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Geomorphology and Geoarchaeology of a Small Foredune
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GEOMORPHOLOGY AND GEOARCHAEOLOGY OF A SMALL FOREDUNE COMPLEX ALONG THE EASTERN SHORE OF LAKE MICHIGAN

By

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ABSTRACT

GEOMORPHOLOGY AND GEOARCHAEOLOGY OF A SMALL FOREDUNE COMPLEX ALONG THE EASTERN SHORE OF LAKE MICHIGAN

By

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Sand dunes commonly occur along the eastern shore of Lake Michigan. Most of these dunes occur in large fields that are prominent on topographic maps and aerial photographs. A variety of much smaller dune fields also occur, however, which have yet to be studied, thus their history is largely unknown. This study fills a portion of that void by focusing on a small dune field at the Antrim Creek Natural Area in northwest Lower Michigan. The goal of the study is to reconstruct the geomorphic evolution of the dunes within the context of an emerging geoarchaeological model associated with coastal dunes.

Geomorphic analyses indicate that the dunes at Antrim Creek consist of three foredunes with distinct ridge and swale topography. In order to determine the age of these dunes, OSL samples were taken from each dune crest in a study transect across the field. Results indicate that dune formation began after 1900 ka. Previous archaeological research on the dunes yielded artifacts associated with the Late Woodland (1500-400 cal. yrs. BP) and possibly Late Archaic (~4000-2000 cal. yrs. BP) periods. This study is a contribution to the developing geoarchaeological model of coastal dunes because it suggests that Late Woodland and younger sites may be preserved in small foredune complexes, whereas Archaic sites are not.

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Many people have helped me tremendously during this process and deserve my thanks and gratitude. First and foremost, my husband, Emery, has provided me with constant and unwavering support throughout the entire process. From spending several weekends with me in the field to providing me emotional support, he has been my rock.

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Bill Lovis and Randy Schaetzl, my committee members, are also deserving of recognition. Bill Lovis guided me in the archaeological aspects of this thesis, as well as regaled me with many entertaining stories. Randy Schaetzl introduced me to soils in several fascinating classes and guided me to a career in soil geomorphology.

Naturally, this study would not have been possible without the assistance of the folks at Antrim County Natural Area. They gave me permission to conduct field work as well as provided supporting documents about ACNA.

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Lastly, my parents, Everette and Karen Freeland, provided emotional and logistical support in the completion of this thesis and my degree.

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Chapter I

Introduction and Problem Definition

The eastern shore of Lake Michigan may contain the largest body of freshwater dunes in the world (Peterson and Dersch, 1981). Because these dunes are an important resource in the state, they have been the focus of geological and geomorphic studies for over 100 years (e.g., Cowles, 1899; Dow, 1937; Olson, 1958; Arbogast et al., 2002). Although these studies have produced a good understanding of how the largest dunes have evolved, they have largely ignored the smaller dune fields, perhaps because they are too small to be represented on topographical maps. These dunes are randomly scattered along the lake shore. The purpose of this study is to add to the information associated with these small fields.

In addition to reconstructing the history of the dunes, a secondary goal of the study is assess how the evolution of the landscape is related to known archaeological sites in the area. The archaeological history of northwest Lower Michigan dates back ~11,000 years, from the Paleo-Indian period through contact with Europeans. The earliest inhabitants (~11,000 years ago) were nomadic hunter-gatherers who manufactured distinctive fluted points indicative of Paleo-Indians (Dekin, 1996; Lovis and Bole, 2002). The Early and Middle Archaic periods are poorly understood in northwest Lower Michigan, probably because the sites were located on topographically lower surfaces that became submerged by higher lake-levels during the Nipissing phase of Lake Michigan (Monaghan and Lovis, 2005). In contrast to preceding periods, the Woodland period is better understood because of the relative youth of the sites and better potential for site preservation. Very little is known, however, about the relationship of any cultural periods with coastal dunes along Lake Michigan.

Background

Coastal Dune Studies

The earliest research on Lake Michigan coastal dunes focused on dune formation and how vegetation affects dune formation (Cowles, 1899). Cowles proposed that vegetation plays an important role in stabilizing dunes and forming dunes. Other researchers focused on the physical mechanisms of dune formation (Dow, 1937; Olson, 1958a). Dow (1937) proposed a model of perched dune formation for the dune fields that mantle topographically high headlands underlain by glacial sediments. These studies have shown that perched dunes form during periods of high lake-levels, when increased wave action erodes the bluff and frees up sediment to form dunes. Olson (1958a) focused on foredunes and proposed a model of foredune formation. He suggested that foredunes form during periods of falling lake-levels, when beach-ridges are exposed and then capped with aeolian sand. Vegetation communities colonize and stabilize the beach-ridge/foredune couplet and protect them from erosion during future periods of high lake-levels.

The advent of technological advances in geochronometric dating has allowed researchers to reconstruct the timing of dune formation (Thompson, 1992; Thompson and Baedke, 1995, 1997; Lichter, 1995, 1997). By dating the organics between beach-ridge/foredune swales in large strandplains along the coast, Thompson and Baedke (1997, 2000) derived three intervals of lake-level fluctuations (30, 150, 600 years) and reconstructed a detailed lake-level curve for Lake Michigan. These intervals are also linked to beach-ridge/foredune formation via Olson's (1958a) model. Other researchers (e.g., Arbogast and Loope, 1999; Arbogast et al., 2002) have focused on determining the chronology of large dune fields that mantle topographically low lake terraces in the southeastern part of the lakeshore. These studies have focused on dating organics from buried soils, and have demonstrated that sand is generally supplied to these large dune systems during periods of high lake-levels, which is consistent with the perched dune model for dunes that mantle topographically high headlands (Dow, 1937). As a result of this similarity, Arbogast (in press) proposed that perched dunes be subdivided in to high and low perched systems. At this point in time, however, no work has been conducted on the age and evolution of very small dune fields.

Geoarchaeology

Numerous geoarchaeological studies, representing variable environments and time-periods, have been completed throughout the United States. These studies combine the use of geomorphic methods (i.e. studying stratigraphy, soils, etc.) with archaeological excavations to understand the relationship between the environment and pre-contact groups. Of particular interest to this research are studies that link stratigraphy, soils, and lake-levels to archaeological site preservation. One such study, conducted in the Lahontan Basin, Nevada (Adams *et. al*, 2008) is especially relevant. In this study, the authors used known dated archaeological sites and the elevation of shoreline features to provide a model of archaeological site preservation for the Lahontan Basin. They found that during the early Holocene, lake-levels played a role in controlling the location of

Paleo-Indian site location and preservation, and suggest that it is possible to predict where sites will be located using the elevations of past shorelines.

A similar study has been conducted in the Great Lakes region. Anderton (1999) studied the link between abandoned shorelines, soil development, and archaeological sites along the Upper Peninsula's Lake Superior shoreline. He found that sites can be dated using soil-development indicators (i.e. the POD index; Schaetzl and Mokma, 1988) when datable organics are absent. Using this method, he concluded that sites (i.e. Yellow Feather, Popper, etc) that were previously assigned a cultural period solely on abandoned shoreline correlation could be more definitively dated using soil development.

Research Objectives

Although geoarchaeological studies have been conducted elsewhere in the Great Lakes region, no studies have been completed in small dune fields along the east coast of Lake Michigan. In order to determine how the geology and archaeology of small dune fields along the coast of Lake Michigan fit together, a small dune field with a previously excavated archaeological site must be studied. In this context I studied the dunes at the Antrim Creek Natural Area, which is such a small field that it is not represented on topographic maps. My goal was to reconstruct the geomorphic history of the study area and to assess the relationship with archaeological deposits in a way that can be applied to comparable dune fields. This thesis therefore encompasses the following objectives: (1) to determine the age and evolution of ACNA dunes, (2) reconstruct the geoarchaeological record of the dunes at ACNA, and (3) fit the geoarchaeological model at ACNA within the framework of small coastal dune fields along Lake Michigan.

Chapter II

Literature Review

Extensive coastal dune fields line much of the Lake Michigan shore in both of Michigan's peninsulas, as well as along the southern coast of Lake Superior (Figure 2:1). According to Peterson and Dersch (1981) these dunes probably represent the largest accumulation of freshwater dunes in the world. The topography, vegetation, and climatic conditions in which these dunes evolved have been studied in various ways at many locations over the past 100 years, resulting in a rich literature base. The earliest research (e.g. Cowles, 1899, Olson, 1958a) focused on the ecology of coastal dunes. Over the years, research on Lake Michigan dunes has gradually shifted to a more systematic geomorphologic and quantitative approach (e.g., Anderton and Loope, 1995, Loope and Arbogast and Loope, 1999; Loope and Arbogast, 2000; Arbogast et al., 2002).

