.001	0.030	-0.827
% Chloridoids	0.439	-0.804	-0.259	-0.308
% Panicoids	0.479	0.576	-0.566	-0.344
% Non-Grass	0.513	0.151	0.782	-0.319

Figure 5.8: Correlations, principal components and coefficients of the vegetation categories using relative values. (A) shows the correlations between the categories (all are significant); (B) is a table and scree chart in bar graph form showing the proportion of the variance carried by each principal component 1-4; (C) displays the coefficients of each principal component 1-4.

remaining 6.1% of the variation. The fact that the first two principal components capture most of the variation signals the analysis is fairly robust.

Again, the coefficients table informs us how each vegetation category is represented on the principal component axes. On PC1, the festucoids category has a fairly strong negative coefficient (-0.561) and the chloridoids (0.439), panicoids (0.479), and non-grass (0.513) categories all have positive coefficients of strengths similar to each other and the festucoids category. When we look at the vectors in the PCA biplot (Figure 5.9) we see the festucoids category pulling to the left, negative side of the origin and the other three categories all pulling to the right, positive side of the origin. This PC appears to capture a festucoid versus non-festucoid dynamic.

On PC2, the festucoids category (0.001) has a coefficient as close to zero as is possible. The non-grass category (0.151) has a weakly positive value, the panicoids category (0.576) has a strongly positive coefficient and the chloridoids category (-0.804) has a very strongly negative coefficient. This PC appears to capture a panicoids versus chloridoids dynamic.

PC3 only accounts for 6.1% of the variation and the relevant categories are non-grass (0.782) and panicoids (-0.566). This PC appears to capture a non-grass versus panicoids dynamic.

In this analysis clusters are somewhat difficult to define. Most of the sample points are to the left of the origin and appear to extend in three rays from a single top-left point (Figure 5.10). The several remaining points are to the right of the origin and offset from the three rays. The top-left point is in fact eight overlapping sample points, 2.2, 2.5, 2.7, 2.9, 3.21, 3.23, 3.25, and 3.26, in which I observed only festucoid morphotypes. The top ray running up and to the right from the top-left point to the sample 3.9 point are all samples with observations of festucoid and non-grass morphotypes only. The left ray running down and to the right from the top-left point to sample MS1 are all samples with observations of festucoid and chloridoid morphotypes only. The last ray is between the first two and also runs down and to the right from the top-left point to sample 3.6B. These samples have observations of festucoid, chloridoid, and non-grass morphotypes but no panicoid types. The remaining five samples, 2.0, 3.0, 3.2, 3.3, and 3.5, are not aligned with any other samples. Sample 2.0 is the only sample to have observations of all three grass types and no non-grass morphotypes. Samples 3.0, 3.2, 3.3, and 3.5 are the only four samples to have observations of morphotypes in all four vegetation categories.

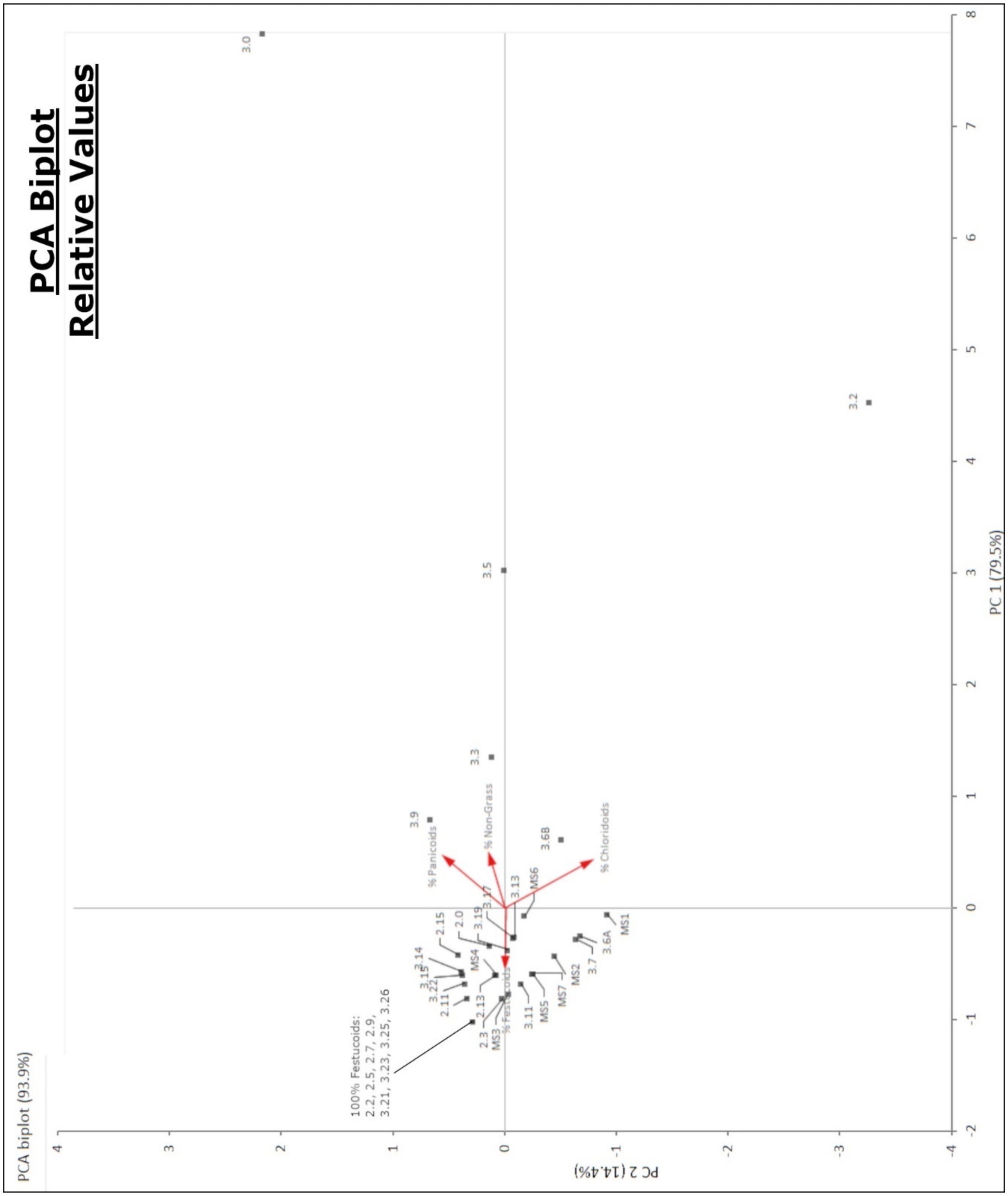


Figure 5.9: PCA biplot from the relative values.

Whether these rays are clusters or not is debatable. I prefer to interpret the data as two gradients of vegetation communities, an open grassland gradient and a mixed grass/woody vegetation gradient. Furthermore, we can interpret the sample points as either two or three groups and one outlier. If we divide the observations into two groups, each group has 17 samples each. The first group consists of the top left point and the left ray and encompasses samples MS1, MS2, MS3,

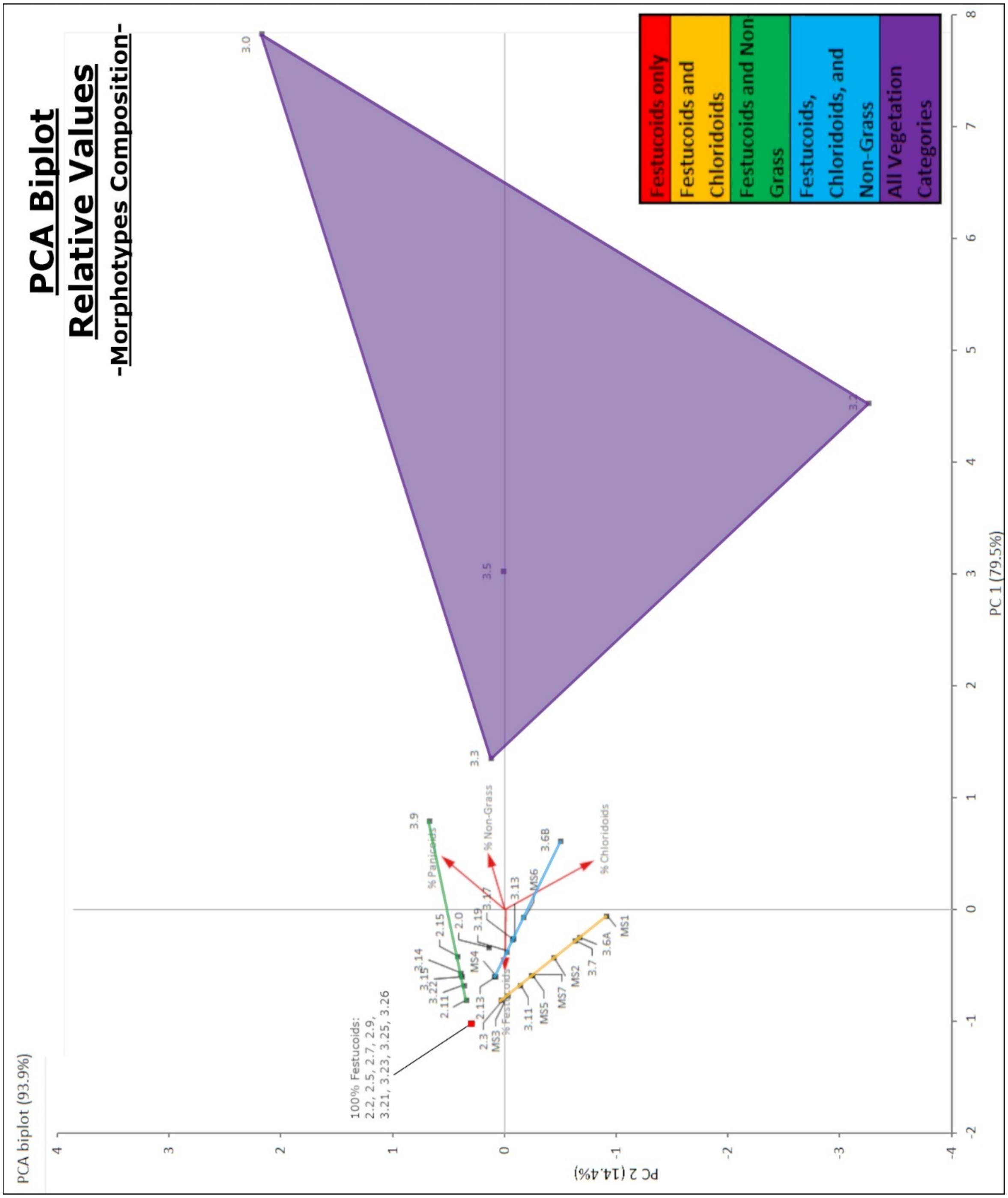


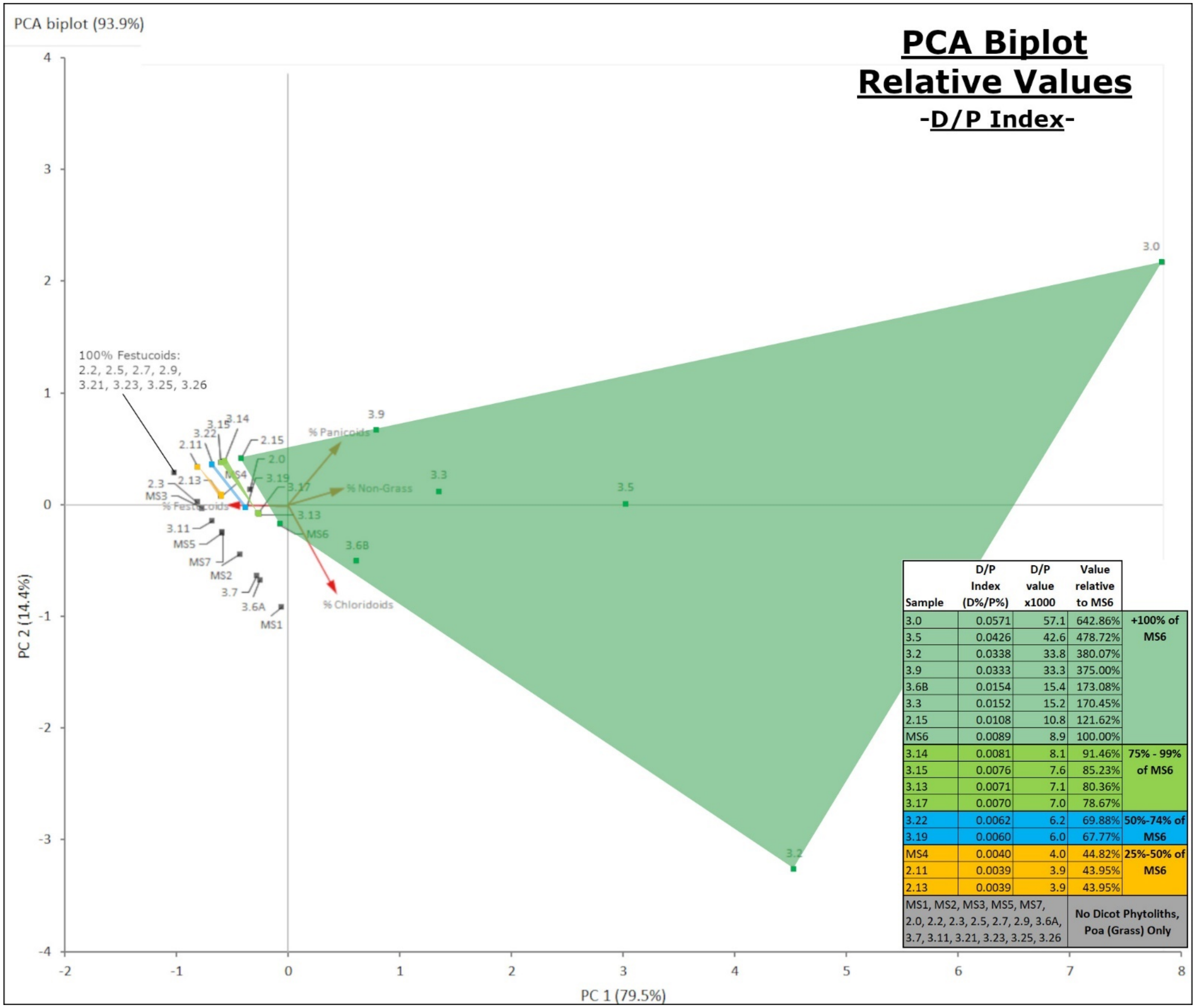
Figure 5.10: Composition of the assemblages by vegetation category overlain on the relative values PCA biplot.

MS5, MS7, 2.2, 2.3, 2.5, 2.7, 2.9, 3.6A, 3.7, 3.11, 3.21, 3.23, 3.25, and 3.26. This group is the grassland gradient representing completely open grassland, dominated by festucoid species and with a chloridoid component ranging from none to 1.87% (MS1). The second group is all the remaining samples, except sample 2.0, and encompasses samples MS4, MS6, 2.11, 2.13, 2.15, 3.0, 3.2, 3.3, 3.5, 3.6B, 3.9, 3.13, 3.14, 3.15, 3.17, 3.19, and 3.22. This group is a mix of grass and woody species exhibiting a gradient of vegetation from mostly open grassland with sparse woody vegetation on the left to enclosed leafy canopy on the right.

We can split this latter single group into two groups if we demarcate between samples with a lower proportion of non-grass observations than sample MS6 and those with more. Sample MS6 was collected from a location with trees and a leafy canopy, therefore it may provide a good threshold value for such a vegetation community. The group with a proportion of non-grass phytoliths higher than or equal to MS6 encompasses samples MS6, 2.15. 3.0, 3.2, 3.3, 3.5, 3.6B, and 3.9. The group with a proportion of non-grass phytoliths lower than MS6 consists of samples MS4, 2.11, 2.13, 3.13, 3.14, 3.15, 3.17, 3.19, and 3.22.

Using relative values changes the D/P index somewhat. The positions of the samples in the leafy canopy group, which all have values higher than MS6, remain the same. The samples with values lower than MS6 exhibit a number of position changes in the ordination, most notably samples 3.14, 3.15, 3.13, and 3.17. These samples previously had values 50%-74% of MS6 but now have values in the 75%-99% range. When we juxtapose these D/P values on the PCA scatterplot (Figure 5.11), we see a woody vegetation gradient emerge rather than the more disorderly groupings of the cardinal values PCA. The use of relative values creates a more coherent and finer-grained ordination of the samples within the D/P index than do the cardinal values.

The Ic index yields exactly the same values with both relative and cardinal counts because the proportion of festucoids relative to the total grass assemblage is identical. As with the D/P index, the projection of the Ic values onto the relative PCA scatterplot describes a gradient of C3/C4 grasses in a more coherent manner than the cardinal PCA (Figure 5.12). The other indices, Iph and Fs, remain impoverished of sufficient datapoints to elucidate any patterns.



Sample	D/P Index (D%/P%)	D/P value x1000	Value relative to MS6	
3.0	0.0571	57.1	642.86%	+100% of MS6
3.5	0.0426	42.6	478.72%	
3.2	0.0338	33.8	380.07%	
3.9	0.0333	33.3	375.00%	
3.6B	0.0154	15.4	173.08%	
3.3	0.0152	15.2	170.45%	
2.15	0.0108	10.8	121.62%	
MS6	0.0089	8.9	100.00%	
3.14	0.0081	8.1	91.46%	75% - 99% of MS6
3.15	0.0076	7.6	85.23%	
3.13	0.0071	7.1	80.36%	
3.17	0.0070	7.0	78.67%	
3.22	0.0062	6.2	69.88%	50%-74% of MS6
3.19	0.0060	6.0	67.77%	
MS4	0.0040	4.0	44.82%	25%-50% of MS6
2.11	0.0039	3.9	43.95%	
2.13	0.0039	3.9	43.95%	
MS1, MS2, MS3, MS5, MS7, 2.0, 2.2, 2.3, 2.5, 2.7, 2.9, 3.6A, 3.7, 3.11, 3.21, 3.23, 3.25, 3.26				No Dicot Phytoliths, Poa (Grass) Only

Figure 5.11: D/P index values overlain on the relative values PCA biplot.