This chapter presents an overview of the research that has been completed on the environmental variables associated with the evolution of Michigan's coastal dunes. The first section centers on the history of lake-level fluctuations in Lake Michigan and Lake Superior. This discussion is relevant because the evolution of coastal dunes is intimately tied to the position of the shoreline at any given point in time (e.g., Hesp, 2000). The second portion of the chapter explores the early research on coastal dunes along Lake Michigan, including how vegetation affects the evolution of foredunes and the development of large dunes in various topographic positions. The third section describes modern research completed on the geomorphology and evolution of Lake Michigan coastal dunes. Examples of relevant international dune studies are given in the fourth part

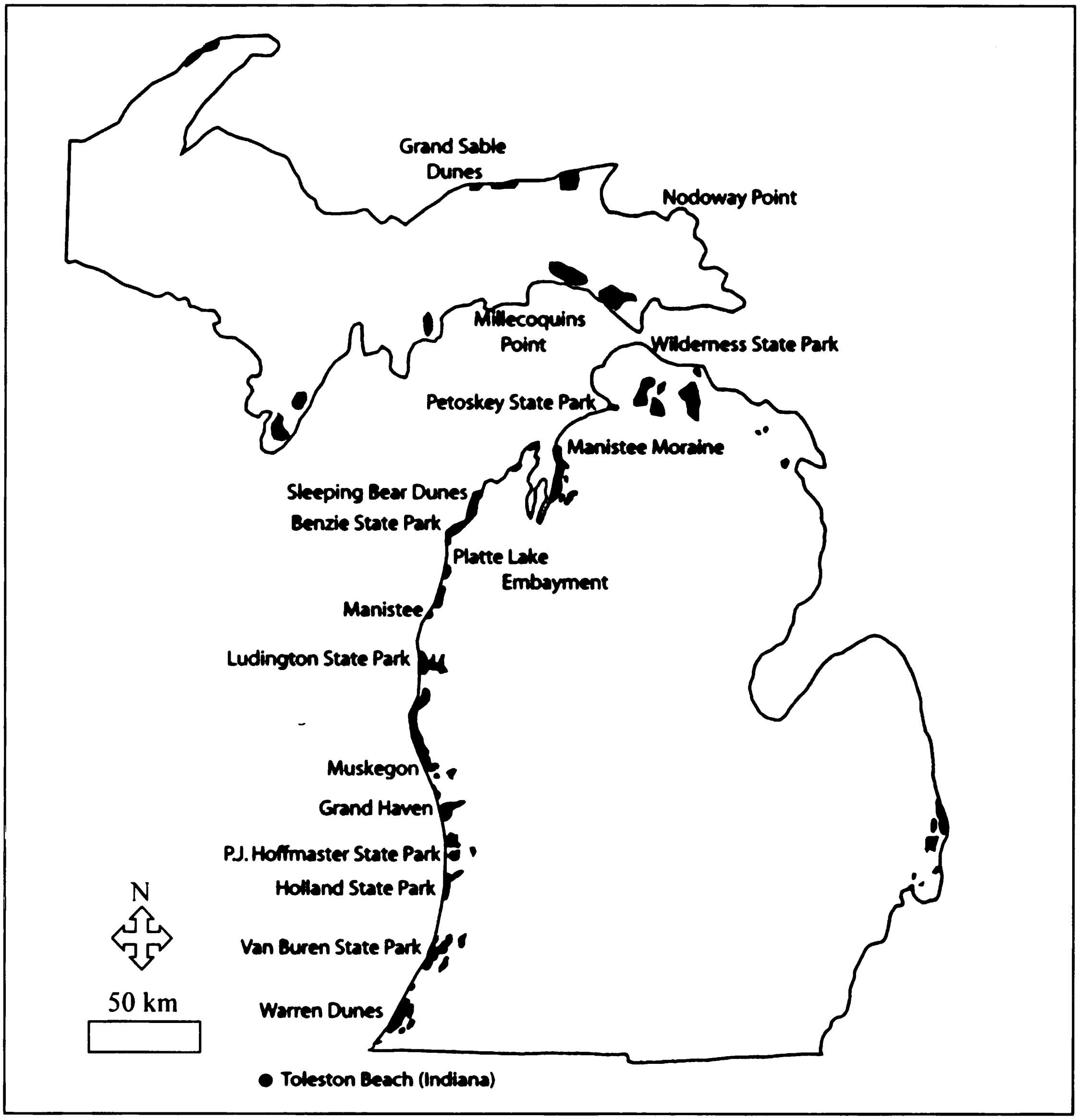

Figure 2:1 Location of coastal dunes in Michigan (Figure adapted from Dorr and Eschman (1970). (dune fields not to scale)

of the chapter. Given the geoachaeological implications of this study, the fifth and last part of this chapter reviews the precontact archaeology of northwest Lower Michigan.

Lake-Level Studies

The geography, geomorphology, and evolution of Lake Michigan coastal dunes is intimately tied to the long history of lake-level fluctuations in the basin (e.g., Arbogast and Loope, 1999; Arbogast et al., 2002). Given this natural relationship, it is appropriate to first discuss the research associated with the history of Lake Michigan because it provides the context for coastal-dune studies presented later in this chapter. The first part of this section generally focuses on the large-scale lake-level fluctuations that occurred during the early Holocene. From there, I will describe the research that has been completed to reconstruct a more detailed record of lake-level fluctuations in the middle and late Holocene.

Early Holocene geologic history

The glacial geology and history of the Great Lakes has been studied for decades (Leverett and Taylor, 1915; Hough, 1963; Mickelson *et al.*, 1982; Dyke and Prest, 1987; Karrow, 1989), resulting in a rich literature catalog. Many researchers have focused on the large-scale evolution of ancestral Lake Michigan during the late Pleistocene and Holocene (Larsen, 1985b, 1987; Hansel and Mickelson, 1988; Schneider and Fraser, 1990; Larson and Schaetzl, 2001). As a result of these studies, Quaternary scientists have a very good understanding of the transgressions and regressions that occurred in association with the deglaciation of the region.

The first major monograph on the history of Lake Michigan was published by Leverett and Taylor (1915), who relied on correlating recessional moraines around the lake basin in order to reconstruct a relative chronology of lake-level fluctuations during the late Pleistocene and Holocene. They suggested that, as glacial ice receded from Michigan, the Straits of Mackinac were exposed, allowing the waters in the Huron and Michigan basins to combine, forming a body of water called Lake Algonquin that drained via outlets at Port Huron and Chicago. Leverett and Taylor (1915) theorized that as glacial ice receded even further, the St. Lawrence River opened and became a main outlet for Lake Algonquin. They further proposed that Lake Algonquin was followed by the Nipissing Great Lakes, which occupied the Lake Huron, Superior, and Michigan basins and initially drained through the Ottawa River at North Bay, Ontario. As isostatic tilting occurred in the North, the North Bay outlet rose and was abandoned in favor of the Chicago outlet. Subsequent downcutting of the Chicago outlet into glacial sediments resulted in a lower lake phase that Leverett and Taylor (1915) called the "Algoma" (Larsen, 1999).

Leverett and Taylor (1915) relied on a theory called the "hinge line" in order to reconstruct the chronology of the Lake Michigan. The hinge line concept of Great Lakes evolution, a product of the "rigid earth" theory of geology, proposes that the Great Lakes are divided into two stable and unstable regions with a "hinge" between them. The unstable north sporadically uplifts, which consequently lifts former shorelines of the lake. The oldest shorelines north of the hinge line are at the highest elevations. In contrast, the shoreline of the southern half of the Lake Michigan basin remains stable and unchanged.

As a result of this relative stability, the shorelines in the southern half of the basin were relied on as constant and unchanging (Larson, 1999).

After Leverett and Taylor's (1915) work, the essential theory of the hinge line remained unchanged for decades. Other researchers continued to rely on the theory as research on the glacial history of Lake Michigan continued. For example, Hough (1963) relied on the hinge line model in his synthesis of Great Lakes geology.

Hough (1963) proposed that Lake Algonquin formed in the Michigan and Huron lake basins as glacial ice retreated from the Port Huron advance. He suggested that ice retreated far enough to allow the waters in the Michigan and Huron basins to combine through a channel that was subsequently destroyed by readvancing ice. Lake Algonquin drained through two outlets, the Chicago outlet to the south and the North Bay outlet. As glacial ice retreated further, lake-levels in the Michigan basin fell to their lowest level, called Glacial Lake Chippewa. Continued uplift in the northern half of the Lake Michigan and Huron basins began to uplift outlet at North Bay, resulting in a transgression, culminating in the Nipissing Great Lakes at 4200 years BP. Hough (1963) proposed that, at its max, Lake Nipissing initially drained through three outlets: the North Bay, Chicago, and St. Clair. However, continued uplift in the north cut off the North Bay outlet completely, resulting in the highest phase of the Nipissing Great Lakes (~184 amsl).

As the lake drained through the southern outlets, the St. Clair outlet downcut into glacial sediments, thereby lowering lake-levels to the lowest phase (~181 amsl) in the Nipissing Great Lakes, the Algoma stage around 3200 years BP. Hough (1963) believed that Algoma water drained through only one outlet, the St. Clair River. The downcutting of the St. Clair outlet paused for some reason during this time, possibly due to overflow into the Chicago outlet. Once downcutting resumed around 2500 years ago, lake-levels fell to their present elevation at about 177 amsl (Hough, 1963).

The introduction of new technologies in the 1980s and 1990s allowed researchers to study the evolution of Lake Michigan in new ways. Reliable dating techniques allowed researchers to assign absolute dates to surfaces, rather than relying on relative dating techniques. In addition, new evidence on isostasy allowed researchers to reconstruct the rate at which shorelines were uplifted around the basin.

Larsen (1985a) plotted isostatically deformed shorelines along the eastern shore of Lake Michigan. In particular, he compared the distance of the Algonquin, Nipissing and Algoma shorelines from the Chicago outlet against elevation. Larsen (1985a) reported that rebound has been occurring steadily since delectation and that the amount increased at an exponential rate with respect to distance from the outlet. Based on this new evidence, a more complete chronology of Holocene lake-level fluctuations in Lake Michigan could be constructed.