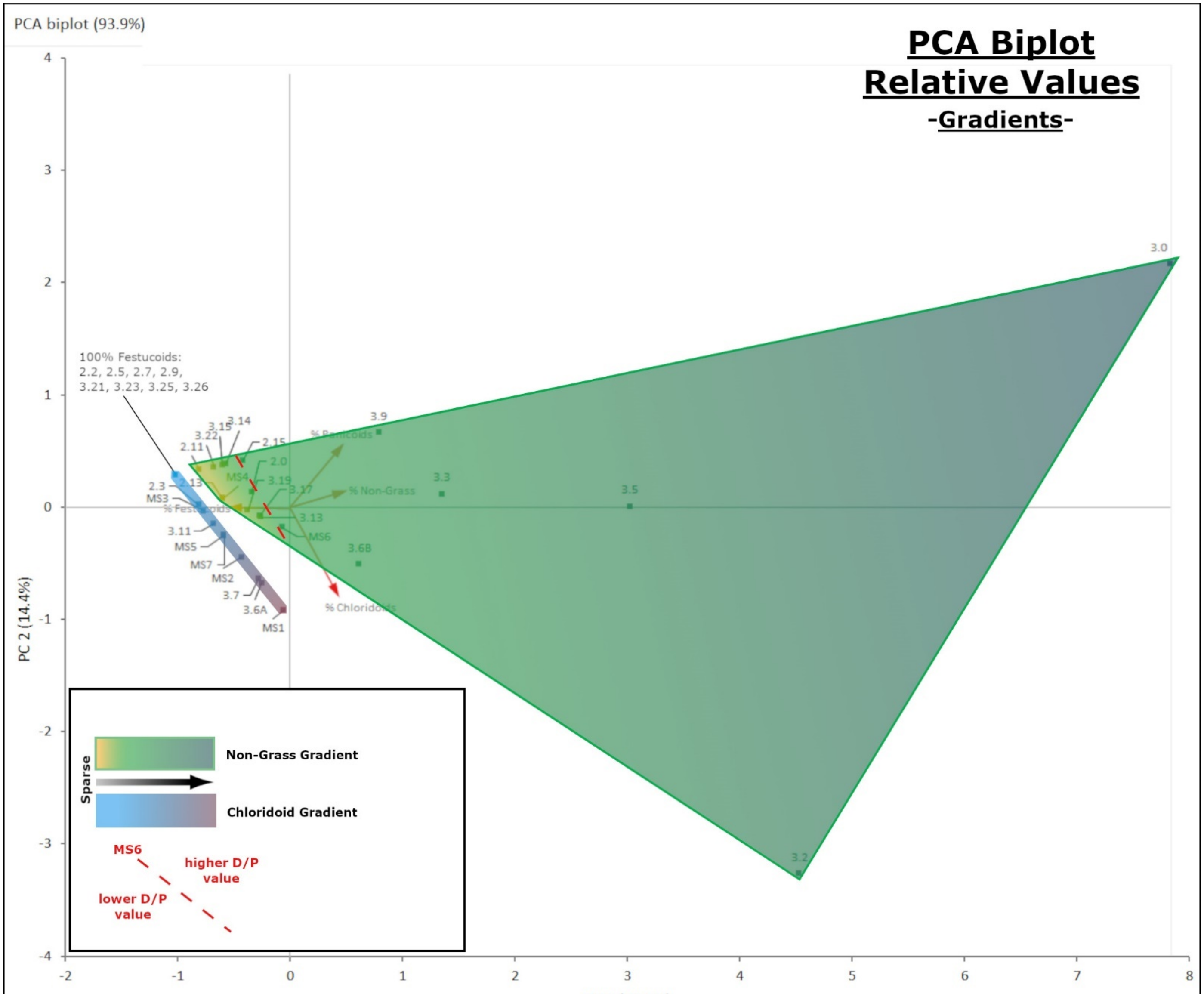


Figure 5.12: Integrating the composition and environmental indices data a picture of two gradients emerges. Moving away from a base point of a cool climate open grassland assemblage, one gradient indicates increasing woody vegetation and the other indicates warmer temperatures.

Sample 2.0 is the only outlier, residing in the space between the enclosed leafy canopy points and the less dense woody vegetation points. The panicoid vector places the point in this space. Sample 2.0 is the only sample with a panicoid morphotype observation without a non-grass (woody vegetation) morphotype observation as well. Interestingly, because sample 2.0 is a surface sample, we know that there are in fact woody shrubs on the outside edge of the upland depression within 50m of where sampling column 2 was taken.

To summarize the relative values PCA results, there are two gradients and one outlier. One gradient moves from phytoliths entirely of C3 grasses to phytoliths of a mix of C3 and warm-arid C4 grasses. The second gradient is a range of mixed assemblages of phytoliths of woody vegetation and grasses (but still overwhelmingly composed of festucoid morphotypes) grading from a low proportion to a relatively high proportion of phytoliths of woody vegetation. The outlier lies within the space of the second gradient but does not fit well into it.

It appears clear to me that using relative values does indeed create a more accurate analysis of the dataset. If I had counted to exactly the same number of phytoliths for each sample, this would have had the same effect. I ran a test PCA on the dataset in which I calibrated the cardinal values to equal 200 and have the same proportions as in the relative values PCA. This illustrative analysis was naturally an exact copy of the relative values PCA detailed above.

5.7 Conclusions

In this chapter I detailed the results of this study. I reported the various morphotypes I observed then analysed the phytolith assemblages in several ways. I checked for indicator morphotypes of certain woodland vegetation communities.

The phytolith assemblage is dominated by cool-climate C3 festucoid morphotypes. Morphotypes of C4 chloridoid grasses that prefer a warmer, arid environment are a much smaller proportion of the assemblage. Morphotypes of C4 panicoid grasses that prefer a warmer and moist environment are very rare. Non-grass morphotypes of woody and herbaceous dicots are also a small proportion of the assemblage. The orbicular/globular verrucate morphotype is the most common non-grass morphotype. The conical morphotype of sedges encompasses the second highest proportion of the assemblage after festucoids. Sedges and festucoids show a strong negative correlation that is statistically significant. I removed five morphotypes from inclusion in further analyses, including three outliers observed only once in any sample; the orbicular/globular psilate non-grass morphotype because it failed to exhibit the strong correlation to woody vegetation is shows in tropical phytolith assemblages; and the irregular polyhedron granulate morphotype because the three observations were all misidentifications of the morphotype. I also observed what are most likely Asteraceae phytoliths, two species of diatom, and another unidentified biogenic silica body. I did not observe any phytoliths indicating specific vegetation communities except the irregular polyhedron psilate morphotype, which is characteristic of conifers but not confined to them.

I used the phytolith observations in four environmental indices. The Iph aridity index relies on the relationship between panicoids and chloridoids, but I observed so few panicoids that the index lost much of its interpretive precision beyond indicating the climate has been generally arid throughout the investigated timeframe. The Fs water stress index relies on the proportion of cuneiform bulliform morphotypes in the assemblage, but I observed so few of these morphotypes that the index has little to no interpretive power, or there was no water stress due to the wetland nature of the sampling locations. The Ic climate index returns extremely high proportions of festucoids relative to the sum of the chloridoids and festucoids, which indicates a cool climate. The D/P forest-grassland index returns very low values in the 17 of the 35 samples that have non-grass morphotypes. Several of the samples returned D/P values within the range of those measured from data in Bozarth's (1993) investigations into phytolith assemblages in the aspen-parkland and boreal forest of Saskatchewan and Manitoba.

In analysing the principal components of the samples, I found PCA was more effective using the vegetation categories rather than the morphotypes themselves. I also found using relative (proportional) values created a more precise analysis than using cardinal values. This was due entirely to how I counted the phytoliths during microscopy. The PCA revealed two groupings of samples. One group of samples has assemblages consisting entirely of festucoid and chloridoid grass phytoliths. These assemblages are dominated by festucoids, in fact, some are entirely festucoids. The samples in the other group are also dominated by grass phytoliths but contain non-grass phytoliths as well. Based on D/P values with the modern surface sample MS6 as the threshold value, this group may be divided into two groups, one with D/P values lower and one with values higher than MS6. The former group has a relatively sparse proportion of non-grass morphotypes, while the latter has a relatively dense proportion of non-grass morphotypes.

In the next chapter I will draw together all these lines of evidence to craft an account of how the local vegetation communities change through time for both sampling-column locations and how this may relate to changes in the local and regional environments.

Chapter 6

Discussion

In the previous chapter, I presented the results of the morphotypes scan and quantified the data into both cardinal and relative values so sample assemblages could be compared. Comparing assemblages against each other places them into relationships with each other. I investigated these relationships using morphotypes data, environmental indices, and principal components analysis.

In this chapter, I explore what the analyses mean, and I reconstruct three basic paleovegetation community types based on my interpretations. I interrogate the data within a chronological framework. I place the results of this study into the wider regional paleoenvironmental context as well as the context of phytolith research in the Canadian Prairie Provinces. I discuss issues I encountered during the course of my research, aspects of the research design I would approach differently with hindsight, and directions for future research.

6.1 Exploring the principal components and reconstructing the paleovegetation

The purpose of a PCA is to take data with multiple variables, determine the significant relationships among them and find the most important dynamics (a dynamic is when at least two but sometimes more variables are placed in tension against each other) within the relationships. The PCA biplot (Figure 5.9 above) is a visual representation of the two most important dynamics, which become the *x*- and *y*-axes, and how much each observation (each sample assemblage) is affected by those two dynamics, as represented by the position of each observation along each axis. The vectors in the biplot show the relationships of the variables (the vegetation categories) to the observations. The occurrence of clusters illustrates which observations are similar to each other and which are not.

While the PCA finds and illustrates the relationships of the observations to the variables, the dynamics, and each other, it does not explain them or what causes them. Once the PCA is performed, the task of the researcher is to explain what the main dynamics are and what causes them. To do that requires outside knowledge of what the observations are reporting and what forces cause the changes in the variables. In this case, what the modern vegetation communities are and how changes in the environment spur the changes in each vegetation category.

In section 5.6.3 above I described the three principal components which account for all the variance in the analysis. These three PCs represent three dynamics. The first dynamic, expressed along the *x*-axis, has the festucoid category in tension against the other three categories. This dynamic would seem to merely describe the proportion of the assemblage composed of festucoid morphotypes, ranging from 100% to 83.2%. The remainder is made up of the other three categories, none of which appears to be more important than the others in describing the variance, given how similar the coefficient values of each are to the other two. But there must be something occurring to diminish the proportion of festucoid phytoliths.

I think PC1 captures a cooler vs warmer climate dynamic. If festucoid grass is clearly a main player in the dynamic, then it seems reasonable that the tension is between it and the other grass sub-families. Both the chloridoid and panicoid sub-families are warm-season grasses. If morphotypes of these sub-families are a larger proportion of an assemblage, then it would seem to indicate warmer conditions as well. Thus, this climate dynamic is expressed as cooler temperatures to the left and warmer temperatures to the right along the *x*-axis. The woody vegetation complicates matters, but it may be that warmer temperatures provide or coincide with better conditions for woody vegetation as well.

The main actors in PC2 are chloridoids and panicoids. Both are warm-season, C4 grass sub-families but chloridoids prefer arid conditions while panicoids prefer moist conditions, so it would seem the dynamic is one of decreased or increased moisture. On the *y*-axis, moving upwards indicates increasing moisture.

The third dynamic is on PC3 which I did not include in the biplot because it captures very little of the variance in the dataset. This dynamic is a tension between the warm-season grass component, most importantly the panicoid sub-family, and the non-grass woody vegetation component. The cause of this dynamic is unclear because the woody vegetation species have more variable behaviours, and because it is unclear which woody species are most important in this dynamic.

The locations on the PCA biplot of the observations of modern surface composite sample phytolith assemblages (MS) and the topmost sample assemblages from each sampling column (2.0 and 3.0) are the only points where the vegetation community is known. These MS samples provide the datum points against which the fossil sediment phytolith assemblages are compared. When a fossil assemblage observation lies close to one of these, or several fossil assemblage observations form a cluster near one, we consider the modern vegetation to be analogous to the paleovegetation. When observations lie farther away, the vectors and other data are needed to indicate in what way the paleovegetation differs from the closest modern analog.

In this study, there are so many festucoid phytoliths and so few phytoliths of the other categories that often one or two vegetation categories were entirely empty of morphotype observations. This caused similar observations to create rays rather than clusters in the PCA biplot. The few with all four variables were less confined or unconfined to those rays. If all observations encapsulated more than three variables – if they contained morphotypes in all vegetation categories or if more variables were introduced, such as a robust sedge category and non-grass categories related to specific families – then the observations would form clusters of like assemblages rather than rays. Nevertheless, and whether organized in rays or clusters, in order to refine interpretations beyond mere similarities and gain a better understanding of the factors at play it is necessary to integrate modern analogs, morphotype composition and environmental index data with the PCA.

The modern analog samples include all the MS samples and samples 2.0 and 3.0 from the tops of the sampling columns. All the MS samples, except for MS6, were collected from open grasslands. With the exception of MS4, all these MS samples show only grassland vegetation with a varying mix of festucoid and chloridoid grasses. The chloridoid proportions and the difference between the extremes is small, ranging from MS1 with 1.9% chloridoids to MS3 with 0.5% chloridoids. Only four fossil sediment samples (2.3, 3.11, 3.7, and 3.6A) have similar assemblage compositions indicating a similar vegetation community of mostly cool-climate open grassland mixed with a small proportion of warm-season grasses, probably based on hyperlocal conditions. It seems fitting to include the eight sediment sample assemblages (four from each sampling column) with only festucoid phytoliths as well to this group to create a pure grassland group exhibiting a gradient of cool-season only to mixed cool and warm-season grasses. These last eight would appear to indicate time periods with a cooler climate than modern. The sampling column assemblages in this grassland group would also indicate more arid conditions than modern since both sampling columns are in wetland locations.

Samples MS4 and MS6 have non-grass woody vegetation morphotypes as well as festucoid and chloridoid grass morphotypes. MS4 was collected from a lowland grassland 60m from ravine #5 and MS6 was collected from a riparian vegetation community with trees, shrubs, forbs, and grasses inside ravine #5. Samples 2.13, 3.19, 3.17, 3.13 and 3.6B have similar compositions. Because MS6 and MS4 are different vegetation communities this group is very confusing if we only look at the modern analogs. This is a situation where bringing in environmental index data helps. The D/P index quantifies woody vegetation communities by measuring the ratio of woody morphotypes to grass morphotypes. The MS6 D/P value describes the lowest D/P value for a known woody vegetation community in the study (sample 3.0 is the only other). In this case, the conservative interpretation is that the samples with a D/P value less than MS6 are also less wooded and closer to MS4. Thus, I interpret samples 2.13, 3.19, 3.13, and 3.17 as relatively to completely open grassland with woody vegetation of light to moderate density at the location or of higher density nearby, depending on how high the D/P value is.

Sample 3.0 was collected from the top of sampling column 3 inside ravine #5 in a riparian community of trees, shrubs, forbs, and grasses. It does not plot near any other observation on the PCA biplot. When we look at morphotype composition, 3.0 has morphotypes from all four vegetation categories, a trait it shares with only three other samples (3.2, 3.3, and 3.5), which are also the closest points to 3.0. The Ic index, which measures the proportion of festucoids in the grass component, shows these four have the lowest values, indicating the warmest climate conditions. The D/P index shows all four have values higher than MS6, indicating a woodland vegetation community.

Sample 2.0 is the only assemblage with morphotypes from all three grass sub-families but no non-grass morphotypes. Although 2.0 is located on the PCA biplot near many other observations, the fact that it is not on a ray and has a unique morphotype composition separates it from its neighbours.

This leaves the observations composing the top ray (2.11, 3.22, 3.15, 3.14, 2.15, and 3.9), which includes no modern analogs. The morphotype composition shows these only have festucoid and woody non-grass morphotypes. The D/P index is the only applicable environmental index because the other three indices require chloridoid, panicoid, or cuneiform bulliform phytoliths not present in these samples. Samples 2.15 and 3.9 have values higher than MS6, indicating a woodland vegetation community. The other four have values between MS6 and MS4, indicating vegetation communities of relatively to completely open grassland with woody vegetation of light to moderate density at the location or of higher density nearby, depending on how high the D/P value is.

By combining all the analyses and data I was able to create interpretations of the paleovegetation from the sampling columns. Based on these interpretations I determined there are three basic, broadly defined paleovegetation community types, open grassland communities, variable density mixed grass and woody vegetation communities, and dense woodland communities. Open grassland communities are always dominated by cool-season festucoid grasses but can include arid warm-season chloridoids and mesic warm-season panicoids, depending on climate and precipitation conditions. Variable density mixed grass and woody vegetation communities have a grass component dominated by festucoid grasses, but which can also include chloridoids (though none include panicoids), and a woody component probably ranging from sparse short shrubs on location or more dense shrubs/trees nearby to moderately dense tall shrubs or sparse trees on location. The final community is a dense riparian woodland of trees, tall shrubs, forbs, and both cool-season and warm-season grasses. These communities blend into each other and form a gradient from open, cool-climate grassland to warm, moist, dense riparian woodland. The phytolith assemblages change as the vegetation communities shift within this gradient through time.

6.2 Trends over time

Now that we have our data on each vegetation type (Festucoids, Chloridoids, Panicoids, and Non-Grass, as well as Asteraceae) and useful environmental index data on tree cover and climate, we can observe how these variables are expressed in the present in the modern surface composite samples and how they change over time in the sampling columns. Below I describe the modern surface composite sample assemblages and environmental index values. For each sampling column, I examine how the values of each vegetation category and environmental index change – moving from the base of the column up to the surface – and what these changes may tell us about the vegetation and climate at the time. All vegetation type counts are amended, i.e., the previously discussed problematic morphotypes have been removed.

6.2.1 Modern surface composites

When a fossil assemblage shows strong similarities with a modern assemblage, we can use the modern vegetation community as an analog of the past vegetation community (Carbone 1977; Crifo' 2019). The modern surface composite (MS) samples provide the phytolith assemblages against which the data from the fossil assemblages in the two sampling columns are compared. When we look at the relative values (Table 5.5), we see that the MS sample compositions are very similar, averaging around 99% festucoid types and 1% chloridoid types. MS1, MS4 and MS6 are the only exceptions to this composition pattern, as detailed below.