Larsen (1985a) proposed that as glacial ice slowly retreated from northern Michigan around 11.0 ka, a series of northern outlets were opened, allowing Lake Algonquin (occupying the Michigan and Huron basins) to drain to the north at North Bay rather than to the south via the Chicago outlet. This drainage resulted in the lowest lake-level phase (~140 m), Glacial Lake Chippewa (~10.0-6.0 ka). As isostatic rebound lifted the North Bay above the elevation of the southern half of the basin, this outlet was abandoned in favor of the Chicago outlet. This shift resulted in an increase in lake-levels, referred to as the Nipissing Great Lakes (~5000 years BP) (Larson and Schaetzl, 2001).

During this period of time, lake-levels in the Lake Michigan basin fluctuated. Between 4740 and 4185 years BP, the lake reached an altitude of 183 m in the southern basin and drained primarily through the Chicago outlet (Larsen, 1985b). This maximum altitude is referred to as the Nipissing I phase and is recognized by a high steep terrace along the coast. Subsequently, lake-levels again dropped to around 178 m before rising to 180.5 meters during the Nipissing II transgression between 4185 and 3800 years BP (Larsen, 1985b). After the Nipissing II phase, the Chicago outlet was largely abandoned and the Port Huron outlet became the major outlet for the lake, initiating the Algoma phase of the Nipissing Great Lakes (Larson and Schaetzl, 2001). The Algoma phase (~3200 years BP) represents a brief high stand of Lake Michigan before falling to modern lake-levels (~177 amsl) (Larsen, 1985b).

Late Holocene Lake-Level Studies

Now that the large-scale changes in lake-level are generally understood, recent research has focused on the details of lake-level fluctuations from the mid Holocene to the present. Researchers such as Thompson (1992) and Lichter (1995) have reconstructed these fluctuations by investigating beach-ridge complexes in places as such as Wilderness State Park that lie at the head of prominent embayments (Figure 2:2). In these areas, well defined strandplains are preserved that consist of numerous erosional notches (i.e., beach-ridges) that are cut into beach sands during distinct lake-level phases. These beach-ridges are commonly overlain by foredunes and are separated from one another by wetland swales (Figure 2:3) that contain organic deposits. Radiocarbon dates from the base of these organics estimate the time for the development of the more lakeward ridge in any couplet (1992).

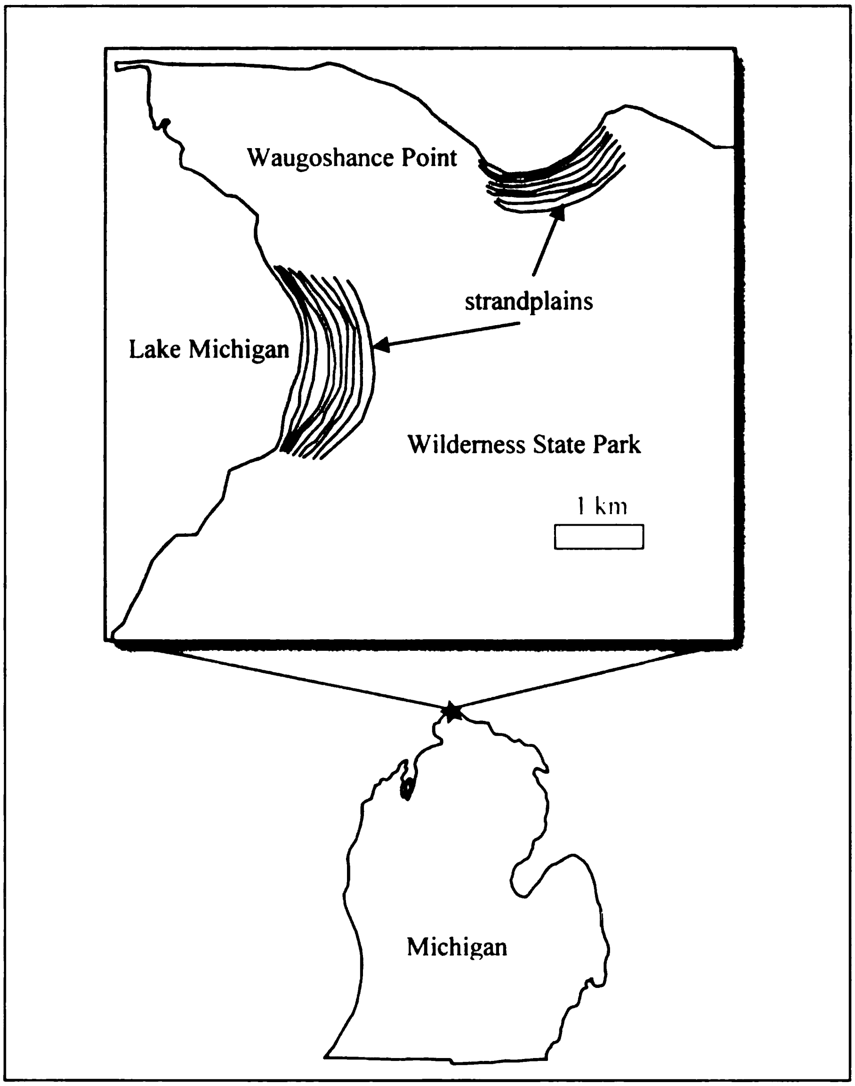

Figure 2:2 Generalized map of the strandplains in Wilderness State Park, northwest lower Michigan (from Lichter, 1995) (not to scale).

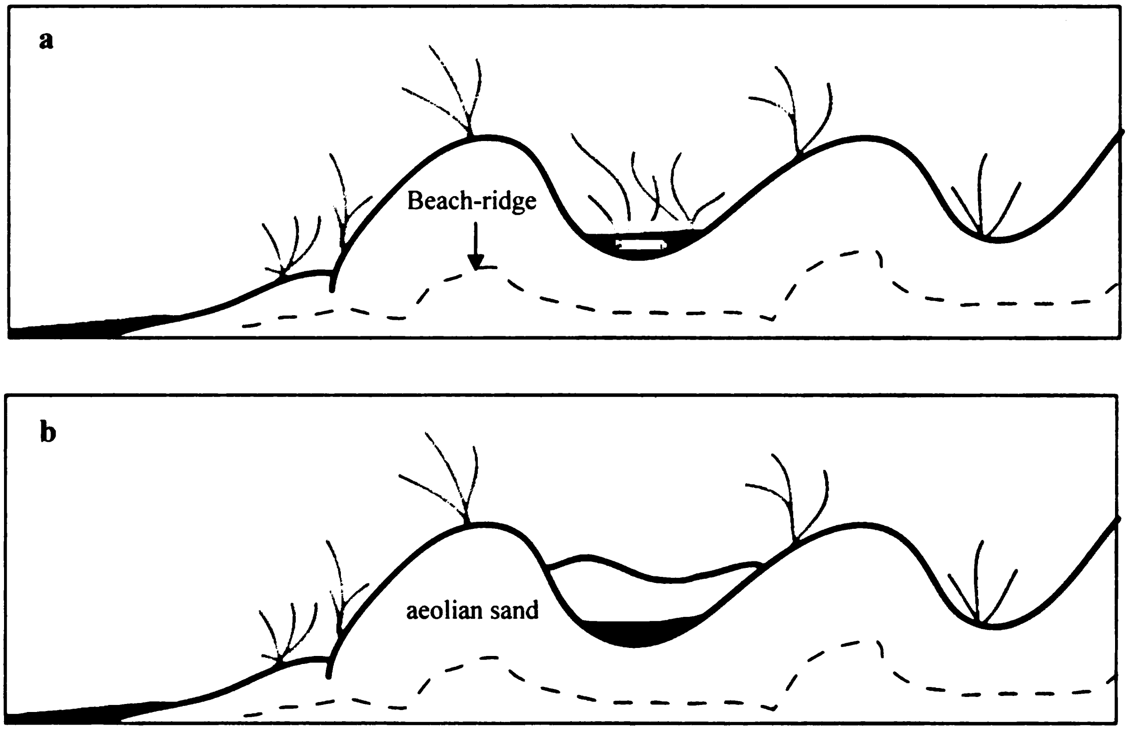

Figure 2:3 Schematic illustration of the formation of wetland in a swale. A: As lake-levels fall, some water may be trapped between dunes. B: Vegetation in the swale dies, forming an organic deposit suitable for radiocarbon dating. A radiocarbon date from the base of interdune peat provides a minimum-limiting age for the lakeward ridge/foredune couplet.

In addition, the elevation of the foreshore deposits in beach-ridges indicates the maximum elevation of the lake at the time the beach-ridge was formed. The combination of lake-level elevation with chronologic age can result in a detailed reconstruction of lake-levels in the Lake Michigan basin for the past ~ 5000 years.

The first study that examined the association of beach-ridges with lake-level fluctuations was conducted by Thompson (1992), who studied a strandplain along the southern shore of Lake Michigan at Toleston Beach in northwest Indiana (Figure 2:1). He found that the age of the ridges and associated foredunes decreases lakeward, and that there is a cyclic nature to the formation of these landforms. Three intervals of quasi-periodic lake-level variations were derived from Thompson's dates. The shortest interval indicates that beach-ridges form approximately every 31 years. The second interval shows a period of ridge formation every 150 years. The third interval represents a period of ridge formation every 500 - 600 years. Thompson (1992) also showed that lake-level decline after the Algoma phase (3200 BP) was punctuated by high lake-levels at 2300, 1700, 1175, and 600 years BP.

Thompson and Baedke (1995) continued Thompson's (1992) research on Lake Michigan beach-ridge formation and associated lake-level fluctuations at the Thompson Embayment near Manistique, Michigan (Figure 2:1). They tested Thompson's (1992) hypothesis of the cyclicity of beach-ridge formation using the same methods Thompson (1992) used. Thompson and Baedke (1995) recognized three intervals (30, 150, 500 years) of periodic lake-level variation at the Thompson Embayment. However, the results obtained from this place differ from those derived from Toleston Beach in that the ridges were eroded from the embayment from 2800 and 1700 cal yrs. BP. Thompson and

Baedke (1995) attributed this discrepancy to sediment supply rates between the northern and southern parts of the Lake Michigan basin. The southern shore of Lake Michigan receives sediment from both the eastern and western shores of the lake, so the ridges on the Toleston Beach were not eroded away as they were on the Thompson Beach, which does not receive as much sediment (Thompson and Baedke, 1995).

Thompson and Baedke (1997) continued their previous work on lake-level fluctuations at five beach-ridge complexes in the Lake Michigan basin. They used stratigraphic evidence from the ridges to determine maximum lake elevations and chronologic evidence to determine the timing of ridge development. They found that two major intervals of ridge formation were apparent at the five sites. Individual ridges formed approximately every 29-38 years after a fluctuation in lake-level of 0.5 meters. Groupings of four to six ridges formed approximately every 150 years after a fluctuation in lake-level from 0.5 -1.5 meters. Major lake-level high stands occurred at 4600-4400 (Nipissing II phase), 4300 - 4000, 3200 -2300 (Algoma phase), and 2000 - 1200 cal. years BP.

Recently, Baedke and Thompson (2000) revisited their 1997 study on lake-levels and isostacy for Lake Michigan. The lake-level curves they produced in their 1997 study cannot be applied outside their original study areas (Thompson, 1992, Thompson and Baedke 1995, 1997) because of the effect of vertical ground movement on the position of shorelines. To correct for the discrepancy vertical ground movement introduces to the curves, Baedke and Thompson (2000) combined the curves and removed the effects of rebound from the equation. This resulted in a smoothed lake-level curve that applies to the entire southern Lake Michigan basin. The curve reflects three major highstands at

4500 - 3400, 3400 - 2300 and 1700 cal. years BP, along with several lower-magnitude lake-level events (Baedke and Thompson, 2000) (Figure 2:4).

Research on the beach-ridges along the northern shores of Lake Michigan has been completed as well. Lichter (1995) used radiocarbon dating to determine the cycle of beach-ridge formation on a strand plain in Wilderness State Park (Figure 2:1 and 2:2). Lichter radiocarbon dated rhizomes found at the base of the beach-ridges, and also relied on tree-ring cores and historical records to reconstruct the timing of ridge formation. His findings supported Thompson's (1992) hypothesis of a 30-year cycle of ridge formation. He also proposed that lake-level variations are tied to drought because the ridges in the historical area date known dry periods.

Although a variety of studies (e.g., Thompson, 1992; Baedke and Thompson, 2000; Lichter, 1995) suggest three intervals of beach-ridge formation, other research suggests a different time frame for lake-level fluctuation. Delcourt *et al.* (1996) studied a series of 75 beach-ridges west of Millecoquins Point in the Upper Peninsula of Michigan (Figure 2:1). Using historical records such as General Land Office survey notes, tree-ring dating, and radiocarbon dates taken from organic-rich sediments found at the base of swales, Delcourt *et al.* (1996) suggested that beach-ridges form every 72 years rather than every 30 years. This cyclicity corresponds with a 65-70 year oscillation in temperature recognized by Schlessinger and Ramankutty (1994). Thus, although Delacout *et al.* (1996) do not challenge that lake-level variation influences the formation of beach-ridges and associated foredunes, they stress that the climatic factors behind the lake-level variations are an important factor to the evolution of these landforms.

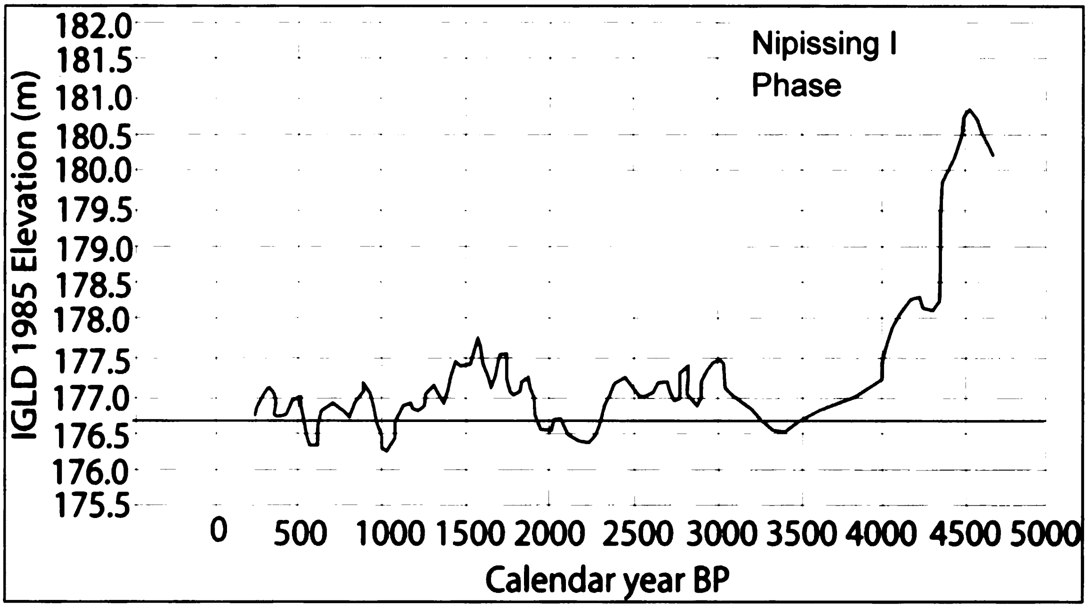

Figure 2:4 Smoothed graph showing generalized lake-level fluctuations observed at all study sites. Red line shows historic average. Figure adapted from Baedke and Thompson (2000).

In addition to the discrepancy in beach-ridge cyclicity, other researchers question the methods that have been used to date beach-ridge formation. Lichter (1997) argued that using carbon from wetland swales between foredunes does not result in reliable dates. He claimed that one cannot assume that wetlands form immediately after the lakeward ridge/foredune couplet develops. Thus, the variability of the dates increases, reducing their usefulness. He suggests that dating macrofossils of plant species found within the toe slope of the ridge is more reliable.

Using this method, Lichter (1997) reported nine radiocarbon dates from the toe slopes of beach-ridges at Wilderness State Park (Figures 2:1 and 2:2). He calculated the mean return period for the time intervals between radiocarbon dates and found that five of the nine time intervals had distributions with modes at 20 years, and the other four intervals had modes at 40, 56, 80, and 132 years per dune. Lichter (1997) suggested that the 20 year modes reflects a 20-year drought cycle recognized in the western U.S., and the 80 and 132-year modes match the 70-year climate oscillation proposed by Delcourt *et al.* (1996) and the 140 - 160 year oscillation proposed by Thompson (1992).

Coastal Dune Research

Early Research

Research on the coastal dunes of Lake Michigan began in the late 1800s. Early investigations focused on the vegetation communities that colonized the dunes and how certain species affect foredune evolution. Cowles (1899) studied the vegetation and development of Lake Michigan foredunes, which are dune ridges located parallel to the shore that formed by aeolian sand deposition. He was most interested in describing the geographic distribution of plant groups along the shores of Lake Michigan and how they relate to the geomorphology of the coast. In that context, Cowles (1899) divided dunes into five geographic/geomorphic and ecologic stages: (1) the beach, (2) primary embryonic dunes, (3) secondary embryonic dunes, (4) wandering dunes, and (5) established dunes.

According to Cowles (1899), the beach functions as the sand source for Lake Michigan foredunes. Winds sweep across the beach from the lake and pick up sand particles. The coarsest particles are deposited when wind speed is reduced, usually by vegetation growing along the beach. Sand piles up around the vegetation, forming a primary embryonic dune. Primary embryonic dunes are characterized by steep windward and gently sloping leeward sides. In contrast, secondary embryonic dunes accumulate more slowly than primary embryonic dunes and are situated further from the coast. After a period of time, the foredunes will again become active (wandering). Dune activation occurs when sand accumulation rates exceed primary vegetation (grasses) growth, or by the death of vegetation. Cowles (1899) argued that wandering dunes will eventually become stabilized by vegetation once again, culminating in established dunes. Established dunes are colonized by the climax community of trees such as basswood (*Tilia americana*).

Cowles (1899) also proposed that dune geomorphology was dependent on the vegetation that colonized the dune. Cowles believed that vegetation is critical to dune formation by trapping sand to form piles and in protecting the dune from wind and water erosion. In addition, the type of vegetation influences the height, area, and slope of a dune. Dune height is determined by how tall the vegetation grows. The area and slope of a dune is influenced by the extent and rate of vegetation growth. In this context, Cowles (1899) believed that dunes vegetated with marram grass (*Ammophila brevigulata*) are long and low with gentle slopes, whereas those covered with shrubs are high and steep due to the shrub's ability for rapid upward growth. Finally, dunes vegetated with cottonwood (*Populus deltoids)* are the tallest and steepest.

Following the Cowles (1899) study, the next research on coastal dunes did not occur until Dow (1937) investigated the formation of what he termed "perched dunes" along the east coast of Lake Michigan. According to Dow (1937) perched dunes are large (>30 m) parabolic dunes that rest upon other high-relief surfaces, such as old beaches or moraines. He was particularly interested in determining the source area for the sand contained within the perched dunes that mantle the Manistee moraine (Figure 2:1).