MS1 was collected from an upland prairie setting within 30m of a shallow drainage leading to two kettle depressions to the southeast. In the three grass sub-families, MS1 had the highest festucoid phytolith count of any sample with 262 festucoid phytoliths; 5 chloridoid phytoliths, the 3rd highest of any sample; and no panicoid phytoliths. MS1 had no non-grass phytoliths. MS1 differs slightly from the average proportional composition with 98.1% festucoid types and 1.9% chloridoid types. This composition is most comparable to samples 3.6A and 3.7, which bracket sample 3.6B, the dark sediment band, in sampling column 3.

MS2 was collected from an upland prairie setting on a flat, exposed area just above and west of the head of ravine #5 (Figure 2.9). MS2 had 260 festucoid phytoliths, the 2nd highest count of any sample; 3 chloridoid phytoliths, the 4th highest count of any sample; and no panicoid phytoliths. MS2 had no non-grass phytoliths.

MS3 was the final modern surface composite sample collected from an upland prairie setting. This sample was collected near the bluff edge 90m to the southwest and uphill from the kettle depression where we collected sampling column 2. This location is much more xeric than the other upland prairie locations due to eolian and pluvial dispersion of leaf litter needed to provide any ameliorating effect. The vegetation is much sparser here as well, with more forbs and less grasses than any other location. MS3 had 199 observed festucoid phytoliths, the lowest of any of the modern surface samples; 1 chloridoid; and no panicoid phytoliths. MS3 had no non-grass phytoliths.

MS4 was collected 50m east of Ravine #5 in a lowland prairie setting on a moderate slope (11.5%) running down to the Red Deer River, which is approximately 170m to the south and 20m below. MS4 had 250 festucoid phytoliths, 1 chloridoid phytolith, and no panicoid phytoliths. MS4 had 1 non-grass phytolith, a woody dicot morphotype. With one recorded cuneiform bulliform cell phytolith, MS4 was the only MS sample with any observation of this morphotype. MS4 is one of only two MS samples with observations of non-grass morphotypes. The proportional composition of MS4 is 99.2% festucoid types (very close to the MS average), 0.4% chloridoid types, and 0.4% non-grass types. Sample 2.13 has an identical composition and samples MS6, 3.13, 3.17, 3.19 have very similar compositions with not quite double the proportions of chloridoids and non-grass types. Sample 3.6B is also very similar, though both the chloridoid and non-grass proportions are roughly triple those of sample MS4.

MS5 was collected within 25m of MS4 from the same lowland prairie and within 40m of Ravine #5 but with a slightly different grass composition. MS5 had 238 observed festucoid phytoliths, 2 chloridoids, and no panicoid phytoliths. MS5 had no non-grass phytoliths.

MS6 was collected in the coulee bottom of Ravine #5 roughly 150m downstream from sampling column 3, 100m upstream from where the coulee mouth empties into the Red Deer River, and 60m southwest of MS4. The sampled location was underneath several large willow and poplar trees in a closed-canopy riparian community dominated by Manitoba maple and with an understory vegetation of early successional forbs and grasses. This area appears to be subjected to regular fluvial disturbances. MS6 had 223 observed festucoid phytoliths, 2 chloridoids, and no panicoids. MS6 had 2 non-grass phytoliths, both woody dicot morphotypes. The proportional composition of MS6 is 98.2% festucoid types, 0.9% chloridoid types, and 0.9% non-grass types. The composition of MS6 is very similar to samples MS4, 2.13, 3.13, 3.17, and 3.19, which all have lower percentages of chloridoid types and non-grass types, as well as 3.6B, which has a higher percentage of those types.

MS7 was collected from a lowland prairie setting on the east side of the horseshoe bend of the Red Deer River. The MS7 locality has a similar topographic setting to MS4 and MS5, sitting on a gentle slope (8.8%) down to the Red Deer River, approximately 340m to the east and 30m below. The MS7 location is roughly 10m, or 50%, higher above the river than MS4 and MS5.

MS7 had 234 observed festucoid phytoliths, 2 chloridoids, and no panicoid phytoliths. MS7 had no non-grass phytoliths.

6.2.2 Sampling Column 2

Sampling column 2 is almost completely dominated by festucoid morphotypes. Of the 1,849 recorded phytoliths (of those morphotypes remaining after observations from seven morphotypes were removed for ambiguity or as outliers), 1,841 are festucoid morphotypes (99.57%), three are chloridoid morphotypes (0.16%), one is a panicoid type (0.05%), and four are non-grass types (0.22%; all are the woody dicot globular/orbicular verrucate morphotype).

The mean number of festucoid phytoliths per sample in sampling column 2 was 205. There were only 4 phytoliths from the other two grass sub-families recorded in this column from only three samples. There was one chloridoid phytolith recorded in samples 2.13 (94-88cmbs), 2.3 (18-12cmbs), and 2.0 (3-0cmbs). There was only one panicoid phytolith, which was recorded at the surface in sample 2.0. The non-grass phytoliths were all the same woody dicot morphotype, globular/orbicular verrucate. There were only four of these phytoliths, all in the oldest levels. Sample 2.15 (105-100cmbs) had two non-grass phytoliths and samples 2.13 (94-88cmbs) and 2.11 (82-76cmbs), had one each. Sample 2.15 has the highest number (n=2) and proportion (1.1%) of non-grass phytoliths in the sampling column. There were no forest indicator morphotypes recorded among the non-grass phytoliths.

Without a uniform count it is better to make comparisons between samples using the relative values rather than the cardinal values. The average relative composition of each sample in sampling column 2 was 99.6% festucoid types, 0.2% chloridoid types, <0.1% panicoid types, and 0.2% non-grass types. Four of the nine samples were 100% festucoid types. The relative composition stacked bar graph (Figure 6.1) allows us to make comparisons between samples. Immediately we see the festucoid component never drops below 98.7%. At the base of the column, at 5700 cal BP, we see festucoid types are 98.9% and non-grass types (globular/orbicular verrucate) are 1.1% of the sample 2.15 assemblage. This is the highest non-grass percentage in the entire sampling column and the D/P index value is high enough it places sample 2.15 in the group of samples which may have had trees and a closed leaf canopy. The festucoid percentage then rises over time to 99.2%, then 99.6%, in samples 2.13 and 2.11

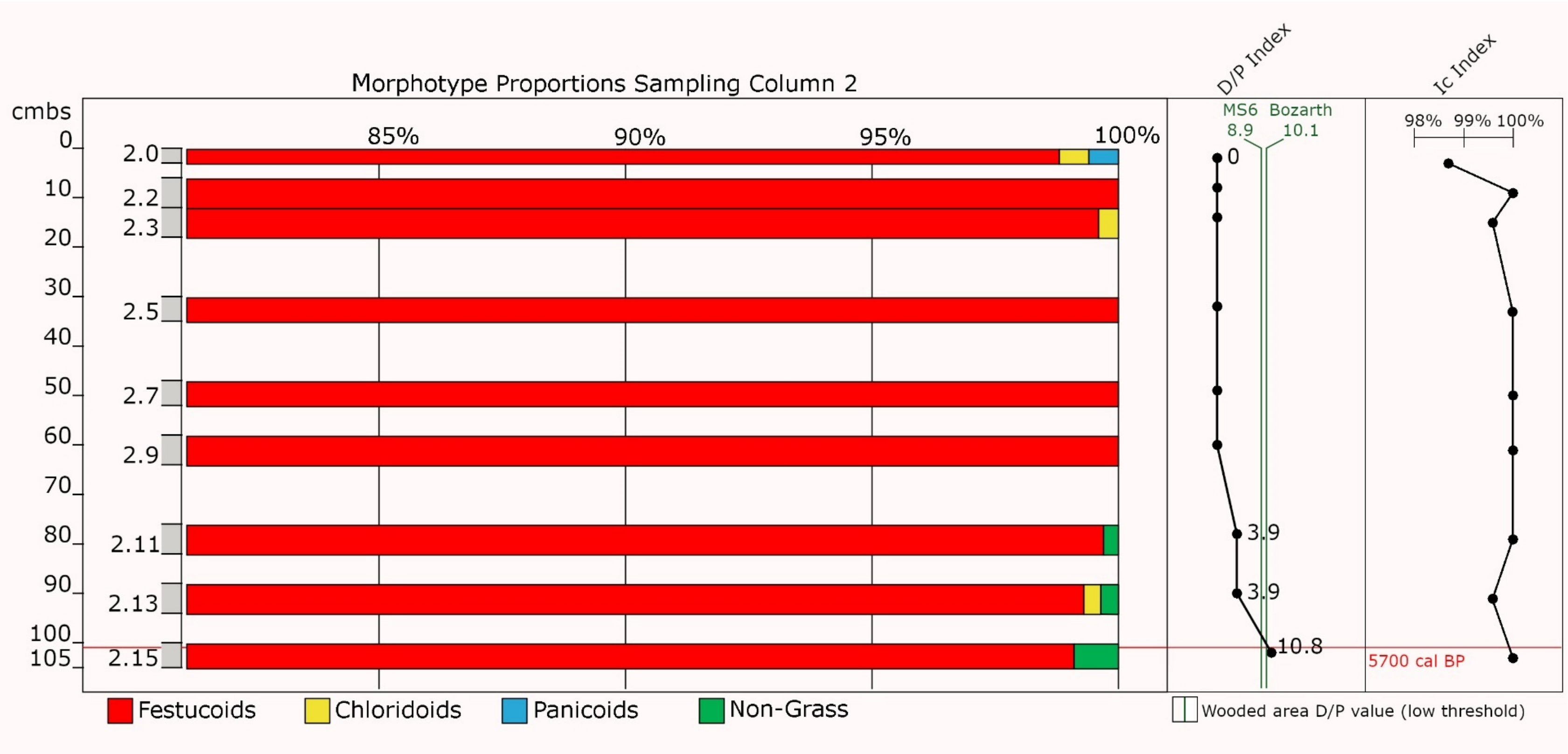


*Figure 6.1: (left) Stacked bar graph for sampling column 2 showing each vegetation type as a proportion of the whole; (center) the D/P index(using relative values) with values from surface sediments taken from Ravine #5 and an aspen (*P. tremuloides*) stand in the boreal forest at Prince Albert National Park, Saskatchewan (Bozarth 1993) as the low threshold reference values for woodlands; (right) Ic index values indicating extremely high festucoid proportions with an increase in chloridoids near the surface.*

respectively. The chloridoid type makes an appearance as 0.4% of the assemblage (1 phytolith) in sample 2.13 before disappearing. The non-grass component holds at 0.4% in both these samples. From this point to nearly the surface the composition remains at 100% festucoid types, except for a small dip in sample 2.3 when a single chloridoid changes the composition to 99.6% festucoid types and 0.4% chloridoid types. The surface sample 2.0 has a composition of 98.7% festucoid types, 0.7% chloridoid types, 0.7% panicoid types (the only panicoid in the column), and no non-grass types. This festucoid percentage is most similar to the base of the column, though the remaining components are very different.

The D/P index is only applicable to the oldest three samples because these were the only samples with non-grass phytoliths. The oldest sample, 2.15, has a D/P value of 10.8 relative. This is a higher number than the D/P index value from sample MS6 (D/P = 8.9), which is the lowest value from a wooded area, and within the range of values (D/P of 0.0101 or 10.1 in my modified system) in Bozarth's (1993) study of boreal forest and aspen-parkland phytoliths. Sample 2.13 has a D/P index value of 3.9 relative and sample 2.11 has a value of 3.9 relative. These values are very close to that of MS4 (4.0 relative), which is within 60m of a wooded coulee. and may indicate the presence of trees or shrubs in proximity to but not at the location. The Ic index, which measures the proportion of C3 to C4 carbon pathway grasses remains between 99% and 100% C3 for all samples but drops down to 98.46% in the surface sample, 2.0.

It may be useful here to summarize and simplify the foregoing into a paleovegetation history of the sampling column 2 location in the upland slough using the three basic community types. In the period before and after ca. 5,700 cal BP, from 105 to 94cmbs, the vegetation community at the sampling column 2 location was woodland but transitioned to a variable density mixed grass and woody vegetation community by 94cmbs, which lasted until perhaps as late as 64cmbs. From 64 to 0cmbs the location has remained cool-climate grassland. There appears to have been a slightly warmer and more arid period from 18 to 12cmbs. The modern surface sample indicates warming and possibly a change in moisture dynamics, allowing both chloridoid and panicoid grasses; panicoids appearing for the first time in the record.

6.2.3 Sampling Column 3

Sampling column 3 shows slightly more diversity of morphotypes than sampling column 2 but it too is comprised overwhelmingly of festucoid morphotypes. Of the 2,813 recorded phytoliths (of those morphotypes remaining after observations from seven morphotypes were removed for ambiguity or as outliers), 2,728 are festucoid morphotypes (96.98%), 31 are chloridoid morphotypes (1.10%), 20 are panicoid types (0.71%), and 34 are non-grass types (1.21%). Of the non-grass category, 23 observations (67.65%) are of the woody dicot globular/orbicular verrucate morphotype.

The mean number of festucoid phytoliths per sample in sampling column 3 was 144. In all the other vegetation categories, there are both few, if any, recorded phytoliths and very little variation of the cardinal values through time from the lowest level until we approach the top 30cm of the sampling column.

Samples 3.26 to 3.9, in the lower 120cm of sampling column 3, have either no recorded chloridoids or, occasionally, one chloridoid. In samples 3.7 to 3.3, from 42-12cmbs, the chloridoid count increases to 2 and 3 in sample 3.5. I recorded the highest magnitude of chloridoid phytoliths in sample 3.2 at 12-6cmbs, which has 10 chloridoid phytoliths, followed by sample 3.0 from 3cmbs to the surface with 6 chloridoid phytoliths.

Panicoid grass phytoliths are entirely confined to the top 30cm of the sampling column in samples 3.5 to 3.0. Indeed, with the sole exception of sample 2.0, which had one panicoid phytolith, these four samples have the only panicoid phytoliths recorded in the entire study.

The non-grass phytoliths follow the same trend as the chloridoid and panicoid phytoliths. From sample 3.26 to sample 3.6A (153 to 30cmbs) the non-grass phytolith counts are low, in fact there is usually only one or none, and all are woody dicot phytoliths of the globular/orbicular verrucate morphotype. Samples 3.5 to 3.0, from 30cmbs to the surface, have more non-grass phytoliths from a wider variety of morphotypes, nearly all of which are only present in these four samples.

When we look at the relative values (Figure 6.2), we can see a few patterns emerge. Again, festucoid morphotypes dominate the assemblage, with no sample falling below 83.2% and usually hovering around the 99% range. We can see a general trend of slowly falling festucoid values, accelerating in the last 400 years from sample 3.5 to the surface.

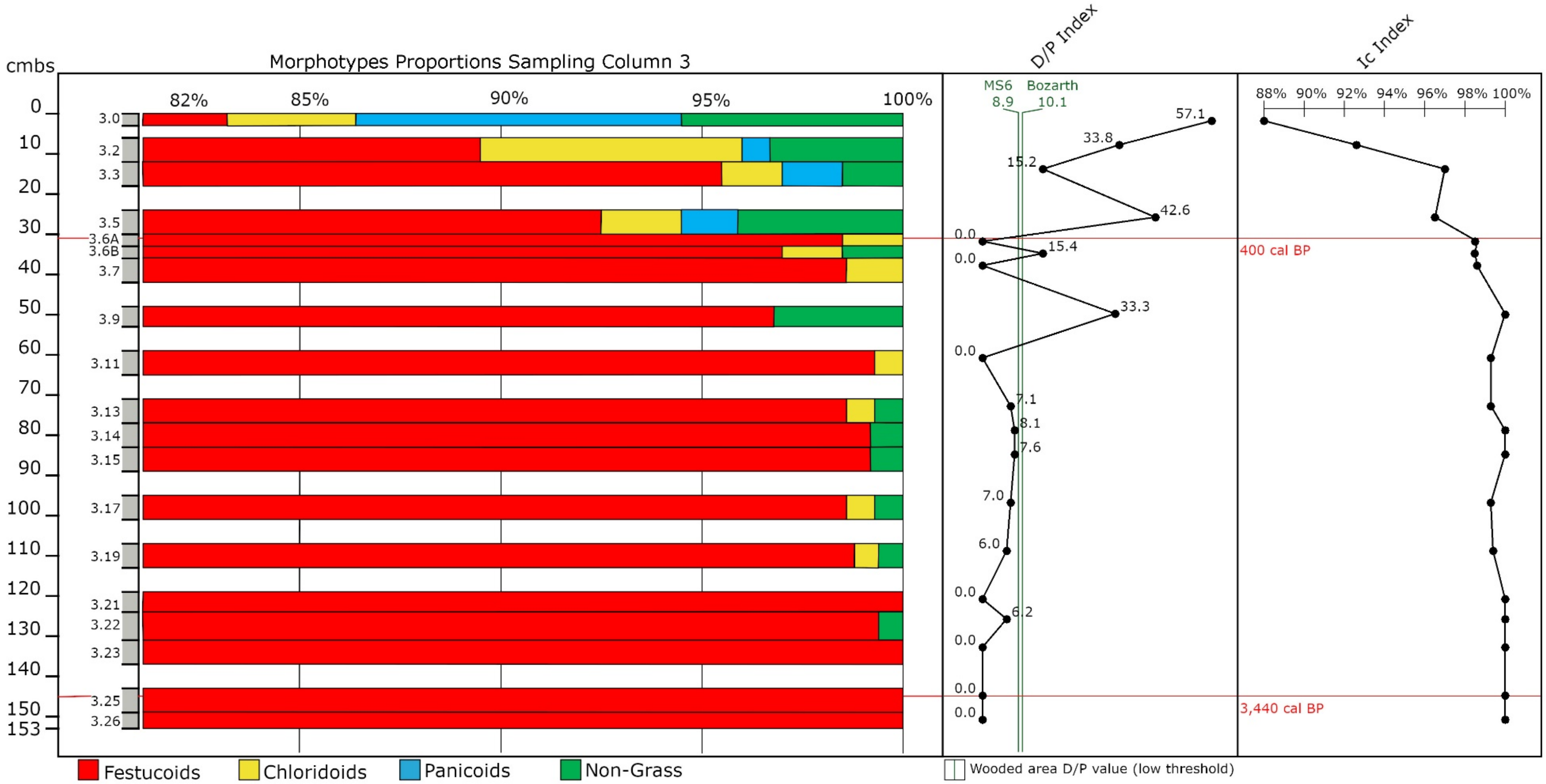


Figure 6.2: (left) Stacked bar graph for sampling column 3 showing each vegetation type as a proportion of the whole; (center)trendline of the D/P index values (using relative values)with values from surface sediments taken from Ravine #5 and an aspen (P. tremuloides) stand in the boreal forest at Prince Albert National Park, Saskatchewan (Bozarth 1993) as the low threshold reference values for woodlands; (right) Ic index values trendline. The index trendlines are both stable for most of the investigated period until a major shift occurs approaching the present, ca. 400 cal BP.