Dow (1937) divided aeolian sands into four classes that reflect source areas: (1) beach sand accumulated due to wind, (2) beach sand accumulated via wind and lake-level drop, (3) sandy drift from moraines, and (4) sand derived from beach and moraines. Each type of sand is associated with different modes of dune formation. He concluded that windblown beach sand and sand from moraines are the two most important sources of sand for perched dunes.

Dow (1937) also introduced a model for the formation of perched dunes. He suggested that perched dunes form during periods of high lake-level when wave action is greater. During these periods of time, waves erode the bluff, freeing sand to blow up the moraine and form dunes on top. He believed that sand from the beach was also probably blown up the moraine onto the dunes, but that sand from the moraine is probably the most important source of sand to the dunes.

Like Cowles (1899), Olson (1958a) also studied the role vegetation plays in forming foredunes. Olson (1958a) used plant structure and distribution to reconstruct changes in dune morphology such as sand deposition, erosion, and stabilization. Specifically, he used the stems of dune-colonizing plants (e.g. *Ammophila brevigulata*) in order to reconstruct the changes dunes undergo on a yearly basis. By looking at the distance between the stem nodes of the dune-stabilizing plant marram grass, Olson reconstructed how much sand accumulated per year. Nodes widely spaced on the stem occur after rapid deposition of sand in the winter. Narrow spacing of nodes reflects the stabilization of the dune—the grass grows more slowly as sand accumulation decreases. Olson (1958a) suggested that active dunes accumulate approximately 0.3048 m of sand per year.

Whereas Cowles (1899) focused on vegetation as the impetus for foredune formation, Olson (1958b) proposed an alternative model for the evolution of Lake Michigan foredunes. He suggested that foredune formation is tied to lake-level fluctuations, with foredune growth occurring during periods of low lake-levels (Figure 2:5). According to Olson, (1958b), foredunes begin to form in the shallow water offshore where waves break, forming a ridge. When lake-levels fall the ridge is exposed, along with a wide beach lakeward of the ridge that functions as a sand source. The ridge then begins to accumulate a cap of aeolian sand, forming a foredune. The foredune continues to grow as vegetation, probably marram grass, begins to colonize the dune. If enough vegetation colonizes the dune, it may survive the next rise in lake-level; otherwise, the foredune will probably be washed away (Olson, 1958b).

Olson hypothesized that lake-level oscillations sufficient to form beach-ridges (and thus foredunes) probably occurred every 30 years (1958c). Thompson's later research on lake-level fluctuations supported this hypothesis.

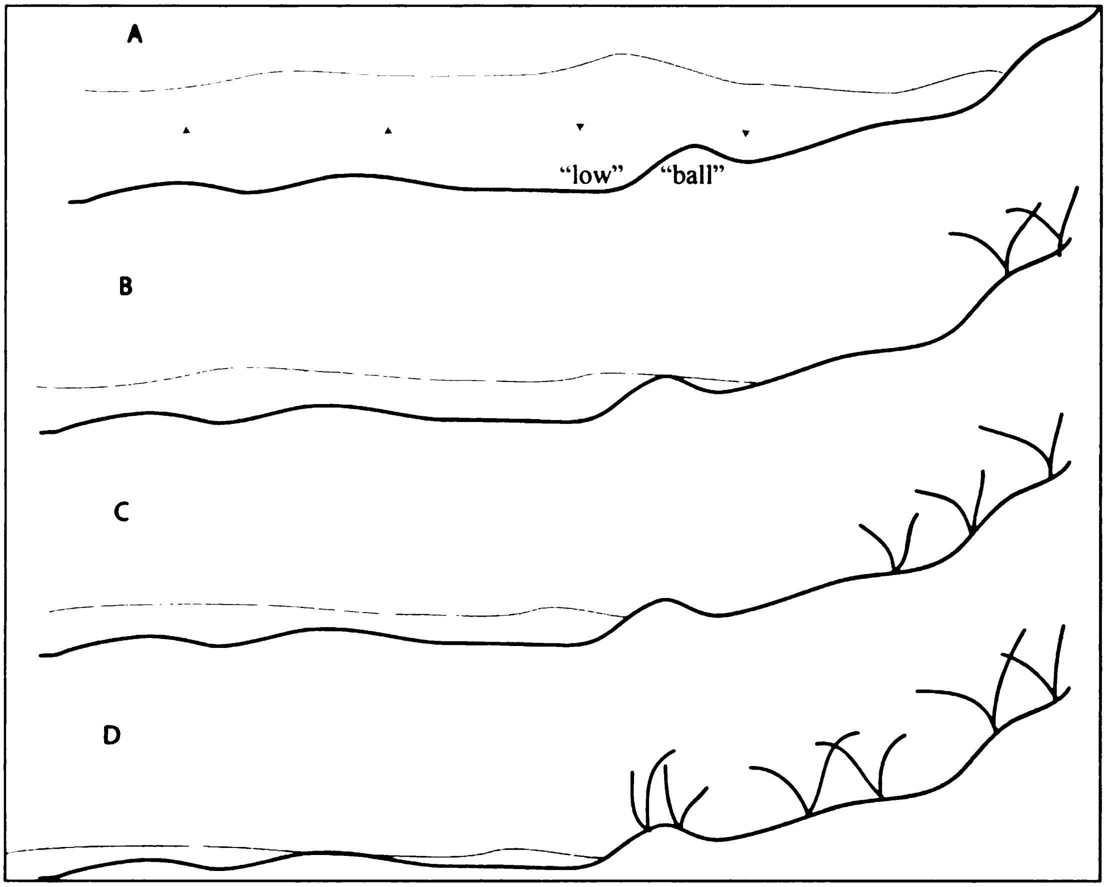

Figure 2:5 Olson's (1958b) model of foredune development. A: The formation of a subaqueous beach-ridge as sand moves along the bottom of the lake. The orbiting water scours sand along the bottom of the lake, creating a depression (low) and a ridge (ball). B: Lake-level begins to fall. C: As lake-levels fall further, the ridge is exposed. D: If lake-levels continue to fall, aeolian sand begins to accumulate on the ridge and beach grass colonizes the dune. Figure adapted from Olson, 1958b (not to scale).

Modern Dune Research

After Olson's work on dunes and dune vegetation in the late 1950s, research on Michigan coastal dunes was not pursued systematically again until the 1990s. By this time, research on coastal dunes had become increasingly quantitative with respect to estimating sand transport and the statistical analysis of radiocarbon dates. Most research focused on determining the geomorphology and evolution of the dunes. These studies can be largely divided into two categories, 1) investigations associated with foredunes, and 2) perched dune studies.

Recent Foredune Studies

Although some studies have largely focused on determining the chronology of beach-ridge (and thus foredune) formation, other research has focused on the specific geomorphic processes that influence foredunes. Van Dijk (2004) studied a pair of foredunes (comprising of a foredune and a secondary foredune with a blowout) at P.J. Hoffmaster State Park (Figure 2:1) in order to determine the contemporary processes that affect foredunes along the coast of Lake Michigan. She used erosion pins, sand traps, and microclimate instruments to measure the changes in dune morphology in each season (i.e. winter, spring, summer, fall). She found that the rate of sand accumulation on the dunes was greatest during the fall, winter, and early spring. Onshore winds are strongest during these months and move the most sand from the beach to the foredune. By late fall, the foredune had grown sufficiently in size to cut off the sand supply to the secondary foredune. Sand movement on the secondary foredune consisted mostly of reworking existing dune sands. Erosion of the secondary foredune and blowout occurred, with those sediments being deposited in a leeward depositional area.

Van Djik (2004) concluded that wind direction and speeds are important geomorphic processes that affect foredunes along the coast of Lake Michigan. However, lake-level and vegetation cover play important roles as well. Foredune growth is made possible by lower lake-levels (Olson, 1958b) that expose wide beaches. Like wind speed and direction, vegetation cover is directly linked to the seasons. Decreased vegetation cover in the fall, winter, and early spring contribute to increased erosion and remobilization of dune sands.

Perched Dune Studies

After Dow (1937) proposed the concept of perched dunes, the large dunes along Lake Michigan were largely ignored until the mid 1990s, as far as geomorphic research is concerned. The only noteworthy references to large coastal dunes in the intervening time were made by Dorr and Eschman (1970), who briefly discussed the basic geomorphology of the dunes in the *Geology of Michigan*, and Buckler (1979), who constructed a classification system for dunes along Lake Michigan. Dorr and Eschman (1970) referred to the large dunes as *high dunes* because of their immense size and generally assigned a Nipissing age to them. Buckler (1979) introduced the term *barrier dunes* because the large dunes form a significant topographic barrier between the lakeshore and the interior. Otherwise, no effort was made to systematically investigate the evolution of the large dunes and to test the applicability of Dow's (1937) model for perched dune evolution.

Beginning in the mid 1990s, interest finally turned toward the reconstructing of large-dune evolution by analyzing dune stratigraphy in conjunction with various dating techniques. Of particular stratigraphic interest in this recent phase of dune research are buried soils, which represent periods of stability when sand supply to the dunes had either terminated or had sufficiently slowed for soil formation to take place in the host deposits. These soils commonly contain organic remains such as wood and charcoal that can be radiocarbon dated. Additional dates have been acquired by optically stimulated luminescence (OSL) dating (Aitken, 1998), which measures the amount of gamma radiation flushed from fissures in quartz sand grains upon exposure to light in a controlled setting. Given that this radiation is derived from surrounding radioactive grains (e.g., feldspars) in the sand deposit from which the analyzed grains are derived, the amount of radiation measured reflects the time since the grain was last exposed to light (i.e., since it was last mobilized).

The new wave of dune studies began when Anderton and Loope (1995) investigated the Grand Sable dunes on the south shore of Lake Superior in Michigan's Upper Peninsula (Figure 2:1). Given that this dune field is a classic perched dune field in the Dow (1937) model, Anderton and Loope (1995) tested the hypothesis that dune building episodes were linked to high lake-levels. In that context, they radiocarbon dated buried soils at 17 localities and compared the dates to lake hydrographs generated by Fraser *et al.* (1990).

Anderton and Loope (1995) found that the basal soil in the Grand Sable dune field is the best developed and dated to 5170 - 4640 ^{14}C years BP. This soil, the Sable Creek Soil, was first recognized by Farrell and Hughes (1985). From a stratigraphic perspective, the Sable Creek Soil is particularly noteworthy because it formed in the uppermost glaciofluvial sediments that underlie the dunes. Using the POD index (Schaetzl and Mokma, 1988), Anderton and Loope (1995) suggested that the Sable Creek Soil began developing immediately after glacial ice retreated from the Lake Superior basin. All other soils recognized in the dune field were buried after 4600 ^{14}C years BP and are less developed. Burial events occurred at 4650, 4000, 3550, 2900, 1500, 1000, and 500 ^{14}C years BP and correlate to known lake-level highstands (Fraser *et al.*, 1990). As a result, Anderton and Loope (1995) argued that the dunes formed in a manner consistent with the perched dune model (Dow, 1937), with dune building and stability occurring during high and low lake phases, respectively (Figure 2:6).

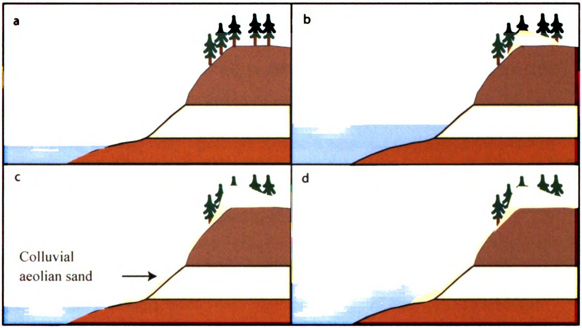

Figure 2:6 Schematic illustration depicting the perched dune model. A: During periods of low lake-levels, the beach is exposed. Soils form on the stable bluff-top. B: As lake-levels rise, wave action erodes the bluff, freeing up sand to form dunes. C: Lake-levels fall and wave action decreases. Sand supply to the dunes is diminished. D: High lake-levels resume, and the sand supply to the dunes resumes once again. Figure adapted from Anderton and Loope (1995).

Following Anderton and Loope's (1995) study, Arbogast and Loope (1999) investigated a variety of large dunes near Grand Haven and Muskegon on the west coast of Lower Michigan (Figure 2:1). These dunes mantle lake terraces that, in comparison to the perched dunes recognized by Dow (1937) and Anderton and Loope (1999), lie only a few meters above the lake. Given the lower topographical position of these large dunes, it had been generally assumed (e.g., Buckler, 1979) that they formed in accordance with Olson's (1958c) foredune model and that they developed shortly after the Nipissing high stand of ancestral Lake Michigan (Dorr and Eschman, 1970). Arbogast and Loope (1999) tested this hypothesis by radiocarbon dating soils formed in the uppermost lake sediments that underlie the dunes at four sites. Whereas dates from three sites suggested that initial dune growth began during to the Nipissing stage (4820 - 4410 cal. yr. BP), a date from one site indicated that the first pulse of aeolian sand occurred during the Algoma high-stand (3,270 - 2940 cal. yr. BP). According to Arbogast and Loope (1999), the results suggested that the soils were buried by aeolian during high lake stages. This latter finding was especially significant because it suggested that, despite the relatively low topographic position of the large dunes, they may have developed in a manner consistent with Dow's (1937) perched dune model.

At about the same time that Arbogast and Loope (1999) determined that dune growth began in topographically-low, large dunes along the shore of Lake Michigan during the Nipissing high stand, a study by Arbogast (2000) on the southern shore of Lake Superior added further evidence that the Nipissing stage was a period of major dune growth. This study focused on the Nodoway dune field, which is perched about 90 m above Lake Superior about 20 km west of Sault Ste. Marie (Figure 2:1). Given this high topographic position and dense forest cover throughout the dune field, Arbogast (2000) tested the hypothesis that the dunes formed during the Nipissing high stand in a manner similar to the Grand Sable dunes (Anderton and Loope, 1995).

To test this hypothesis, Arbogast (2000) used a combination of soils analysis and radiocarbon/OSL dating to determine the age of the dunes. A maximum-limiting age date obtained from the edge of the bluff provided a date of 7000 cal. yrs BP, which suggested to Arbogast (2000) that dune building probably occurred during the Nipissing II transgression (4000 cal. yrs BP), presumably because later high lake-level stages (e.g., Algoma) were insufficiently high to have destabilized the bluff. Arbogast (2000) also suggested that the dunes stabilized more or less concurrently based on the presence of well-developed soils across the field. OSL and radiocarbon dates supported this conclusion, indicating that the dunes stabilized around 3200 cal. yrs BP.

As the surge in coastal dune research in Michigan accelerated, Loope and Arbogast (2000) conducted a study that more rigorously tested the hypothesis that large dunes on topographically low lake terraces in Lower Michigan enlarged during high lake stages, as suggested by the Arbogast and Loope (1999) study near Grand Haven and Muskegon (Figure 2:1). In this later study, Loope and Arbogast (2000) radiocarbon dated 75 buried soils at 32 sites along the eastern coast of Lake Michigan. Given the large sample size, they were able to statistically compare the radiocarbon distributions to the lake-level curve produced by Thompson and Baedke (1997, 2000). The overall results of this statistical analysis added further evidence that dune building episodes on the topographically lower large dunes correlate with periods of high lake-levels approximately every 150 years. These results support the hypothesis that the dunes formed via Dow's (1937) perched dune model wherein sand is eroded from bluffs during high lake-levels and blown up into dunes on top of the bluffs.

In 2002, Arbogast *et al.* continued research on perched dunes near Holland (Figure 2:1) by dating a sequence of buried soils exposed along the lakeshore. They found that the dunes initially began forming during the Nipissing I high stand (~5500 cal. years BP). Rapid dune growth occurred from 4000 - 2500 cal. yrs BP during periods of falling lake-levels after the Nipissing II high stand. This period of dune formation may correspond to Olson's (1958c) model of foredune development in that sand was supplied as the lake regressed. Later periods of dune growth at 3200, 2400, and 900 cal yrs BP are tied to higher lake-levels and thus correlated with the perched dune model (Arbogast *et al.*, 2002).

The stratigraphy and chronology of the perched dunes at Holland (Arbogast *et al,* 2002) have been recognized in other locations along the coast as well. Van Oort *et al.* (2002) expanded on the research of Arbogast et al (2002 at Van Buren State Park near South Haven (Figure 2:1). Van Oort *et al* (2002) tested whether the dunes at Van Buren share the same geomorphic and chronologic history as dunes located elsewhere along the coast (Arbogast and Loope, 1999; Loope and Arbogast, 2000; Arbogast et al., 2002). Van Oort *et al.* (2002) recognized a variety of buried soils in a series of excellent exposures and radiocarbon dated charcoal/wood in them to approximate time of burial. The basal soil at Van Buren is a peat layer that formed at the top of lake sediments. This peat, provided maximum and minimum-limiting ages of between about 6170 and 4900 cal. yrs BP, respectively, suggesting that a marsh existed for 700 to 1000 years before the dune began to form.

Above the peat layer is a sequence of Entisols formed in dune sand. These Entisols date from 3690 - 1970 cal. yrs BP. This sequence represents a period of episodic dune building that lasted about 3500 years. The best developed buried soil is an Entisol with Spodosol-like characteristics found in the upper portion of the dune. Charcoal from the A horizon in this soil provided an age of about 500 cal. yrs B.P. Given the date of about 2000 cal. yrs. B.P. from the next lower buried soil, coupled with the relatively high degree of development in the Entisol, Van Oort et al. (2002) argued that the soil formed over an approximately 1500-yr period of time. Above this Entisol, a pair of Entisols occurs, which developed sometime between about 300 cal. yrs B.P. and the present. Overall, Van Oort *et al.* (2002) concluded that the dunes at Van Buren are similar in both chronology and geomorphology to the dunes near Holland (Arbogast *et al.*, 2002).

Research on the coastal dunes along the east coast of Lake Michigan has largely focused on the large dunes that front the lake. However, some research has been completed on the smaller backdune complexes associated with perched dunes as well. Hansen *et al.* (2002) studied a backdune complex in Allegan County to determine whether the backdunes formed earlier than the shoreward larger dunes (Figure 2:1). In order to test determine the chronology of these dunes, Hansen *et al.* (2002) obtained OSL samples from the uppermost sand deposits in the dunes.

Results from the study indicate that the backdunes near Holland are much younger than originally thought. A basal sample provided an age range of 4.3 -0.6 ka, whereas those taken from the crests of the dunes range in age from 4.0 - 3.7 ka. These dates indicate that the backdunes and the lake-fronting dunes were active during the same time period. Hanson *et al.* (2002) suggest two possible scenarios of dune formation.