The chloridoid proportion appears to increase over time. From sample 3.26 at the base to sample 3.21 there are no chloridoids. From sample 3.19 to sample 3.11, the chloridoid type appears and holds at around 0.7% of the assemblage when present. From sample 3.7 to sample 3.3 the chloridoid proportion holds at around 1.5%. Samples 3.2 and 3.0 have much higher chloridoid proportions of 6.5% and 3.2% respectively.

Panicoids do not appear until sample 3.5 and there is no discernible pattern. The panicoid proportion is 1.4% and 1.5% for samples 3.5 and 3.3 respectively, then drops to 0.7% in 3.2 before jumping to 8.1% in the surface sample 3.0.

Non-grass morphotypes also appear to increase over time. There are none observed near the base but beginning in sample 3.22 and running through sample 3.13, non-grass types hold steady between 0.6% and 0.8% of the sample assemblages. From sample 3.11 to 3.6A, non-grass types appear twice but as a higher proportion of the assemblage – 3.2% of the sample 3.9 assemblage and 1.5% of the sample 3.6B assemblage. Samples 3.5 to 3.0 have the highest proportions of non-grass morphotypes, topping out at 5.4% of the assemblage in sample 3.0. Until samples 3.5 to 3.0, the woody dicot globular/orbicular verrucate morphotype is the sole non-grass morphotype present in the sample assemblages.

While MS6 defines the lower threshold D/P index value for a wooded area with leafy canopy, the surface sample 3.0 value defines the upper boundary in the dataset. At the base of the column there were many samples without non-grass phytoliths. The non-grass phytoliths that are present at these depths are all of the globular/orbicular verrucate morphotype in the woody dicot category and always occur as a single recorded phytolith. Below 53cmbs the D/P index, when calculable, is always between 6.0 and 8.1 relative. These samples approach but do not meet the wooded vegetation threshold defined by the D/P index of MS6 as described above. They may however indicate the presence of woody shrubs in the vicinity as the D/P index among these samples is higher than that of MS4 (4.0), which is within 60m of the wooded coulee bottom where sampling column 3 was removed. Samples 3.9 (53-48cmbs), 3.6B (36-33cmbs), 3.5 (30-24cmbs), 3.3 (18-12cmbs), 3.2 (12-6cmbs), and 3.0 (3cmbs to surface) all have a D/P index value higher than both MS6 and within the range calculated from Bozarth (1993). Of these 3.6B and 3.3 are both very near the lower threshold, whereas the other four samples are between approximately two and seven times the D/P index value of MS6.

All the samples from column 3 have a very high Ic index value between 99% and 100% until sample 3.7 at 42cmbs. At this point the Ic index values begin to drop as we near the surface. Samples 3.7, 3.6B, and 3.6A have Ic index values around 98.5%. Samples 3.5 and 3.3 are in the 96% range, then sample 3.2 drops sharply by 4% to 92.57% and then 4.5% again to 88% in sample 3.0. While C3 grasses remain vastly dominant, there is a persistent increase over time in C4 grasses as a proportion of the whole grass assemblage from 42cmbs to the surface – in other words, from shortly before 400 cal BP to the present.

Again, the data can be summarized into a paleovegetation history of the sampling column 3 location in ravine #5, using the three basic community types. In the period before and after ca. 3,440 cal BP, from 153 to 131cmbs, the vegetation community was a cool-climate grassland. From 131 to 125cmbs the vegetation becomes a variable density mixed grass and woody vegetation community, then moves again to cool-climate grassland from 125 to 119cmbs. There is a long period from 119 to 71cmbs where the vegetation community is variable density mixed grass and woody vegetation before moving to grassland with slightly warmer and more arid conditions from71 to 53cmbs. From 53 to 42cmbs the vegetation becomes a woodland community for the first time in the investigated period. From 42 to 36cmbs the vegetation becomes a warm-arid grassland, then in quick succession becomes woodland from 36 to 33cmbs and back to warm-arid grassland again from 33 to 30cmbs, which is dated to ca. 400 cal BP. After ca. 400 cal BP, from 30 to 0cmbs, the vegetation at the sampling column 3 location remains woodland to the present with warm-mesic panicoid grass observed for the first time and a trend of increasing warmth and increased moisture fluctuation.

6.2.4 Asteraceae morphotype

The opaque perforated tabular morphotype phytoliths characteristic of the Asteraceae family are not usually used as an environmental proxy. While I did not include them in my count total, I did keep track of them and analyse them out of curiosity. In sampling column 2, the opaque perforated tabular morphotype makes a single appearance in sample 2.0, the surface sample. In sampling column 3, they appear to follow the same general trend as the other non-festucoid vegetation categories – they are rare below 30cmbs and more abundant and varied above 30cmbs.

6.2.5 Summary of trends over time

When looking at trends over time, all samples in sampling column 2 in the upland depression are overwhelmingly festucoid morphotypes but there are some woody morphotypes in the lowest levels. The samples in sampling column 3 are also dominated by festucoid morphotypes but their proportion of the whole decreases approaching the present. Conversely, chloridoid and non-grass morphotypes show a general increase approaching the present. Panicoid morphotypes reveal no strong pattern over time, except they are only present in the most recent samples above sediments dated to 400 cal BP. In both sampling columns the Ic index values are lower approaching the surface. In sampling column 2, the D/P index only applies in the lowest three samples. In sampling column 3 above 53cmbs, the D/P index increases beyond the woodland threshold and also fluctuates significantly and frequently.

6.3 Placing the study area within regional paleoenvironments

Having reported the results of my analyses of the two sampling columns in the previous chapter, I will now place them within the paleoenvironmental context described in chapter 3. Radiocarbon dating of the sediments in the two sampling columns places both within the latter half of the Holocene, in a period when environmental conditions are approaching modern at all the paleoenvironmental sites I surveyed in chapter 3.

6.3.1 Sampling Column 2

Sampling column 2 begins at the end of the Altithermal, as recorded at nearby sites. At all sites except Mariana Lake in the boreal forest, the waning days of the Altithermal remain arid, though the periods of highest aridity have passed. At the nearest paleoenvironmental record site, at Chappice Lake, Vance et alia (1993) report decreased lake size with high salinity and seasonal fluctuations.

At sampling column 2, taken from an upland depression near the bluff edge (Figure 6.3), modern conditions of open, cool season grassland, with no major fluctuations are stable for nearly the entirety of the period. The phytolith assemblages and D/P index values (Figure 6.1) in the bottom 29cm of the sampling column (76-105cmbs), indicate woody vegetation may be present at the beginning of the investigated period, ca. 5,700 cal BP. I recorded no other woody vegetation phytolith morphotypes at any other level, including the uppermost levels and the surface. It is unclear why the only indication of woody vegetation occurs when other sites in the region still record higher aridity.

Figure 6.3: Sampled upland depression (slough). Dr. Glenn Stuart is standing approximately at the sampling column 2 location.

Currently, in the depression, when water collects, an area of increased moisture is created, even when surface water is not present. Woody shrubs are present and confined to the outer edge of this area of increased moisture. Because they are approximately 30-50m from the center of the depression, where the sampling column was collected, the shrubs may be too far from the sampling column for their phytoliths to be transported there. This may indicate the depression received less water at the beginning of the record, creating a smaller area of increased moisture. This condition would have brought the shrub zone at the edge of increased moisture much closer to the center – close enough for shrub phytoliths to enter the soil assemblage. This interpretation accords with the evidence and accounts for the lack of woody morphotypes in the modern samples as well as their presence in the higher average aridity conditions at the end of the Altithermal.

The presence of one chloridoid morphotype in the assemblage at 6-12cmbs, and one chloridoid and one panicoid morphotype in the uppermost 3cm, may also indicate more recent warmer conditions during the Medieval Warm Period, and of the modern warming climate, respectively. The only other chloridoid morphotype I recorded was between 88.5cmbs and 94cmbs, in the region of the column containing woody morphotypes, as discussed above. This may corroborate warmer conditions during the timespan covered by the lowest levels. Further sampling and more radiocarbon dates would be required to test this hypothesis and enable firmer conclusions to be drawn.

The Ic index, which measures the proportion of C3 to C4 carbon pathway grasses remains between 99% and 100% C3 for all samples but drops down to 98.46% in the surface sample, 2.0. This indicates a cool climate throughout the time period represented by the sampling column with a possible slight warming in recent times.

These data appear to show this area has been a cool weather grassland community for most of the sampled timeframe. The earliest level indicates the presence of some wooded vegetation, possibly even trees, at this location, which then transitioned to shrubs either here or nearby before losing all woody vegetation. In recent times, as reflected in surface sample 2.0, a drop in Festucoids combined with the presence of Chloridoids and Panicoids appears to indicate the climate may be becoming a little warmer and wetter than in the past. This appears to be in line with measured trends which show warmer temperatures (mostly expressed in warmer minimum temperatures, especially in winter) and either an increase in precipitation or the same precipitation but more rain and less snow, depending on the study (Akinremi et al. 2001; Millett et al. 2009; McGinn 2010).

6.3.2 Sampling Column 3

At sampling column 3, the record shows near modern conditions of a cool, open grassland often with low levels of woody vegetation for most of the period. There are increased fluctuations in vegetation community composition and higher levels of woody vegetation in the latter part of the period approaching the present.

The record from sampling column 3 (Figure 6.2) does not begin until shortly before ca. 3,440 cal BP, well into the period of modern conditions recorded at all the paleoenvironmental sites I described in chapter 3. In the lowest 22cm of the column (131-153cmbs), the phytolith assemblages indicate a cool climate, open grassland with no woody vegetation. This region of the column includes the radiocarbon dated sediments at 145-146cmbs, which returned a date of ca. 3,440 cal BP. Assuming similar sediment deposition rates in this portion of the sampling column, this region of the column may represent a period from ca. 3,600 cal BP to ca. 3,000 cal BP.

The nearest locations with paleoenvironmental records indicate this was a period of aridity with increasing moisture – at the Stampede site and Harris Lake in the Cypress Hills until ca. 3,200 cal BP, and at Chappice Lake until ca. 2,800 cal BP – after which point modern conditions prevail. The lowest levels of sampling column 3 may represent this arid period, in which soil moisture levels were not high enough to sustain woody vegetation at the location. Vance et alia (1993) mentioned this was a period of glacial readvancement in the mountains. Perhaps lower meltwater levels at the Red Deer River headwaters and less precipitation translated into lower river levels and a lower water table at the study location. Given that sampling column 3 is located at the upstream edge of the wooded portion of the coulee (Figure 6.4), it makes sense that in periods when the water table is lower, whether through reduced precipitation or reduced montane glacial melt, the woody vegetation would recede towards the river.

In the middle 72cm of sampling column 3, between 131cmbs and 59cmbs, the phytolith assemblages indicate a cool climate and mostly open grassland with low levels of woody vegetation, likely low shrubs on the slopes of the coulee. The period is relatively stable with only low-level soil moisture fluctuations. This vegetation community is very similar to that present today upstream from the sampling column (Figure 6.5). The water table of the Red Deer River may have been lower than today if glacial melt in the mountains at this time was stable or reduced. All paleoenvironmental records from the other sites I surveyed indicate a long period of stability with conditions very similar to modern.

The uppermost 59cm of sampling column 3 is characterized by moisture and temperature fluctuations. There is a strong indication of warming and increased soil moisture by circa 15cmbs, or perhaps as early as about 27cmbs. The only dated sub-surface level is 3.6A (the possible Ahb horizon) which returned an age of ca. 400 cal BP at 31-32cmbs. If we assume the rate of deposition is stable and the samples comprise equal periods of time, the beginning of this

Figure 6.4: Sampling column 3 location is under the willow trees in the coulee (center), the last trees before shrubs take over. Trees farther downstream are Manitoba maple and the tallest trees in the top right of the photo are cottonwoods.

section, at 59cmbs, would occur ca. 800 cal BP. If we assume a stable rate of deposition but factor in compression of the sediments, then the beginning of this section is possibly several centuries older.

This section of the column likely covers the Medieval Warm Period (MWP) from ca. 1,200 cal BP to ca. 700 cal BP (800 to 1300 CE); the Little Ice Age (LIA) from ca. 400 or 500 cal BP to ca. 50 cal BP (1450 or 1550 to 1900 CE); and modern global warming beginning ca. 50 cal BP (1900 CE to present). Modern global warming is sometimes referred to as the onset of the Anthropocene (Crutzen and Stoermer 2000; Smith and Zeder 2013) or, perhaps more accurately, the Capitalocene (Moore 2017). I prefer to use ‘modern global warming’ for the purposes of this

Figure 6.5: Upstream from sampling column 3 the vegetation is low shrubs on the coulee slopes and grasslands above. The central channel is a slope fen.

study because I am reporting effects of environmental changes, whereas the terms Anthropocene and Capitalocene make arguments as to the causes of environmental changes (Moore 2017).

This section of the column indicates a complex relationship between climate, precipitation, riparian gradient (the Red Deer River water table), and vegetation. Similar fluctuations occur at Chappice Lake, the nearest paleoenvironmental site, which has a series of low water levels at the end of the MWP, followed by high water levels during the LIA, then low levels again after ca. 100 cal BP. The paleoenvironmental study at Chauvin recorded conditions of aridity, similar to modern, prior to ca. 1,200 cal BP, wetter conditions for most of the MWP until ca. 800 cal BP, followed by a return to modern arid conditions. All other records registered no change in conditions, except the most distant, Moon Lake in southeastern North Dakota, which recorded a drier phase coinciding with the MWP from ca. 1,200 to ca. 700 cal BP. The differences between records illustrate the particularity of each location, contingent on local conditions and the scale and resolution captured by different proxies.

6.3.3 Summary of local results within the regional context

In summary, each sampling column captured the particularities of its situation. In both locations, phytoliths, at least non-grass phytoliths, do not appear to travel very far, in accordance with Piperno (1988). Sampling column 2 in the upland depression registers effective soil moisture from precipitation. Sampling column 2 appears to closely match synoptic climate trends recorded in the other paleoenvironmental studies. Sampling column 3 in the river valley coulee registers the changing soil moisture due to the riparian gradient in the non-grass morphotypes, and perhaps the effects of temperature fluctuations on growing seasons in the grass morphotypes. Sampling column 3 is difficult to correlate to other records due to the riparian gradient effect of the Red Deer River. The only other record that exhibits similar effects is Klassen's (2004) study at the Stampede site (DjOn-26), which recorded riparian effects at the beginning of the record due to proximity to a creek before the stream bed shifted.

6.4 Issues and directions

For the most part, the issues I encountered and the directions for future research I describe fall into four categories, sampling, analysis, taphonomy, and the cultural element. Although a number of issues are related to my lack of experience, many are related to a paucity of phytolith research in the Prairie Provinces. Of course, this paucity means there are many avenues open for future research.

6.4.1 Sampling

When deciding on locations to sample, we looked for wetland environments, as described in chapter 1. Phytoliths can be sampled from any aggrading landform, however, and it would be very interesting to compare the phytolith assemblages and potential for phytolith data of a purely terrestrial sampling column to the data from the wetland columns.

The center of the upland depression is an aggrading landform. It appears that a location like the upland depression is better for capturing regional data. While phytoliths can be transported by any natural process that translocates silt-sized particles (Fredlund and Tieszen 1994), most phytoliths remain within 20m of the location of their originating plant (Piperno 1988). The main transport mechanism on the Great Plains is fire-eolian transportation of grass phytoliths over long distances (Bozarth 1993; Fredlund and Tieszen 1994). At a location like the upland depression, non-grass plant phytoliths remain in place and might not reach the center of the depression, while grass phytoliths may be amplified by fire-eolian transport. In other words, the already faint non-grass signal can be further muted by the grass noise in such a location.

The coulee bottom is likely subject to both aggradation and degradation of sediments. The coulee has ample non-grass woody and herbaceous vegetation, mostly on the slopes, but the side slopes are steep, and the bottom is frequently subjected to fluvial/pluvial disturbances. Detecting phytoliths from woody vegetation requires robust soil formation and a fairly deep leaf litter/ fibre/ humus (LFH) layer (Kerns et al. 2001). Soil development is hindered in the coulee by the steep slope of the banks. On the coulee bottom, soil formation is halted by rainwaters occasionally washing away the LFH layer or depositing sediments on top of the LFH layer. Partly due to this weak soil formation caused by frequent disturbance at this location, the non-grass vegetation signal is faint in the grass noise, even though woody and herbaceous vegetation is abundant.

Interruption of soil formation may be a bigger problem closer to the river, as demonstrated by MS6, collected from the coulee bottom 150m downstream from the sampling column, which had many fewer woody phytoliths than there were at sampling column 3. I cannot be sure of this, though, because I am comparing MS6, a composite randomly sampled from within an area of 1,000,000cm^2, to sample 3.0, collected from one hyperlocal spot only 19.6cm^2 in area, or .002% of the area represented by MS6. Complicating matters further, Linowski, our consulting botanist, identified only Manitoba maple at the MS6 location and only willow and poplar at the sampling column 3 location. In hindsight, I recognize I also should have created modern surface composite samples centered on the sampling columns. This would have enabled me to better understand the relationship between the extremely limited surface assemblage at the top of the column and the wider surface assemblage surrounding the column. It would also have clarified the relationships between the surface assemblage of the vegetation community at each sampling location and the surface assemblages of similar vegetation communities nearby, such as between sampling location 3 and the MS6 location.

The sampling column 3 location choice contained a measure of serendipity because I believe the vegetation, and thus the phytolith assemblage, is strongly related to the intrariparian gradient of the coulee, which is also the transriparian gradient of the river valley. Because sampling column 3 is located at the upstream edge of the wooded zone, it is better situated to capture vegetation community shifts due to changes in the gradient than a location in the middle of the wooded zone. I think it would be very informative to take MS samples along the coulee intrariparian gradient, which would correlate vegetation to soil moisture. Obtaining quantitative data by directly measuring soil moisture would enhance this metric.

Although I was more concerned in this study with the general character of the phytolith assemblages of the vegetation communities at the MS locations, a more detailed inventory of the plant species at the MS locations would allow more detailed interpretations, such as the exact proportions of *Bouteloua*/*Stipa*/forbs. These proportions may allow researchers to infer disturbances, perhaps even to identify an anthropogenic disturbance signature.

We sampled wetland locations, but it would be interesting to see what phytolith assemblages more terrestrial locations returned. The sediments on the grasslands in the river valley are cumulic regosols but are disturbed much less frequently and less severely than the sediments in the coulee bottom, therefore there may be more Ahb horizons in these sediments than in the coulee bottom. Because phytoliths are not transported very far below an Ahb horizon within the sediment column (Piperno 1985), these areas may be good locations to track both vegetation communities and disturbance frequencies from floods and fires in the river valley. It may be that these areas have been grasslands for a very long time (Strong and Hills 2005) and vegetation changes may be limited to changes in *Bouteloua*/*Stipa*/forbs ratios. Sampling columns in alluvium and colluvium near the valley walls may also provide interesting information and potentially contain Ahb horizons.

6.4.2 Analysis

The main issues I encountered when analysing the samples were lack of a reliable regional reference collection of morphotypes and a less than optimal count size. My interpretations were also affected by using environmental indices uncalibrated to high-latitude temperate species and phytolith assemblages.

6.4.2.1 A regional reference collection

As mentioned in several studies discussed previously (Blinnikov 2005; Gallego and Distel 2004; Kerns 2001), a robust reference collection of phytolith morphotypes and assemblage composition data for species of the region is vital for creating robust interpretations from the data. While grasslands of the North American Great Plains have received much attention since the 1960s, as I discussed in the Methods chapter, woody and herbaceous species, especially of the micro-environments and marginal environments within the grasslands, have been neglected. This study would have greatly benefited from a localized reference collection.

Such a collection would be the most beneficial project for future phytolith research in the Prairie Provinces and compiling such a collection will be the work of decades and numerous researchers. A suitable reference collection would capture the full diversity of the region and include not just grasslands species but species from sloughs, lakes, river valleys, coulees, streams, and isolated uplands. Such a collection, ideally, would be made available in an easily accessible, centralised, online database. The database would be searchable by taxonomic levels, vegetation community, morphotype attributes, and place of origin, at the least. A central global database, searchable by region would be even better. The beginnings of such a database exist at www.phytcore.org and at www.phytoliths.org but these are currently extremely limited geographically and did not provide much help when I decided which morphotypes to include in this study.

When creating the reference collection, phytoliths taken from vegetation samples should be correlated to phytoliths in sediment samples taken at the location the vegetation samples were collected, as was done by Bozarth (1993). Phytoliths extracted from vegetation samples would be most useful in archaeological contexts, where identifying species can greatly affect interpretations. Sediment samples would be most useful in identifying vegetation communities and how they change over time. Correlating vegetation samples to sediment samples may lead to the identification of new high-latitude community indicator species. Assemblage composition studies could also be undertaken at several levels – species, community, and landscape – to strengthen quantitative methods for identifying trends at each of these levels. Methods to dampen the grass signal and amplify other morphotypes may also be quite useful. Most phytolith research has been undertaken to investigate paleoenvironments and agriculture, both prehistoric and historic (Pearsall 2015). These lines of investigation follow the model of hunter-gatherers as living in environments without affecting or managing them, as discussed in chapter 3. More phytolith research needs to be done from a perspective of hunter-gatherers as ecological resource managers.

6.4.2.2 Morphotypes

I removed several morphotypes from use in analyses. Most were outlier observations of a single example of a morphotype removed to avoid skewing the principal components analysis. I removed one as a false identification of the irregular polyhedron granulate morphotype. Two, globular/orbicular psilate and bilobates, were removed as part of testing the viability of the morphotype in Canadian grasslands. And one, the conical irregular base morphotype, was an unexpected removal. I want to take a moment here to discuss these last two morphotypes, bilobate and conical irregular base.

The conical irregular base (CIB) morphotype revealed itself as problematic when I was testing correlations among morphotypes. Conicals are produced abundantly in festucoid grasses but are also produced in lesser quantities in all grasses (Fredlund and Tieszen 1994). When researching why the conical irregular base morphotype was negatively correlated to other festucoid morphotypes, I came across research indicating sedges in the Cyperaceae family abundantly produce conicals morphologically similar to festucoid conicals (Ollendorf 1992; Ollendorf et al. 1987). Mulholland co-authored with Ollendorf research on Israeli sedge morphotypes (Ollendorf et al. 1987), so it is probable that she coined the term “rondel” for grass conicals (Mulholland 1989) precisely because she was aware that morphologically similar conicals are produced by sedges. Mulholland (1989) never states this to be the case, however, and in fact never mentions sedges or sedge conicals because she is focusing on morphotype distributions solely in North Dakota grasses. Fredlund and Tieszen, in their study of phytolith assemblages from the North American Great Plains, state explicitly that their pooid/festucoid conicals are Mulholland’s rondels (1994:324). Without mentioning conical morphotypes occur in both grasses and sedges, an inexperienced phytolith researcher of grasslands may easily overlook conicals of sedges. Strömberg (2004:Table 3) provides an excellent list of morphotypes with references, which includes descriptions of conical morphology in both sedge and grass silica short cell phytoliths. I used this resource when I was researching woody and herbaceous dicot morphotypes after I had already determined which grass monocot phytoliths to include in the count. Because sedge is a non-grass but also a monocot, I overlooked it at this stage.

Because we took sampling columns from wetland locations and sedges are commonly a wetland plant (Murungi and Bamford 2020; Ollendorf 1992; Ollendorf et al. 1987), it seems reasonable that many of the CIB observations are sedge conicals. Due to the uncertainty surrounding the CIB morphotype and the probability my observations of it are a mix of festucoid and sedge morphotypes, I chose to remove the morphotype from analyses, such as PCA. This was unfortunate and I view it as a lost opportunity.

Incorporating a sedge component into an analysis of the soil phytoliths in a wetland location in the dry mixed grassland subregion would have brought an extra dimension and depth to the study. It may have allowed better discrimination among wetland dynamics at the locations as well as strengthened interpretation of the wooded-grassland dynamics. A taxonomic study of sedge phytolith morphotypes on the Canadian prairies may be a fruitful avenue of research. Conical morphotypes of the sedges have distinctive and complex morphologies that may provide taxonomic discrimination below the family level (Ollendorf 1992). If so, sub-family, genera, or species identifications may provide insight into hydrological changes over time in wetland locations. Sedges may also be useful in high-latitude grasslands in a mesic index of some sort, similar to the Iph aridity index, in which sedges replace panicoids as the mesic component.

One of the other morphotypes I removed from analysis was the bilobates morphotype in the panicoid subfamily. Fredlund and Tieszen (1994) mention this morphotype is commonly produced in non-panicoid grasses in the Alberta prairies. The non-panicoid bilobates are most commonly produced in the festucoid sub-family by species of *Stipa* (needle-and-thread-grass) and are known as *Stipa*-types (Gallego and Distel 2004; Mulholland 1989; Strömberg 2004). These were differentiated from panicoid bilobates by Mulholland (1989) by their trapeziform or plateau-top morphology whereas panicoid bilobates are tabular.

With a little more experience, I believe I could have kept both of these morphotypes in the analysis and perhaps used them to refine my analyses. One aspect of this is knowledge of the types but another is visibility. Both of these morphotypes require good visibility to distinguish them from morphologically similar phytoliths in other families or sub-families. I do not believe I could have distinguished between them using the glycerine mounting medium I used. This underscores the necessity of understanding the relationship between the refractive indices of the mounting medium and the microscopic bodies being studied as discussed above in section 4.3.1.

6.4.2.3 Count size

When it comes to count size, with the benefit of hindsight I would have used a count size of 300 or 400 rather than 200. While a 200 count is frequently sufficient, this applies best to experienced analysts working with morphotypes repeatedly validated in the research location. A buffer should be built into the count based on the level of experience the researcher has in the area and how much confidence they have in the morphotypes they are analysing. Either of these factors may require the researcher to remove some observations from the dataset and a buffer allows them to do so without jeopardizing the statistical significance of their findings. If the researcher has a number of modern surface samples from a variety of vegetation communities, it might be useful to create morphotype accumulation curves (Zurro 2017) for each community or use some other metric to help determine a minimum count size. As described by Zurro (2017), to create a morphotype accumulation curve, the researcher counts to 50 phytoliths and notes how many morphotypes they observed. They then count another 50 phytoliths and note any new morphotypes. This continues until no new morphotypes are observed after two consecutive sets of 50. The total number of phytoliths counted by the end of the last set with new morphotypes should be sufficient to the phytolith assemblages in the sediments being studied.

If I were to do a study of this nature again, I also would stop scanning the slides once I reached the arbitrary count of 200 or whatever the suitable count was determined to be. Although converting cardinal values into proportions of the total is a sufficient work-around to make comparisons between samples, it is much easier to start with easily comparable data points. Part of the reason I did not stop at 200 was an anxiety to capture every last phytolith in the last field of view to avoid missing rare morphotypes. Using a technique like a morphotype accumulation curve would help here too. Besides aiding in determining the count size, morphotype frequencies can be determined. When I scanned a field of view, I was looking for only a few morphotypes at a time, then I would scan again for a few more morphotypes. I did this because I am inexperienced and do not know many useful morphotypes by heart. I scanned first for morphotypes I expected to encounter at high frequencies, then moved to less common morphotypes. I should have approached a scan in exactly the opposite way – searching for less common types first. If the researcher has a relatively large but limited set of reference phytoliths and is scanning for only a few morphotypes at a time, as I did, beginning with a good understanding of how frequently they should encounter each morphotype will greatly aid the accuracy of the scan. Furthermore, building a morphotype accumulation curve will rapidly familiarize the researcher with the morphotypes present in the phytolith assemblage before beginning microscopy in earnest.

6.4.2.4 Calibrating environmental indices

In Canadian latitudes, environmental indices, in their current formulations, need to be recalibrated if they are to be useful. Recalibration would likely entail finding suitable morphotypes from northern species to replace the tropical morphotypes currently used. As it stands, in order to record a sufficient number of index-relevant morphotypes to attain sufficiently high levels of confidence in the results, it can require total counts in the thousands (Strömberg 2009).

The Iph aridity index (chloridoids/[chloridoids+panicoids]) is greatly hindered by the dearth of species in these grass sub-families on the Canadian prairies. These C4 grasses are commonly less than 20% of the grass community in the Prairie Provinces (Twiss 1992). Panicoid species, especially, seem to be limited to certain conditions and locations. In tropical Africa, where the index was first developed, the opposite was true and festucoid species were rarely encountered. Simply adding festucoid morphotypes into the formula (as recommended by Twiss 1987) seems to confuse rather than clarify the index. Perhaps C3 grasses in northern latitudes occupy both moist and arid niches in the environment.

These circumstances also affect the Ic climate index (festucoid/[festucoid+chloridoid]). In the Canadian prairies the Ic index will rarely be lower than 80% due to the aforementioned dominance of the C3 festucoids. Climate differences in the Holocene past may only be detectable as minute differences in the index. Fredlund and Tieszen (1997) were able to calibrate phytolith assemblages in the Central Great Plains using historical climate data and extrapolate temperature ranges. It remains to be seen if such a calibration is possible on the northern edge of the Great Plains as well.

Another consideration is that C3 and C4 grasses both exist in a location because C3 grasses are cool-season grasses and grow before and after peak summer heat when the C4 grasses thrive

(Twiss 1992). They share the location and avoid competition by occupying different thermal/temporal niches. In southern Alberta, the growing season is very short, and the climate remains cool for most of it, the heat occurring during only a very short time period, if at all. The brevity of the hot portion of the growing season limits the C4 grasses to a small proportion of the grass biomass each year. Whether global warming extends the cool seasons or lengthens and intensifies the hot season will determine how the vegetation community composition and the soil phytolith assemblages are affected. It is likely warming will also bring unpredictability and destabilization within years and between years. The soil phytolith assemblage will only record the average or trend.

Off all the indices, the tree cover index D/P provided the most interesting results in this study. The D/P index may prove extremely useful in certain areas of the prairies with some refinements. First, however, this would require intensive research into morphotypes to define those that reflect woody vegetation of the region. Second, taphonomic research needs to be done to better understand what phytolith morphotypes are most likely to persist over time. Studies of phytolith dissolution (Cabanes and Shahack-Gross 2015; Cabanes et al. 2011) and comparisons between archaeological and modern vegetation phytolith assemblages (Tsartsidou et al. 2007) recently conducted in a Mediterranean context provide a good template. Bozarth's (1993) work comparing modern sediment phytolith assemblages to vegetation assemblages in the aspen-parkland and boreal forest of Canada is a good beginning. Third, a wide surface sampling program of a variety of modern locations on the northern plains with woody vegetation communities (shrubs, trees, and associated forbs and sedges) such as rivers, creeks, coulees, lakes, and kettles. These investigations would note the types of vegetation present and measure the leaf canopy cover to calibrate the D/P index such as was done by Bremond, Alexandre, Hély, and Guiot (2005). Following the work of Alexandre, Meunier, Lézine, Vincens, and Schwartz (1997) and Barboni et alia (2007), the goal of the project would be to develop the capacity to differentiate between different types of woody vegetation, short shrubs, tall shrubs, and trees from the phytolith assemblage. It may be that duration, density, and extent of wooded vegetation in these areas are factors in the proportion of wooded area phytoliths in an assemblage. A good example of such a study was undertaken in a Ponderosa pine forest in Arizona by Kerns et alia (2001). Such measures could vastly improve the D/P index on the Canadian Plains. It is interesting that with some major refinements, the tree cover index may be able to detect hyperlocal wooded areas (within approximately 50m of the sample), such as in coulees or kettles – areas with important resources for people on the Plains. Such a project would be helpful in paleoenvironmental reconstructions to indicate not just the presence of woody vegetation but what type, which would also help indicate soil moisture. It might also indicate how attractive the area might be to past humans as a resource area and for potential resource intensification methods, as discussed in chapter 3.

The last index, Fs water stress (cuneiform bulliform/sum of all grass types), was inconclusive in this study due to the rarity of the morphotype. The extremely low number of observations (5) of the cuneiform bulliform morphotype seems strange, as the study area is in one of the most arid regions on the Canadian Great Plains. It may be, however, that there is very little water stress in this particular location due to the Red Deer River and the presence of numerous springs and seeps among the bluffs and coulees here. The lack of these morphotypes in the deeper areas of the sampling columns, may indicate this area has had reliable water throughout the sampled timeframe, as far back as 5700 cal BP. On the other hand, fire-eolian deposition logically should be bringing in allochthonous phytoliths, including of the cuneiform bulliform morphotype. Furthermore, Bremond, Alexandre, Peyron, and Guiot (2005) found cuneiform bulliform production increased with aridity and especially in plants in wet locations in arid areas – exactly the conditions at the sampling column locations. It may be there are differences in bulliform production between grasses and sedges of the tropics and those of high latitudes. This will have to remain a mystery for now.

6.4.2.5 Forest indicators

The irregular polyhedron psilate morphotype is neither distinctive enough nor exclusive enough to be classified as a true indicator morphotype. It is common to conifers and especially white spruce but also produced by some grasses (Bozarth 1993). White spruce is highly adaptable and flexible in terms of edaphic and climatic conditions, but it needs the correct hydrologic conditions to survive (Nienstaedt and Zasada 1990). Isolated populations of white spruce do presently occur upstream from *maok-skoistch* where the river valley is narrow (Cordes et al. 1997), usually in the shadow of north-facing river valley walls where evapotranspiration is minimized (Zoltai 1975). The presence of the irregular polyhedron psilate morphotype in a narrow band at the top of sampling column 3 may indicate a recent period when conditions were suitable at this location for such an isolated conifer community – possibly during the LIA. There are no conifers present at this location currently. It is also possible this morphotype is produced by grasses at this location and preservation conditions confine the morphotype to the narrow band and disintegrate below it. But the small surface area and lack of delicate structures in this morphotype are characteristics that should make the phytoliths more resistant to dissolution. This lends support to the possibility of a recent, temporally constrained, localized conifer population. An observation of the rectangular flat marginally lacunose morphotype diagnostic of white spruce would confirm this interpretation. But the large surface area and flat nature of this morphotype would make it much more likely to dissolve under poor preservation conditions.

6.4.3 Taphonomy

Sampling column 2 appears to be an Orthic Vertisol based on the heavy clay content and lack of A and B horizons. The uniform, homogeneous nature of the sediments may indicate mixing or that the source and deposition vector of the sediments – such as low-energy pluvial erosion of the slopes into a shallow ephemeral water body – has remained constant over the timeframe covered by the sampled sediments. Although no slickensides were observed, within 50m of the sampling location I observed large cracks at the surface when we visited in mid-June. Slickensides may indicate an increased occurrence of mechanical damage to phytoliths. There was no gleying, indicating the sediments in this upland depression do not remain saturated with water for long.

Sampling column 3 is a gleyed cumulic regosol, which matches the official soil description for this locality. This location is frequently disturbed by fluvial action, likely both runoff channeled into the coulee and occasional flooding from the Red Deer River. Furthermore, based on the presence of redoximorphic features, this location appears to be an area where groundwater is very near the surface and the sediments frequently remain saturated for long periods. This saturation would make it a good area for vegetation during droughts. During drought times, or at least during periods between fluvial disturbances, the surface would be stable enough to begin soil formation. This seems to have occurred in the timeframe of the soil column at least once.