During the Nipissing I transgression (~ 4500 cal. yr BP) large amounts of sand may have been eroded from dune faces. This sand could have been continually reworked by winds for several hundred years before the dunes stabilized. This scenario is consistent with the application of the perched-dune model (Dow, 1937) to other topographically low, large dunes at other locations along the coast (e.g., Loope and Arbogast, 1999; Arbogast *et al.*, 2002). In contrast, the evidence suggests that the dunes were also active as the lake fell after the Nipissing II highstand. In this scenario, falling lake-levels would have exposed a wide beach to supply sand for dune building via Olson's model (1958c). In either case, OSL dates suggest that the dunes stabilized between 4000 and 3500 ka. Hansen et al (2002) hypothesized that sand delivery to the backdunes ceased because the lakeward dunes (Arbogast *et al.,* 2002) grew sufficiently to cut the sand supply off, allowing vegetation to stabilize the dunes (Hansen *et al.*, 2002)

Although most dune research has focused on the southeastern part of the Lake Michigan coast, recent detailed investigations have focused on the northwest coast of Michigan. Lepczyk and Arbogast (2005) studied the geomorphology of the isolated dune complex at Petoskey State Park near the city of Harbor Springs, MI (Figure 2:1). In order to determine the chronology of the dune field, Lepczyk and Arbogast (2005) radiocarbon dated buried soils and OSL dated the aeolian sand. Five geomorphic map units were identified in the park (from most inland to lakeward): (1) lake terrace, (2) parabolic dunes, (3) onlap dunes (dunes that overlap the parabolic dunes), (4) linear dunes and shadow dunes, and (5) active dunes.

Results from this study indicate that the lake terrace corresponds with Nipissing lake-levels and is overlain by parabolic dunes. According to Lepczyk and Arbogast

(2005), OSL dates from the parabolic dunes indicate that aeolian sands accumulated around 4800 - 4400 cal. yrs BP during the Nipissing II transgression and accumulated for approximately 1300 years. The onlap dunes are smaller than the parabolic dunes, implying that they took less time to form (Lepczyk and Arbogast, 2005). The onlap dunes probably formed in the shorezone after the Nipissing II transgression. After lake-levels dropped, lacustrine sands and an aeolian cap were deposited over the shorezone. Radiocarbon dates from the onlap dunes indicate that a soil was buried approximately 2800 cal. years BP, which corresponds with the Algoma transgression.

The linear and shadow dunes did not contain any buried soils to date; however, they mantle the Algoma surface, implying that they formed after the Algoma transgression. Dates from the active dunes indicate three periods of stability at 515 - 315, 470 - 290, and 300 - 0 cal. yrs BP. Lepczyk and Arbogast (2005) concluded that dune building at Petoskey State Park was cyclic and related to the high lake-level changes proposed by Thompson and Baedke (1997).

International dune studies

Although there is a large literature base for Lake Michigan coastal dunes, international dune research provides a broader context for Lake Michigan dune studies. The same aeolian and lacustrine/oceanic processes that affect coastal dunes in other parts of the world play a role in Lake Michigan coastal dunes as well. A comprehensive body of international coastal dune research exists and includes studies on the geomorphology, ecology, and management of coastal dunes, as well as a variety of other topics. Most research is centered on Australia, Europe, and North America. Below are several examples of international research from Australia, the Netherlands, and British Colombia.

A large body of research on coastal dune processes has been completed in Australia, specifically along the southeastern coast. Hesp (1988a) studied a series of foredunes in the Myell Lakes region in order to determine the interactions between surfzone, beach types, and dune morphology. Hesp (1988a) proposed correlations between foredune height and beach morphology by measuring accretion rates of aeolian sands. He found that onshore sand transport increases on wide, gently sloping beaches. Hesp (1988a) suggested that dissipative beaches allow wave energy to move more sediment beachward, thus supplying more sand for aeolian transport.

Hesp (1988a) expanded his discussion of wave energy to the effect of wave erosion on dune morphology. He proposed that the type of wave erosion (rip erosion, scarping, etc.) is in direct response to wave energy. In turn, wave erosion affects the type of foredune erosion (e.g. scarp backwearing, blowout development, etc). Hesp (1988a) concluded that more research on surfzone and beach interactions needs to be completed in order to better understand the processes that affect foredune morphology.

More recently, Hesp (2002) revisited the subject of foredune morphology and reviewed the formation and geomorphology of foredunes. Hesp indicated that two main types of foredunes: (1) incipient foredunes, and (2) established foredunes. Incipient dunes develop on new foredunes that formed within pioneer plant communities. Their morphological development depends on a number of factors including plant density, distribution, height, and cover, wind velocity, and rates of sand transport.

After incipient dunes are formed, established dunes develop and are differentiated from incipient dunes in their greater morphological complexity, height, age, geographical position, and the plants that colonized them. For example, established dunes will have shrubs and other woody plants growing on them. Their morphological development depends on sand supply, plant species present, and sea/lake-level (Hesp, 2002).

Hesp (2002) also discussed the morphology and development of blowouts. Blowouts are of two general types: saucer and trough. Their shape, size, and location depend largely on the size of the dune in which they are developing. Blowouts may be initiated in several ways including wave erosion, climate change, vegetation cover, and human activities. For example, blowouts may be initiated where vegetation cover is weakened or killed off due to a drought or fire. As a result of this research, Hesp (2002) concluded that more research on the interactions between the surfzone, beach and dune dynamics, sediment supply, and sea level histories needs to be completed in order to more fully understand the functioning of coastal dunes (Hesp, 2002).

Although Australian dune studies have focused on the processes that form coastal dunes, studies in other parts of the world have focused on the physics of dune building. In Europe, research by Arens *et al.* (2002) tested the prevailing theories of changes in grain size distribution during transport. Their study centered on a beach-foredune transect on Schiermonnikoog, one of the Dutch Wadden islands, where they collected saltating and suspended sand using 11 omnidirectional sand traps. In total, 95 samples were collected from which grain size distributions were determined. Sediment grain size parameters were determined via computer model and then correlated with process parameters, transport rates, heights of traps above the surface, and terrain features.

Their results shows that mean grain size either decreases with, or shows no relation to, height. Sorting on the foredune is poorer than on the beach, with the poorest sorting found along the upper slope. Significant differences in grain size existed such that the profiles could be separated into upper and lower layers. In the upper transport layer, changes with height are more pronounced than in the lower layers (Arens *et al.*, 2002).

Arens *et al.* (2002) concluded that changes in grain size and sorting could be explained by the drag exerted by vegetation growing on the dunes. Grains in saltation jump to certain heights depending on their size. Smaller grain sizes are influenced more strongly by air drag produced by vegetation and surface roughness than larger grains, meaning that larger grains decelerate less than smaller grains. Thus, larger grains reach larger heights.

A final example of international dune research is from an investigation in Canada where Anderson and Walker (2006) examined the influence that vegetation and topography have on airflow and sediment transport on dunes in a foredune-parabolic plain in Naikoon Provincial Park, British Columbia, Canada. They measured airflow, sediment transport, grainfall, vegetation density, surface elevation, and grain sizes.

Anderson and Walker (2006) found that topography greatly influences air flow. For example, air flow over the dunes accelerated. Faster, steadier flows in trough blowouts result in more sediment transported in these areas. In addition, trough blowouts channel air flow and sediment through the dune and beyond the beach-foredune plain. Topography also influences sediment sorting (Anderson and Walker, 2006). For example, on the backshore, well sorted medium sands become poorly sorted in the blowout throat and again better sorted over the foredune plain.

Sediment transport is influenced by topography and vegetation density, distribution, and height. During the growing season, negligible amounts of sand are transported via saltation beyond the foredune plain. However, during the winter season, when vegetation is largely absent, significant amounts of sand are transported via suspension as far as 300 m beyond the foredune plain. Thus, sand carried in suspension may contribute to active dune fields hundreds of meters landward of the shoreline. Anderson and Walker (2006) concluded that onshore aeolian transport should be considered well beyond the beach and foredune.

Summary

A variety of well-developed dune fields occur along the eastern shore of Lake Michigan. These dunes have been studied in a variety of ways since the very late 1800s. Lake Michigan coastal dune research has evolved from focusing primarily on the ecology of coastal dunes to the geomorphology and evolution of coastal dune forms. The first research, published by Cowles (1899), emphasized the importance of vegetation in stabilizing foredunes. He promoted the idea of plant succession on dunes, indicating that grasses, shrubs, and trees colonize dunes in an ordered way, and the shape and size of dunes reflect the differences in plant height and cover. After Cowles (1899), research on the geomorphology of the Lake Michigan coastline shifted to determining the chronology and extent of lake-level fluctuations.

Reconstructing lake-level history has been the focus of much research in the Lake Michigan basin. This research began in the early 20th century (Leverett and Taylor, 1915) and continues today (Larsen, 1985b, 1987; Schneider and Fraser, 1990; Larson and Schaetzl, 2001). Early research relied on using deformed shorelines and recessional moraines to reconstruct past lake-levels. As technology improved, ages could be assigned to lake-level fluctuations. Large-scale fluctuations in the Lake Michigan basin occurred ~11,000 (Lake Algonquin), 10,000-6000 (Lake Chippewa), ~5000 (Nipissing I), ~4100 (Nipissing II), and ~3200 cal. years BP (Algoma). Because lake-level fluctuations are key factors in shoreline morphology, research in the latter half of the 20th century focused on determining the smaller-scale fluctuations in lake-level.

Olson's (1958b) model focused on the link between lake-level fluctuation and foredune development. He proposed that foredunes begin as off-shore beach-ridges, which are exposed when lake-levels fall. As time progresses, these ridges are then enlarged with a cap of aeolian sand. His model provided the framework and the springboard for future research on foredunes and reconstructing lake-level history.