I did not expect the sediments in the coulee to be as saturated as they were. How this affects the phytolith assemblage is uncertain. As described by Pearsall (2015) the pathways of phytolith disintegration are chemical and mechanical. Chemical dissolution of phytoliths is caused by wet, alkaline conditions. In general, it is worse for preservation when sediments cycle between saturated and dry than if they are constantly saturated or constantly dry. Mechanical destruction of fragile phytolith morphotypes may occur when there is frequent turbation of the sediments. The high latitude of the study area might combine with the wet conditions to create frequent cryoturbation, damaging gracile morphotypes beyond recognition.

Poor preservation conditions tend to bias the phytolith assemblage towards robust types, such as grass silica short cells, over other, more fragile types, especially woody and herbaceous morphotypes. Given the presence of non-grass phytoliths in the lower levels of both columns, it is likely there is minimal phytolith dissolution related to sediment saturation and alkalinity. This does not mean there is no ill effect acting on the phytoliths, as the only non-grass morphotype below 24cmbs is the globular verrucate morphotype of woody vegetation. Due to its compact nature, similar to the grass silica short cell morphotypes, and lack of fragile ornamentation or structures, this type is more robust than other non-grass types. If this is the case, interpretations at the sampled sites, and in the study area generally, may be limited to whether woody vegetation is present, as the more gracile morphotypes necessary to identify species or other narrow taxonomic classes are destroyed, as was the case with several potentially diagnostic morphotypes identified by Bozarth (1993). Nearly all of the morphotypes I observed have a small surface area with simple rather than complex structures, and no or little ornamentation. The two morphotypes I observed with more complex structures – elongate sulcate tracheid and opaque perforated tabular – were small fragments of larger phytoliths but recognizable due to their unique morphologies. Furthermore, there were large amounts of amorphous silica debris in all the samples. These observations tend to point to less-than-ideal preservation conditions for phytoliths at *maok-skoistch*. Some exploration of taphonomy and preservation differentials among the various environments of the prairies should be undertaken to better understand how phytolith morphotypes change in the transition from the live plant to sediment component.

6.4.4 Cultural contexts

It would be interesting to see assemblages from cultural contexts, by which I mean not just archaeological sites but areas where the species composition has been influenced by human activities. At the study area, it would be very interesting to see how assemblages collected from various stone constructions compare to nearby ‘natural’ prairie assemblages. A better understanding of the phytolith assemblages of various culturally important, especially ceremonially important, plants would be necessary for this.

Some more experimental projects might attempt to identify signals of Indigenous ecological management in phytolith assemblages. Assemblages could be sampled from areas under Indigenous management or plots to which various Indigenous resource intensification techniques have been applied. Assemblages sampled from modern First Nations ceremonial locations may also be very interesting, though there is a chance that modern ceremonies are too different from the past to tell us much. These projects could and should be undertaken in partnership with and under the guidance of First Nations. Such an ambitious project would have to be multidisciplinary, and phytolith research would be just one of several productive lines of inquiry.

6.5 Conclusion

This study appears to fit well within the paleoenvironmental framework constructed from other studies in the region. Sampling phytoliths from a non-lacustrine, non-archaeological setting is a novel approach in the Prairie Provinces and appears to produce valid results. Methodological refinements to future studies, such as the creation of a more robust morphotype reference collection and a calibration of non-grass woody vegetation discussed above, would greatly enhance future studies. So too would investigation of soil phytolith assemblages from many vegetation communities in many topographic settings. Experimental studies and research designed to investigate proxy signatures of indigenous ecological management may allow archaeologists to extend ethnographically documented practices of First Nations, such as the Nitsitapii, farther into the archaeological past.

Chapter 7
Conclusion

Maok-skoistch is an amazing location, both naturally and archaeologically, with hundreds of intact stone constructions along the bluffs and uplands above the Red Deer River Valley. In this study, I set out to investigate the soil phytolith assemblages of different local modern vegetation communities and compare them to the phytolith assemblages taken from sediment cores. I wanted to learn about past environments and see if I could tease out the human element in those environments. I was able to achieve my primary research goal but not my secondary research goal.

The primary goal of this thesis was to investigate vegetation changes over time through phytolith proxies in sediments and thereby infer paleoenvironmental conditions. I collected sampling columns at three locations and extracted phytoliths from two of the three columns. I was successfully able to use phytoliths to infer vegetation communities and the results concur with previous paleoenvironmental studies in the region.

The first sampled location, sampling column 1, was a slope fen in a coulee. The sediment column included a middle layer of water and very loose sediments. I decided not to pursue phytolith extraction from this column due to discontinuity of the column and the higher potential of contamination in the loose sediments.

Sampling column 2 was collected from the center of a seasonally wet upland depression and provided a continuous column of sediments with a high clay content. Sampling column 2 has a record extending back ca. 5,700 years, to the waning Altithermal, indicating increased aridity at the beginning of the record, ameliorating to modern conditions. The local vegetation has remained a relatively stable, cool climate grassland vegetation community throughout the investigated period. A hyperlocal signal of woody vegetation is present in the phytolith assemblage during higher aridity conditions at the beginning of the record, most likely due to soil moisture dynamics and aspects of phytolith transportation.

Sampling column 3 was collected from a riparian coulee under a closed canopy community of trees and tall shrubs just a few meters downstream from the transition to a mixed grassland and marginal low shrub community. This location provided a long column of continuous sediments but terminated in a layer of water-saturated, very loose sediment. Sampling column 3 has a shorter record extending back ca. 3,500 years. The phytolith assemblages here indicate an initial open grassland community, followed by a long stable period of grassland and marginal shrubs, before a recent period of fluctuation between open grassland, mixed grassland and shrub, and closed canopy tall shrub and tree vegetation communities. The vegetation appears to be linked to the transriparian soil moisture gradient of the Red Deer River, expressed locally as the intrariparian soil moisture gradient of the coulee. When the water table sinks, the open grassland vegetation community advances from upstream and when the water table rises, the woody vegetation community, including shrubs and even trees, advances from downstream. Because the river levels are influenced most heavily by precipitation and glacial melt in the mountains, at this location the phytolith assemblage likely records a hyperlocal vegetation response to extra-regional conditions. Further testing is required to support this hypothesis.

Marginal and micro-environment vegetation communities within the Grassland Natural Region may be more sensitive to environmental changes than the dominant vegetation community. The phytolith record from the riparian coulee sampling column was more diverse and evidenced more fluctuation than the assemblage from the depression in the upland mixed grassland. Additionally, the coulee sampling location was at the margin of the high moisture zone within the coulee intrariparian gradient, which may have made relatively small water table fluctuations more visible in the record. These results appear to support the proposition that ecotones may be well suited to achieving higher resolution paleoenvironmental data. On the other hand, perennial river valleys, such as the Red Deer River, may also obfuscate climate changes, providing perennial water when the region is experiencing higher aridity. A sediment record longer than the one we collected from the coulee and extending into the Altithermal would better illuminate how the vegetation community changes in a perennial river valley during periods of increased regional drought. A study of this kind would also need to take into account precipitation and glacial melt conditions at the river headwaters in the mountains.

The secondary goal of this thesis was to examine whether there is any evidence of potential human impact on the vegetation, specifically an increased abundance of beneficial plants relative to other flora. I was not able to achieve this goal. The groundwork to make identifications of this type has yet to be done and will require a list of plants of known ethnobotanical importance, a robust phytolith reference collection of those plants, and for those plants to be identifiable by their phytoliths, whether through diagnostic morphotypes or through statistically identifiable assemblage compositions. There are ethnobotanies of First Nations groups who inhabit or inhabited the northern prairies (Hellson 1974; Johnston 1982; Wilson 2014; Zarrillo and Kooyman 2006) but there has not been enough research on the phytoliths of these plants. This question would provide fertile ground for future researchers.

Maok-skoistch is a location with fantastic potential for humans to influence the environment. This ecotonal location is already a mosaic of environments – grasslands, upland slough wetlands, slope fens, mixed grass and shrub, riparian coulee woodlands, river valley, badlands, and dune fields. Such an attractive location would certainly be revisited often. Human Traditional Ecological Knowledge gained over generations of observing, interacting, learning, and teaching would have translated into Traditional Ecological Relationship Maintenance. These are behaviours that maintain proper, reciprocal relations between human and non-human nature, which allow both to thrive and reproduce, creating increased abundance and diversity. The cultural practices that maintain good relationships were taught through stories explaining what to do, where and why to do it, and how the practices originated, as well as anchoring proper behaviours in a moral framework (Hernandez 1999). In this way the ritual and the quotidian merge to become a lifeway (Hernandez 1999) rather than a collection of techniques to maximize economic efficiencies.

The stone constructions are highly visible evidence that lifeways changed the physical world in which people lived, in ways necessary to reproducing themselves, their culture, and the non-human world. It is not a large logical leap to conclude if people were moving stones, they were likely also influencing plant species and communities in the various environments present in the study area. It seems likely people have been creating and maintaining these sorts of relationships with land and stone, plants and animals into the deep human past and certainly as long as humans have lived on the Northern Great Plains. These relationships change and grow organically in response to not just changes in temperature, precipitation, and insolation, but also the history of interactions among all human and non-human members of the community. We, as researchers, seek to understand these relationships and their long history.

I hope this study will be helpful to other researchers new to phytoliths to understand some of the issues and considerations necessary to be successful. I also hope this study will inspire future researchers to take up some of the questions and resolve some of the issues necessary to advance paleoenvironmental, paleoecological, and archaeological research using phytoliths in the Canadian Prairie Provinces.

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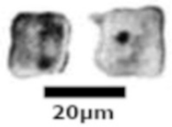
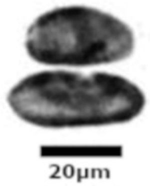
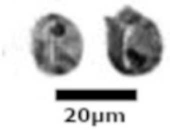
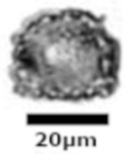
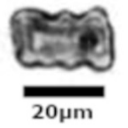
Appendix A: Morphotypes Reference Collection

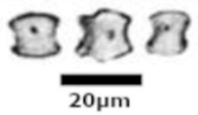
Grass (Poa) Diagnostic Morphotypes

Pooid/Festucoid Sub-Family

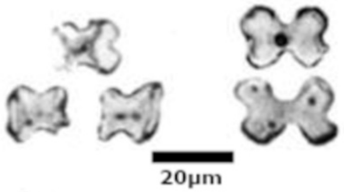
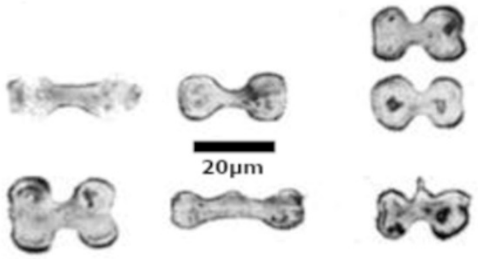
Image Source	Previous Name	ICPN	Microphotographs
Twiss 1987	Circular (rondel)	Orbicular (2D); Rondel (3D)	
Twiss 1987	Rectangular	Rectangular (2D); Trapeziform short cell (3D)	
Twiss 1987	Elliptical	Oblong	
Twiss 1987	Crescent, hat, biconvex, crescent moon, elliptical	Conical irregular base	
Twiss 1987	Circular crenate	Orbicular crenate	
Twiss 1987	Oblong	Compressed trapeziform psilate (3D); oblong psilate (2D)	

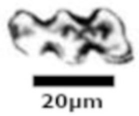
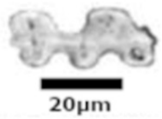
Twiss 1987	Oblong, sinuous	Compressed trapeziform sinuate (3D); oblong sinuate (2D)	

Chloridoid Sub-Family

Image Source	Previous Name	ICPN	Microphotographs
Twiss 1987	Saddle	Saddle	
Twiss 1987	Thin saddle	Elongated saddle	

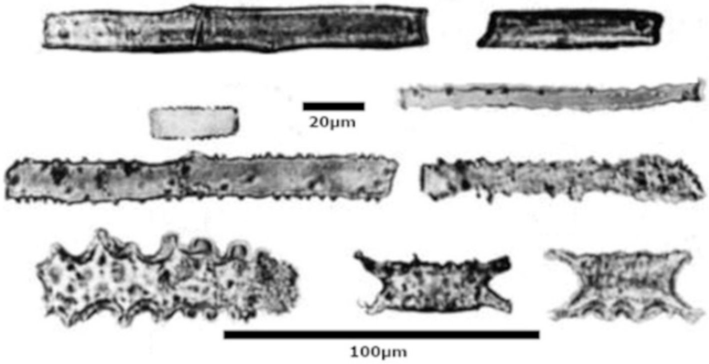
Panicoid Sub-Family

Image Source	Previous Name	ICPN	Microphotographs
Twiss 1987	Cross	Cross	
Twiss 1987	Dumbbell	Bilobate short cell	

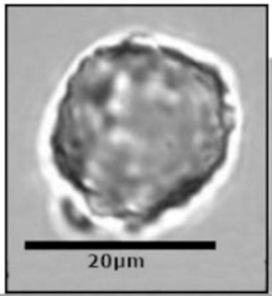
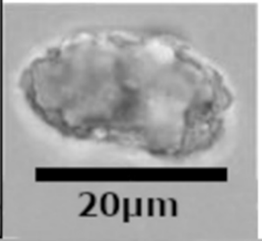
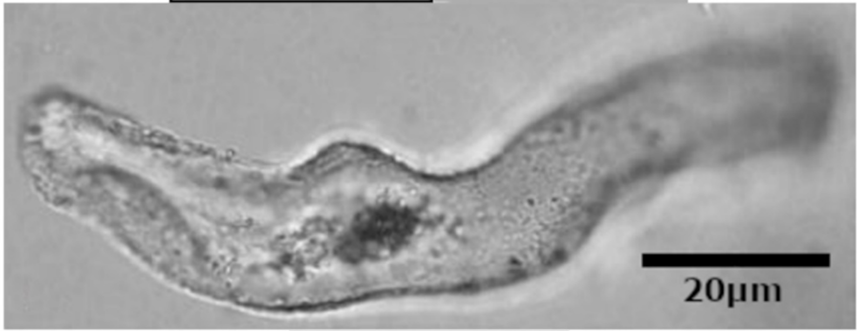
Twiss 1987	Complex dumbbell (polylobate), regular	Polylobate regular	
Twiss 1987	Complex dumbbell (polylobate), irregular	Polylobate irregular	
Twiss 1987?	Crenate	Oblong crenate	

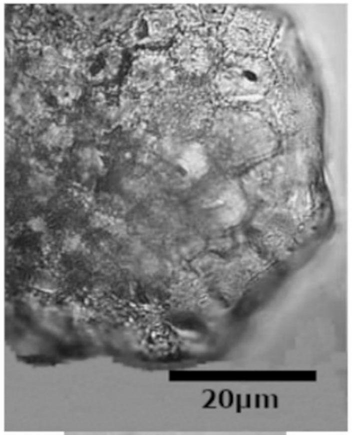
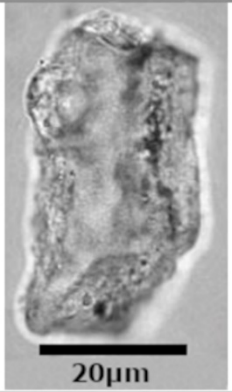
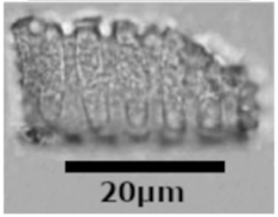
All grass sub-families (not part of count)

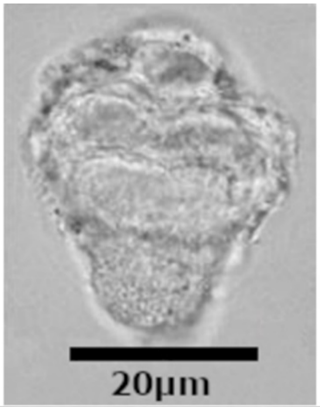
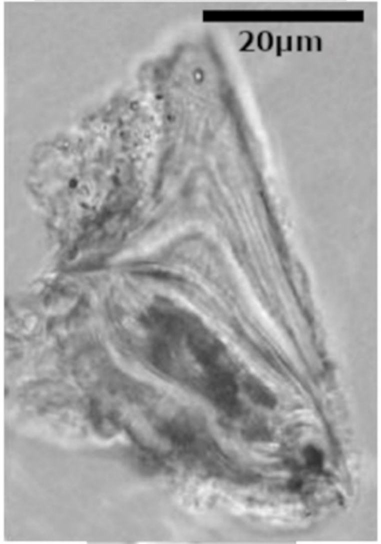
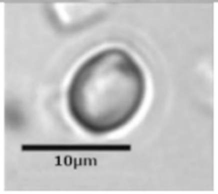
Image Source	Previous Name	ICPN	Microphotographs
Bremond, Alexandre, Peyron, and Guiot 2005	Fan-shaped bulliform	Cuneiform bulliform cell	

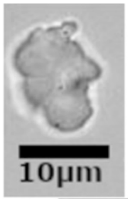
Bremond, Alexandre, Peyron, and Guiot 2005	Acicular	Acicular	
Twiss 1987	Elongate; grass long cells	Rectangular psilate; rectangular sinuous; rectangular echinate; elongate terminally concave;	

Non-Grass – woody and herbaceous dicots, conifers, and ferns

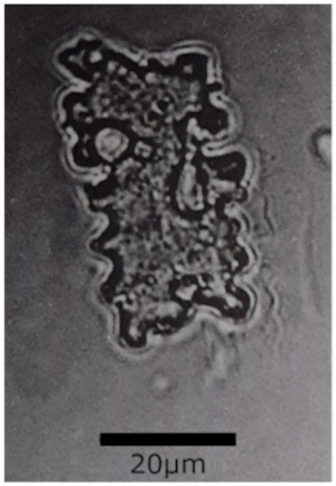
Study	Previous	ICPN	Microphotographs
(L) Bremond, Alexandre, Peyron, and Guiot 2005; (R)Stromberg 2004	Rugose/rough spherical	Globular verrucate (3D); Orbicular verrucate (2D)	 
Stromberg 2004	Elongate with tapering ends, branched, faceted, or knobby surface	Irregular or contorted terminally attenuated elongate occasionally facetate, verrucate, or with processes sclereids	
Stromberg 2004	Polyhedral (8+ sides) plates or sheets	Irregular flat polyhedron	

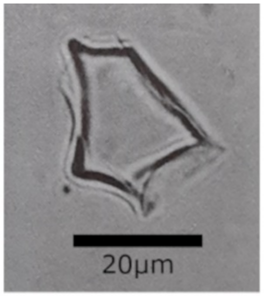
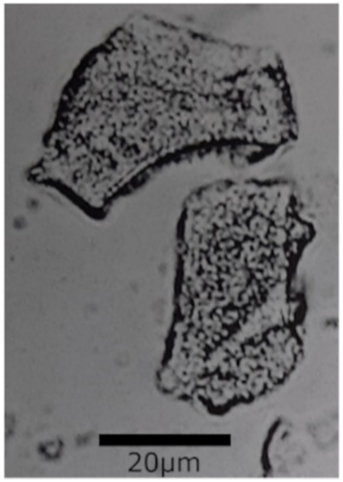
Stromberg 2004	Jigsaw puzzle plates or sheets	Irregular flat marginally lobate	
Stromberg 2004	Honeycomb/Aggregate	Irregular polyhedron favose	
Stromberg 2004	Polyhedral (8+ sides) blocky, relatively plate-like, faceted	Polyhedron favose sub-tabular	
Stromberg 2004	Elongate with annular, helical, or reticulate ornamentation	Elongate sulcate or reticulate tracheid (2D); cylindrical sulcate or reticulate tracheid (3D)	

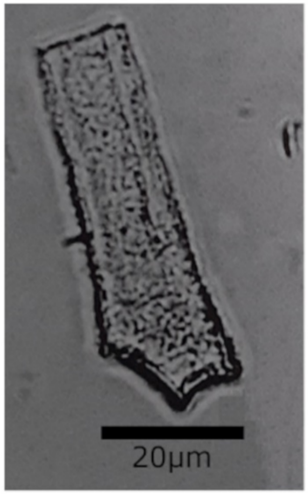
Stromberg 2004	Verrucate cystolith	Orbicular verrucate single abaxial process	
Stromberg 2004	Armed, articulated hair (non-grass trichome)	Acicular articulated multicellular (>2) trichome or Stellate or bi-armed trichome hair	
Bremond, Alexandre, Peyron, and Guiot 2005; Stromberg 2004	Small, smooth, opaque spheres	Globular psilate (3D); Orbicular psilate (2D)	

Stromberg 2004	Compound sphere	Articulated fine polyglobular	 10μm
Stromberg 2004	Spherical, Angular, or Irregular bodies with concentric internal lamina (vesicular infilling)	Globular (3D)/Spherical (2D), Angulate, or Irregular bodies with concentric internal lamina	 10μm 10μm

Forest Indicators of Bozarth (1993)

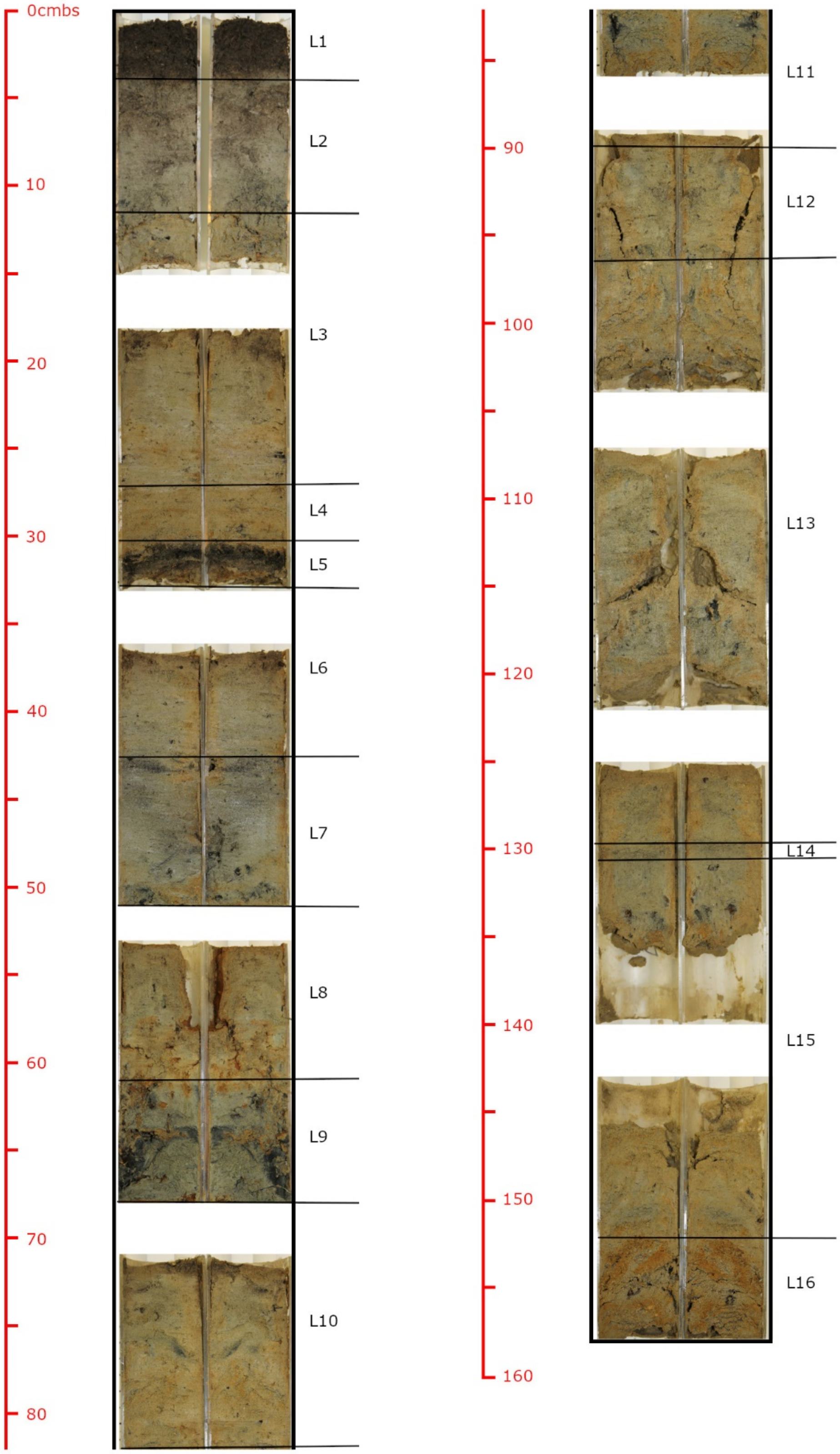
Species	Previous	ICPN	Microphotographs
Picea glauca (white spruce)	Thin plate with wavy margins on all 4 sides	Rectangular flat marginally lacunose	 20μm

Most common in *Picea glauca* (white spruce) but also common in many conifers, and some grasses	Blocky smooth polyhedrons	Irregular polyhedron psilate	
Picea mariana (black spruce)	Blocky grainy-surfaced polyhedrons	Irregular polyhedron granulate	

Pinus banksiana (jack pine)	Elongate polyhedron tracheids with bordered pits	Elongate polyhedron bordered scrobiculate	
Larix larciana (larch)	Smooth elongate plate, parallel sides, pointed end	Elongate sub-rectangular flat single abrupt terminal apex	

Appendix B: Sampling Column 3 Sediment Layers

Sampling Column 3 Layers



Appendix C: Radiocarbon Dating Results

A.E. Lalonde AMS Laboratory
Canadian centre for AMS and environmental radionuclide research
uOttawa

October 02, 2018

Matthew Larsen (Dr. Glenn Stuart)
University of Saskatchewan
55 Campus Drive
Saskatoon, Saskatchewan
S7N 5B1
Canada
mel847@mail.usask.ca
glenn.stuart@usask.ca

RE: Radiocarbon analysis results, *Project Title: Minor Medicine Wheel Ceremonial Site Complex Paleovegetation Reconstruction*

Dear Mr. Larsen and Dr. Stuart,

Please see below for radiocarbon analysis results for 4 organic samples received 2018-08-28. Your samples were processed without issue.

The preparators for your samples were Sarah Murseli and Carolyn Dziawa, and the AMS analyst was Dr. Xiao-Lei Zhao. If you have specific questions about the analyses or calibration, please direct them to smurseli@uottawa.ca. If this data is used in publication or for a graduate thesis, we would appreciate a copy of the abstract for our records. In the interest of future researchers, we encourage you to take the time to submit your radiocarbon results to either the Canadian Archaeological Radiocarbon Database (CARD), or to the Neotoma Paleoecology Database.

Thank you for choosing the André E. Lalonde AMS Laboratory. We look forward to working with you again.

Sincerely,

Dr. W. E. Kieser
Director, A. E. Lalonde AMS Laboratory
Associate Professor, Department of Physics
25 Templeton St., Ottawa, ON, K1N 6N5, Canada
www.ams.uottawa.ca

Sample Processing

Sample pretreatment techniques and definitions of media codes can be found in Crann et al. (2017). For more information about the equipment used for sample preparation, please see St-Jean et al. (2017). Both manuscripts can be found at www.ams.uottawa.ca/Research

Reporting of Data

In this analysis report, we have followed the conventions recommended by Millard (2014).

Radiocarbon Analysis

Radiocarbon analyses are performed on a 3MV tandem accelerator mass spectrometer built by High Voltage Engineering (HVE). $^{12,13,14}C^{+3}$ ions are measured at 2.5 MV terminal voltage with Ar stripping. The fraction modern carbon, $F^{14}C$, is calculated according to Reimer et al. (2004) as the ratio of the sample $^{14}C/^{12}C$ ratio to the standard $^{14}C/^{12}C$ ratio (in our case Ox-II) measured in the same data block. Both $^{14}C/^{12}C$ ratios are background-corrected and the result is corrected for spectrometer and preparation fractionation using the AMS measured $^{13}C/^{12}C$ ratio and is normalized to $\delta^{13}C$ (PDB). Radiocarbon ages are calculated as $-8033\ln(F^{14}C)$ and reported in ^{14}C yr BP (BP=AD 1950) as described by Stuiver and Polach (1977). The errors on 14C ages (1σ) are based on counting statistics and $^{14}C/^{12}C$ and $^{13}C/^{12}C$ variation between data blocks. We do not report $\delta^{13}C$ as it is measured on the AMS and contains machine fractionation.

Calibration

Calibration was performed using OxCal v4.3 (Bronk Ramsey, 2009). Calibrated results are given as a range (or ranges) with an associated probability as point estimates (mean, median) cannot represent the uncertainties involved (Millard, 2014). We acknowledge that point estimates are often desired and are thus included on the calibration plots in the Appendix, but we recommend that data tables used in publication maintain calibrated age ranges.

Where the $F^{14}C$ is less than 1, the IntCal13 calibration curve was used for Northern Hemisphere samples and ShCal13 for Southern Hemisphere samples (Reimer et al., 2013).

For samples with an $F^{14}C$ greater than 1, the post-bomb atmospheric curve was used (Hua et al., 2013). Post-bomb samples have two age ranges due to calibration on both sides of the bomb pulse. There are methods for deciding which side of the bomb pulse to select as the more appropriate date so feel free to contact us for further information.

Samples that calibrate between the 1700's and early 1950's will always result in a calibrated age range covering the majority of this period. This is due to the "Seuss Effect", which is a flat portion of the calibration curve caused by the burning of fossil fuels.

Rounding

Calibrated ages and ranges are rounded to the nearest year which may be too precise in many instances. Users are advised to round results to the nearest 10 yr for samples with standard deviation in the radiocarbon age greater than 50 yr, but rounding should only be done at the final reporting stage as intermediate rounding may introduce errors (Millard, 2014).

References

Bronk Ramsey C. 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51: 337–360.

Crann CA, Murseli S, St-Jean G, Zhao X, Clark ID, Kieser WE. 2017. First status report on radiocarbon sample preparation at the A.E. Lalonde AMS Laboratory (Ottawa, Canada). Radiocarbon 59(3): 695–704. http://doi.org/10.1017/RDC.2016.55

Hua Q, Barbetti M, Rakowski AZ. 2013. Atmospheric radiocarbon for the period 1950-2010. *Radiocarbon* 55(4): 2059–2072.

Millard A. 2014. Conventions for reporting radiocarbon determinations. *Radiocarbon* 56(2): 555–559.

Reimer PJ, Bard E, Bayliss A, Beck JW, Blackwell PG, Bronk Ramsey C, Buck CE, Cheng H, Edwards RL, Friedrich M, Grootes PM, Guilderson TP, Haflidason H, Hajdas I, Hatté C, Heaton TJ, Hogg AG, Hughen KA, Kaiser KF, Kromer B, Manning SW, Niu M, Reimer RW, Richards DA, Scott EM, Southon JR, Turney CSM, van der Plicht J. 2013. IntCal13 and MARINE13 radiocarbon age calibration curves 0-50000 years calBP. Radiocarbon 55(4): 1869–1887.

St-Jean G, Kieser WE, Crann CA, Murseli S. 2017. Semi-automated equipment for CO2 purification and graphitization at the A.E. Lalonde AMS Laboratory (Canada). Radiocarbon 59(3): 941–956. https://doi.org/10.1017/RDC.2016.57

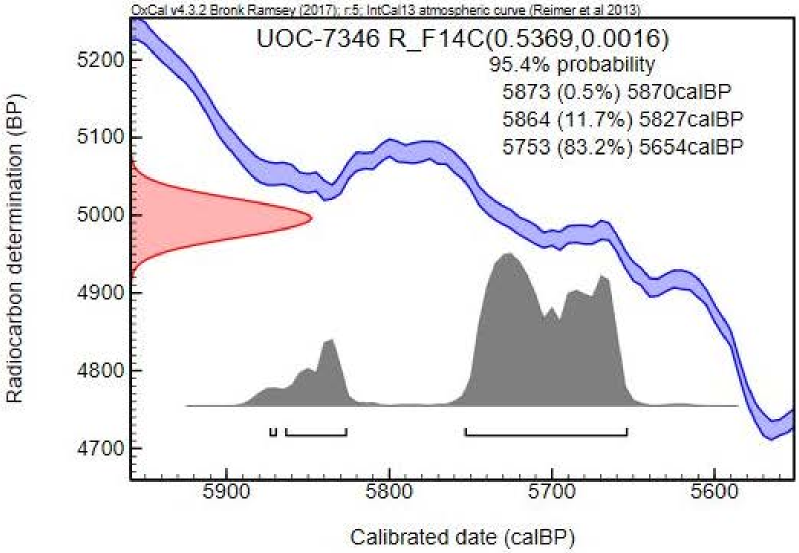
Stuiver M, Polach HA. 1977. Discussion: reporting of 14C data. Radiocarbon 19(3):355–63.

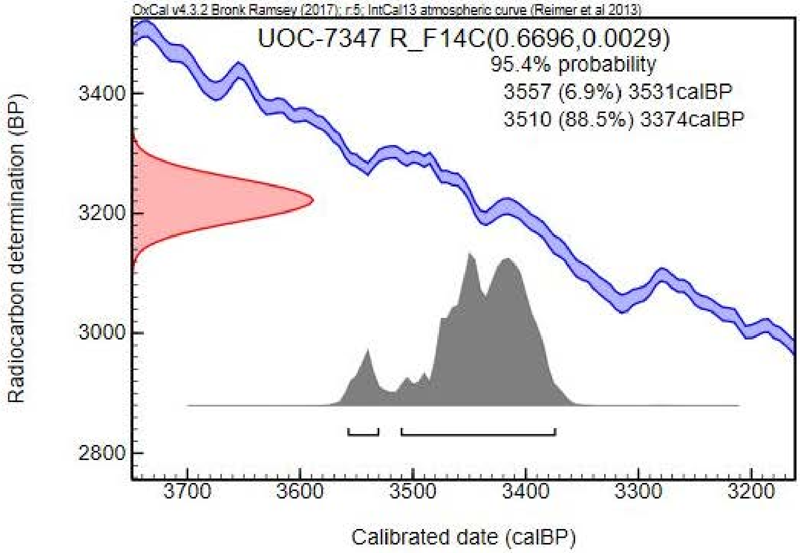
Table 1. Radiocarbon results. Calibration was performed using OxCal v4.3 (Bronk Ramsey, 2009) and the IntCal13 calibration curve (Reimer et al., 2013). Material codes are described in Crann et al. (2017).

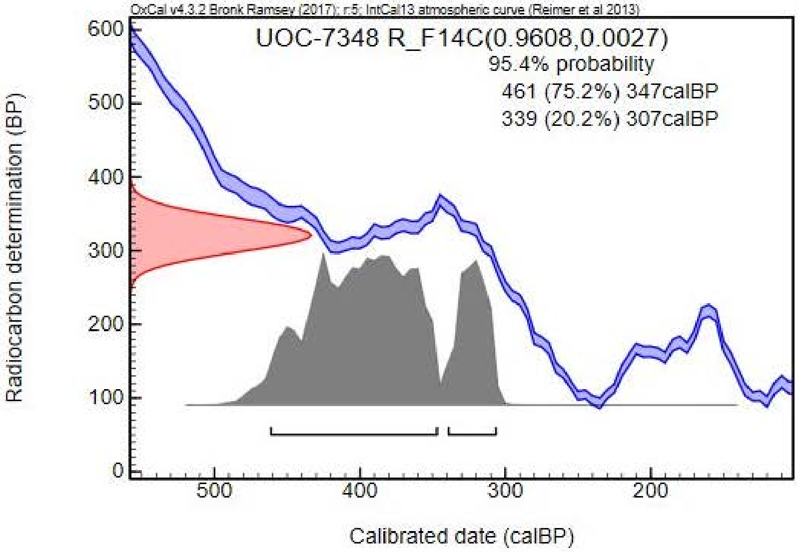
Lab ID	Submitter ID	Material	Mat. Code[a]	^{14}C yr BP	±	F^{14}C	±	cal BP
UOC-7346	CL2.15	Sediment	A	4996	24	0.5369	0.0016	5873 – 5870 (0.5%) 5864 – 5827 (11.7%) 5753 – 5654 (83.2%)
UOC-7347	CL3.25	Sediment	A	3222	34	0.6696	0.0029	3557 – 3531 (6.9%) 3510 – 3374 (88.5%)
UOC-7348	CL3.6A	Sediment	A	321	22	0.9608	0.0027	461 – 347 (75.2%) 339 – 307 (20.2%)
UOC-7349	CL3.14	Botanical	AAA	177	22	0.9782	0.0027	288 – 260 (18.1%) 222 – 140 (56.8%) 25 – 0 (20.6%)[‡]

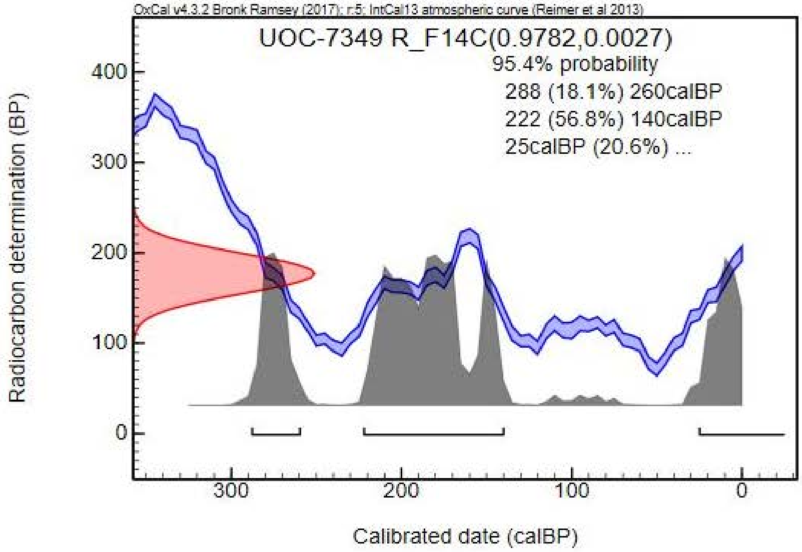
[‡] Seuss Effect

Appendix – Calibration plots






OxCal v4.3.2 Bronk Ramsey (2017); r:5; IntCal13 atmospheric curve (Reimer et al 2013)
UOC-7348 R_F14C(0.9608,0.0027)
95.4% probability
461 (75.2%) 347calBP
339 (20.2%) 307calBP
Radiocarbon determination (BP)
600
500
400
300
200
100
0
500
400
300
200
Calibrated date (calBP)


OxCal v4.3.2 Bronk Ramsey (2017); r:5; IntCal13 atmospheric curve (Reimer et al 2013)
UOC-7349 R_F14C(0.9782,0.0027)
95.4% probability
288 (18.1%) 260calBP
222 (56.8%) 140calBP
25calBP (20.6%) ...
Radiocarbon determination (BP)
400
300
200
100
0
300
200
100
0
Calibrated date (calBP)

5

Appendix D: Morphotypes Results Tables – Cardinal Values

Table D. 1: Morphotypes results - cardinal values for all morphotypes observed at least once.

			MS1	MS2	MS3	MS4	MS5	MS6	MS7	Total
Grass	Pooid/Festucoid	Orbicular / Rondel	36	40	30	27	33	37	27	230
		Rectangular / Trapeziform short cell	211	203	155	210	187	176	192	1334
		Oblong	15	17	14	13	18	10	15	102
		Conical irregular base	19	12	12	17	29	20	9	118
		Orbicular crenate								
		Compressed trapeziform psilate (3D) / Oblong psilate (2D)								
		Compressed trapeziform sinuate (3D) / Oblong sinuate (2D)								
		Total	262	260	199	250	238	223	234	1666
	Chloridoid	Saddle	5	3	1	1	2	1	2	15
		Elongated saddle						1		1
		Total	5	3	1	1	2	2	2	16
	Panicoid	Bilobate short cell	2				1	1	1	5
		Polylobate regular								
		Polylobate irregular								
		Oblong crenate								
		Total								
Non-Grass	Woody Dicots	Globular verrucate (3D) / Orbicular verrucate (2D)				1		2		3
		Irregular or contorted terminally attenuated elongate occasionally facetate, verrucate, or with processes sclereids								
		Total				1		2		3
	Woody and Herbaceous Dicots, Conifers, Ferns	Irregular flat polyhedron								
		Irregular polyhedron favose								
		Polyhedron favose sub-tabular								
		Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)								
		Globular psilate (3D) / Orbicular psilate (2D)	3	2	2	1	1	2	6	17
		Globular (3D) / Spherical (2D), Angulate, or Irregular bodies; with concentric internal lamina								
		Total								
	Forest Indicators	Irregular polyhedron psilate								
		Irregular polyhedron granulate								
		Total								
		GRAND TOTAL	291	277	214	270	271	250	252	1825
		OBSERVATIONS REMOVED FROM PCA	24	14	14	18	31	23	16	140
		REMAINING TOTAL	267	263	200	252	240	227	236	1685

			MS1	MS2	MS3	MS4	MS5	MS6	MS7	Total
Others	Asteraceae	Opaque perforated tabular								
	Unidentified	Stellate (y-shaped)								
	Grass non-diagnostic	Cuneiform bulliform cell				1				1
		Acicular	2			1				3
		Elongate, various types	14	10	7	14	14	7	7	73
	Diatoms	Circular coronal (a centric sp. [Aulocoseira?])								
		Oblong striate (a biraphid sp.)								

Table D.1 (cont.): Morphotypes results - cardinal values for all morphotypes observed at least once.

			2.0	2.2	2.3	2.5	2.7	2.9	2.11	2.13	2.15	Total	Mean	Median	sd
Grass	Pooid/Festucoid	Orbicular / Rondel	36	44	45	50	37	55	54	61	49	431	47.89	49	8.28
		Rectangular / Trapeziform short cell	92	104	186	165	144	114	188	181	132	1306	145.11	144	36.82
		Oblong	18	7	10	16	6	13	14	13	4	101	11.22	13	4.76
		Conical irregular base	13	8	22	39	34	26	31	21	29	223	24.78	26	9.92
		Orbicular crenate	2									2	0.22		0.67
		Compressed trapeziform psilate (3D) / Oblong psilate (2D)													
		Compressed trapeziform sinuate (3D) / Oblong sinuate (2D)	1									1	0.11		0.33
		Total	149	155	241	231	187	182	256	255	185	1841	204.56	187	41.77
	Chloridoid	Saddle	1							1		2	0.22		0.44
		Elongated saddle			1							1	0.11		0.33
		Total	1		1					1		3	0.33		0.50
	Panicoid	Bilobate short cell		2	2	1						5	0.56		0.88
		Polylobate regular													
		Polylobate irregular													
		Oblong crenate	1									1	0.11		0.33
		Total	1									1	0.11		0.33
Non-Grass	Woody Dicots	Globular verrucate (3D) / Orbicular verrucate (2D)							1	1	2	4	0.44		0.73
		Irregular or contorted terminally attenuated elongate occasionally facetate, verrucate, or with processes sclereids													
		Total							1	1	2	4	0.44		0.73
	Woody and Herbaceous Dicots, Conifers, Ferns	Irregular flat polyhedron													
		Irregular polyhedron favose													
		Polyhedron favose sub-tabular													
		Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)													
		Globular psilate (3D) / Orbicular psilate (2D)	77	44	24	12	14	7	7	10	6	201	22.33	12	23.79
		Globular (3D) / Spherical (2D), Angulate, or Irregular bodies; with concentric internal lamina													
		Total													
	Forest Indicators	Irregular polyhedron psilate													
		Irregular polyhedron granulate													
		Total													
		GRAND TOTAL	241	209	290	283	235	215	295	288	222	2278	253.111	241	35.473
		OBSERVATIONS REMOVED FROM PCA	90	54	48	52	48	33	38	31	35	429	47.6667	48	18.021
		REMAINING TOTAL	151	155	242	231	187	182	257	257	187	1849	205.444	187	41.899

			2.0	2.2	2.3	2.5	2.7	2.9	2.11	2.13	2.15	Total
Others	Asteraceae	Opaque perforated tabular	1									1
	Unidentified	Stellate (y-shaped)										
	Grass non-diagnostic	Cuneiform bulliform cell										
		Acicular	5			1					1	7
		Elongate, various types	85	18	29	20	14	9	11	20	15	221
	Diatoms	Circular coronal (a centric sp. [Aulocoseira?])										
		Oblong striate (a biraphid sp.)	3									3

Table D.1 (cont.): Morphotypes results - cardinal values for all morphotypes observed at least once.

			3.0	3.2	3.3	3.5	3.6A	3.6B	3.7	3.9	3.11	3.13	3.14
Grass	Pooid/Festucoid	Orbicular / Rondel	31	32	30	24	23	39	38	8	30	16	25
		Rectangular / Trapeziform short cell	84	98	90	110	107	88	98	80	113	122	97
		Oblong	29	6	8	2	2	1	1	2	5	1	1
		Conical irregular base	3	57	74	49	67	72	59	96	50	62	79
		Orbicular crenate	2										
		Compressed trapeziform psilate (3D) / Oblong psilate (2D)	2	1									
		Compressed trapeziform sinuate (3D) / Oblong sinuate (2D)	6										
		Total	154	137	128	136	132	128	137	90	148	139	123
	Chloridoid	Saddle	6	10	2	3	2	2	1		1	1	
		Elongated saddle							1				
		Total	6	10	2	3	2	2	2		1	1	
	Panicoid	Bilobate short cell	1					1					
		Polylobate regular	5	1									
		Polylobate irregular	2		2								
		Oblong crenate	8			2							
		Total	15	1	2	2							
Non-Grass	Woody Dicots	Globular verrucate (3D) / Orbicular verrucate (2D)	8	1	1	2		2		3		1	1
		Irregular or contorted terminally attenuated elongate occasionally facetate, verrucate, or with processes sclereids	1										
		Total	8	1	1	2		2		3		1	1
	Woody and Herbaceous Dicots, Conifers, Ferns	Irregular flat polyhedron	1	1									
		Irregular polyhedron favose		1		1							
		Polyhedron favose sub-tabular				1							
		Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)		1		1							
		Globular psilate (3D) / Orbicular psilate (2D)	10	2		2	1	3	5	13	1	2	
		Globular (3D) / Spherical (2D), Angulate, or Irregular bodies; with concentric internal lamina	1										
		Total	1	3		2							
	Forest Indicators	Irregular polyhedron psilate	1	1	1	2							
		Irregular polyhedron granulate	1		1	1							
		Total	1	1	1	2							
		GRAND TOTAL	202	212	209	200	202	208	203	202	200	205	203
		OBSERVATIONS REMOVED FROM PCA	17	59	75	53	68	76	64	109	51	64	79
		REMAINING TOTAL	185	153	134	147	134	132	139	93	149	141	124

Others	Asteraceae	Opaque perforated tabular	1	10	3	4					1	1	
	Unidentified	Stellate (y-shaped)				2							
	Grass non-diagnostic	Cuneiform bulliform cell		1	1	2							
		Acicular	13	2	2	3		1	1				
		Elongate, various types	167	25	36	38	49	14	38	12	26	34	14
	Diatoms	Circular coronal (a centric sp. [Aulocoseira?])		1	1						1		
		Oblong striate (a biraphid sp.)											

Table D.1 (cont.): Morphotypes results - cardinal values for all morphotypes observed at least once.

			3.15	3.17	3.19	3.21	3.22	3.23	3.25	3.26	Totals	Mean	Median	sd
Grass	Pooid/Festucoid	Orbicular / Rondel	29	26	30	44	36	57	51	42	611	32.16	30	11.58
		Rectangular / Trapeziform short cell	99	116	125	116	115	125	119	99	2001	105.32	107	14.01
		Oblong	4		8	7	10	6	4	5	102	5.37	4	6.41
		Conical irregular base	62	58	34	42	38	23	38	52	1015	53.42	57	21.23
		Orbicular crenate				1					3	0.16		0.50
		Compressed trapeziform psilate (3D) / Oblong psilate (2D)			2						5	0.26		0.65
		Compressed trapeziform sinuate (3D) / Oblong sinuate (2D)									6	0.32		1.38
		Total	132	142	165	168	161	188	174	146	2728	143.58	139	21.87
	Chloridoid	Saddle		1	1						30	1.58	1	2.52
		Elongated saddle									1	0.05		0.23
		Total		1	1						31	1.63	1	2.52
	Panicoid	Bilobate short cell								1	3	0.16		0.37
		Polylobate regular									6	0.32		1.16
		Polylobate irregular									4	0.21		0.63
		Oblong crenate									10	0.53		1.87
		Total									20	1.05		3.44
Non-Grass	Woody Dicots	Globular verrucate (3D) / Orbicular verrucate (2D)	1	1	1		1				23	1.21	1	1.84
		Irregular or contorted terminally attenuated elongate occasionally facetate, verrucate, or with processes sclereids									1	0.05		0.23
		Total	1	1	1		1				23	1.21	1	1.84
	Woody and Herbaceous Dicots, Conifers, Ferns	Irregular flat polyhedron									2	0.11		0.32
		Irregular polyhedron favose									2	0.11		0.32
		Polyhedron favose sub-tabular									1	0.05		0.23
		Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)									2	0.11		0.32
		Globular psilate (3D) / Orbicular psilate (2D)	6		3	2		1		3	54	2.84	2	3.52
		Globular (3D) / Spherical (2D), Angulate, or Irregular bodies; with concentric internal lamina									1	0.05		0.23
		Total									6	0.32		0.82
	Forest Indicators	Irregular polyhedron psilate									5	0.26		0.56
		Irregular polyhedron granulate									3	0.16		0.37
		Total									5	0.26		0.56
		GRAND TOTAL	201	202	204	212	200	212	212	202	3891	204.789	203	4.5041
		OBSERVATIONS REMOVED FROM PCA	68	58	37	44	38	24	38	56	1078	56.7368	58	21.408
		REMAINING TOTAL	133	144	167	168	162	188	174	146	2813	148.053	146	22.673

			3.15	3.17	3.19	3.21	3.22	3.23	3.25	3.26	Totals
Others	Asteraceae	Opaque perforated tabular	1								21
	Unidentified	Stellate (y-shaped)									2
	Grass non-diagnostic	Cuneiform bulliform cell									4
		Acicular		1	1				1		25
		Elongate, various types	21	15	24	22	33	21	11	34	634
	Diatoms	Circular coronal (a centric sp. [Aulocoseira?])									3
		Oblong striate (a biraphid sp.)									

Table D. 2: Morphotypes results - Assemblage totals and basic statistics.

			Cardinal totals	Proportion of grand total	Cardinal mean	Cardinal median	Cardinal sd	Mean of sample relative values	Median Sample relative value	Sample relative value sd	Removed from analyses
Grass	Pooid/Festucoid	Orbicular / Rondel	1272	20.04%	36.34	36	11.80	20.42%	20.16%	6.08%	
		Rectangular / Trapeziform short cell	4641	73.12%	132.60	116	40.55	72.90%	74.44%	7.97%	
		Oblong	305	4.81%	8.71	7	6.58	4.48%	4.17%	3.18%	
		Conical irregular base	1356		38.74	34	23.25				X
		Orbicular crenate	5	0.08%	0.18		0.55	0.09%		0.30%	
		Compressed trapeziform psilate (3D) / Oblong psilate (2D)	5	0.08%	0.26		0.65	0.08%		0.29%	
		Compressed trapeziform sinuate (3D) / Oblong sinuate (2D)	7	0.11%	0.25		1.14	0.11%		0.56%	
		Total	6235	98.24%	178.14	165	48.38	98.09%	99.17%	3.36%	
	Chlorido id	Saddle	47	0.74%	1.34	1	2.07	0.77%	0.44%	1.25%	
		Elongated saddle	3	0.05%	0.10		0.31	0.04%		0.15%	
		Total	50	0.79%	1.43	1	2.06	0.81%	0.50%	1.25%	
	Panicoid	Bilobate short cell	13		0.41		0.67				X
		Polylobate regular	6	0.09%	0.32		1.16	0.10%		0.47%	
		Polylobate irregular	4	0.06%	0.21		0.63	0.07%		0.31%	
		Oblong crenate	11	0.17%	0.39		1.55	0.18%		0.76%	
		Total	21	0.33%	0.60		2.56	0.35%		1.40%	
Non-Grass	Woody Dicots	Globular verrucate (3D) / Orbicular verrucate (2D)	30	0.47%	1.00	1	1.55	0.55%		0.93%	
		Irregular or contorted terminally attenuated elongate occasionally facetate, verrucate, or with processes sclereids	1		0.05		0.23				X
		Total	30	0.47%	0.86		1.48	0.55%		0.93%	
	Woody and Herbaceous Dicots, Conifers, Ferns	Irregular flat polyhedron	2	0.03%	0.11		0.32	0.03%		0.14%	
		Irregular polyhedron favose	2	0.03%	0.11		0.32	0.04%		0.16%	
		Polyhedron favose sub-tabular	1		0.05		0.23				X
		Elongate sulcate or reticulate tracheid (2D) / Cylindrical sulcate or reticulate tracheid (3D)	2	0.03%	0.11		0.32	0.04%		0.16%	
		Globular psilate (3D) / Orbicular psilate (2D)	272		7.77	3	14.69				X
		Globular (3D) / Spherical (2D), Angulate, or Irregular bodies; with concentric internal lamina	1		0.05		0.23				X
		Total	6	0.09%	0.17		0.62	0.11%		0.40%	
	Forest Indicato rs	Irregular polyhedron psilate	5	0.08%	0.26		0.56	0.09%		0.29%	
		Irregular polyhedron granulate	3		0.16		0.37				X
		Total	5	0.08%	0.14		0.43	0.09%		0.29%	
		GRAND TOTAL	7994		228.4	212	33.244				
		OBSERVATIONS REMOVED FROM PCA	1647		47.057	48	23.005				
		REMAINING TOTAL	6347		181.34	168	47.725				

Others	Asteraceae	Opaque perforated tabular	22
	Unidentified	Stellate (y-shaped)	2
	Grass non-diagnostic	Cuneiform bulliform cell	5
		Acicular	35
		Elongate, various types	928
	Diatoms	Circular coronal (a centric sp. [Aulocoseira?])	3
		Oblong striate (a biraphid sp.)	3
		TOTAL OBJECTS	8992