Modern research on foredunes expanded on Olson's (1958b, 1958c) theory of lake-level fluctuations. These studies focused on using the beach-ridges that underlie foredunes to reconstruct the detailed history lake-level fluctuations in the late Holocene. Most of this research has been conducted by Thompson (1992) and Thompson and Baedke (1995, 1997, 2000) who have used both stratigraphy and radiocarbon dating of beach-ridges to derive lake-level curves for the past 4,000 years. Their results indicate that three quasi-periodic intervals of ridge formation occur for the Lake Michigan basin, and provide a methodological framework for future studies on beach-ridges.

Numerous studies have been completed on the large dunes that occur along the coast as well. These studies (e.g., Arbogast and Loope, 1999; Arbogast *et al.,* 2002; etc.) rely on radiocarbon dating and lake-level curves to test Dow's (1937) perched dune model and link perched dune building to high lake-levels. The addition of OSL dating (Hansen *et al.,* 2002; Lepczyk and Arbogast, 2005) has provided greater chronological control and a greater understanding of the evolution of perched dunes along the coast of Lake Michigan.

Precontact Archaeology of Northwest Lower Michigan

Michigan has a rich archaeological history that ranges in time from the very latest Pleistocene to the time of European contact (Cleland, 1972; Fitting, 1975; Martin, 1994; Halsey, 1999; Lovis, 1989; etc.). Given the geographic scope of this study (the Lake Michigan coastal zone between Grand Traverse Bay and the Straits of Mackinac) the archaeology of northwest Lower Michigan is particularly relevant and forms the focus of this discussion. Here, the archaeological record extends back approximately 10,000 years and includes all the cultural periods of the Eastern Woodlands (Figure 2:7). These cultural periods are based on a number of characteristics, specifically technological changes in projectile points and other stone technologies, the introduction of pottery, and the beginning of domestic plant use.

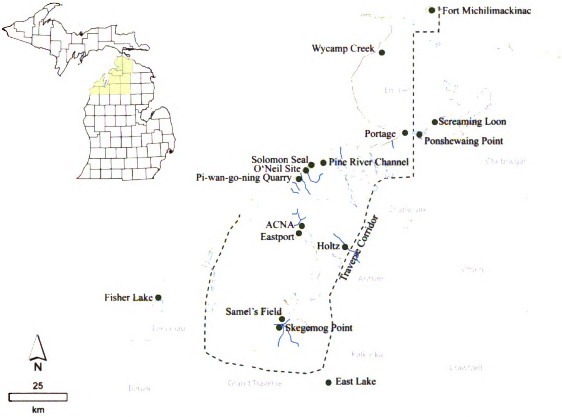

Figure 2:7 Location of archaeological sites discussed in text. Location of the Traverse Corridor adapted from Brashler and Holman (2004).

Paleo-Indian Period

The first people to inhabit Michigan are known as Paleo-Indians, which is the same term for which the cultural period is named. The Paleo-Indian period is thought to have ranged in time from around 12,000 - 11,000 BP (10,000 - 9000 B.C.; Monaghan and Lovis, 2005). This period is characterized by large, "fluted" bifaces (i.e. tools worked on both sides, and thinned with large flakes driven from the base) that were used by highly nomadic hunters and gatherers who, in this part of the Great Lakes region, exploited large game such as mastodon and caribou (Shott and Wright, 1999).

In northwest Lower Michigan, the Paleo-Indian time period is very poorly represented. A single fluted point was found at the Samel's Field site (Figure 2:7) in Grand Traverse County (Dekin, 1966). This point is associated with the Lake Algonquin terrace, which would date the spearpoint to around 11,200 - 11,000 cal. yrs BP (Cleland and Ruggles, 1996).

In addition to this point, a preform biface was found in East Lake, Kalkaska County (Figure 2:7); Lovis and Bole, 2002). Several lines of evidence suggest that the Samel's Field fluted point and the East Lake preform are related stylistically and chronologically. The East Lake preform was found at an elevation (340m) that is consistent with the positioning of the Samel's Field point relative to glacial features. In addition, the preform is morphologically consistent with the point found at Samel's Field, suggesting they were manufactured around the same time. Reduction techniques suggest that the preform dates to an early phase of the Paleo-Indian period (~ 11,000 - 10,600 cal. years BP). Together, these artifacts suggest that Middle, if not Early, Paleo-Indian groups had begun to exploit northwest lower Michigan, but probably at a low level of intensity (Lovis and Bole, 2002).

Although scattered evidence that Paleo-Indians settled northwest Michigan exists, too few sites have been found to draw detailed conclusions about the lifeways of these groups in this area. Cleland *et al.* (1998) explain the paucity of Paleo-Indian sites in northwest Lower Michigan on the basis of environmental conditions at that time. They contend, based on the distribution of mastodon remains, fluted points, and ecological shifts as glacial ice retreated, that Paleo-Indians entered Michigan from the south and moved northward as the climate changed from tundra to open spruce forest around 11,000 BP. In this scenario, northwest Lower Michigan would have been one of the last places inhabited.

The Archaic Period

The transition between the Paleo-Indian and Archaic periods in this region is murky and poorly understood (Lovis, in press). It is coincident with the onset of essentially modern forest types in the region, the warming period variably known as the Hypsithermal or Altithermal, and substantial readjustments of water planes in the conjoined Michigan-Huron basin (Lovis, in press). Generally, the onset of the Archaic period, which is often subdivided into Early, Middle, and Late phases, is largely based on changed technologies including the absence of fluted bifaces, as well as a shift in economic subsistence (Robertson et al., 1999). In northwest Lower Michigan, the transition from the Paleo-Indian period to the Early Archaic occurred between 10,000 – 8,000 cal. years BP is (Monaghan and Lovis, 2005), primarily because few sites have survived (Cleland, 2002). Nevertheless, it appears that late Paleo-Indians and Early Archaic groups were very similar from a cultural perspective (Shott, 1999).

What is known about the Early Archaic in northwest Michigan has come from one site, an Early Archaic base camp/worksite at the Samel's Field site (Cleland and Ruggles, 1996; Figure 2:7). Distinctive lanceolate points and other tools such as gravers and scrapers were found at the site. Four distinct groupings of debitage were found there as well, which are thought to represent open-air work zones. Most of the tools found were made of a distinctive variety of Norwood Chert, which outcrops at the Fritz Trail locale near the Pi-wan-go-ing Quarry in Charlevoix County (Cleland, 1973; Cleland and Ruggles, 1996). Cleland and Ruggles (1996) concluded that the Samels Field site was occupied on a short-term but very intensive basis. Thus, Samels Field is an important site because it represents a full range of domestic activities during the Early Archaic period.

The Middle Archaic period (8000-5000 cal. years BP) (Monaghan and Lovis, 2005) is not well represented in northwest lower Michigan (Cleland, 2002); however, recent data suggests the presence of at least one Middle Archaic age archaeological deposit, (Lovis, personal communication). The almost complete absence of Middle Archaic sites has been attributed to fluctuating lake-levels in Lake Michigan. As glacial ice retreated from Michigan approximately 10,500 - 9,500 years ago, the topographically lower outlet at North Bay was uncovered, allowing water from Lakes Michigan and Huron to drain through the topographically lower St. Lawrence Seaway rather than the Mississippi River (Larson and Schaetzl, 2001). As a result, lake-levels fell drastically (~ 140 m) to the Chippewa Low phase. Over the next 6000 years, the North Bay outlet isostatically uplifted, closing off the outlet and resulting in the slow rise in lake-levels associated with the Nipissing transgression (Larson and Schaetzl, 2001). Under these circumstances, lake-level rise would have inundated existing shorelines. Any archaeological sites that were located along the shores of the Chippewa Low phase may now be under water and inaccessible to archaeologists (Cleland, 2002; Lovis in press).

The Late Archaic period spans the period from 5000 – 2000 cal. years BP (Monaghan and Lovis, 2005) in northwest Lower Michigan. This cultural period is better understood than the Early and Middle Archaic periods in northwest Michigan, simply because more sites have been found and thus investigated than in the previous Archaic periods. (Robertson *et al.*, 1999). The Screaming Loon site (Figure 2:7) offers a glimpse into the settlement/subsistence strategy of Late Archaic groups (Lovis, 1990). This site dates to approximately 3600 – 3500 cal. years BP. Several features, including smudge pits, roasting pits, a storage pit, and hearths were found, indicating that a full range of domestic activities took place at the site. Faunal remains (fish, turtle, large and small mammals, etc) suggest that the site was occupied during the spring and/or summer. In addition, the lithic remains indicate that the group had cultural affiliations with northern groups. Lovis (1990) interpreted the site as a series of warm season Late Archaic residential occupations of small groups of hunter-gatherers.

Other Late Archaic sites provide information about the lithic technologies used by people during this period. The Solomon Seal site (Figure 2:7), located on dunes that are thought to have formed during the Nipissing stage, is one of a series of sites at Fisherman's Island State Park (Lovis, 1976). Limited excavations at the site yielded lithics made from Norwood chert that probably represent primary reduction activities. The Eastport Site (Binford and Papworth, 1963), located in Eastport, Antrim County

(Figure 2:6), and the Nipissing II Terrace site (Cleland, 2002) at ACNA yielded similar triangular bifaces, often known as either cache blades or preforms, made of Norwood Chert from the Pi-wan-go-ing Quarry (Figure 2:7) (Cleland, 2002). Binford and Papworth (1963) dubbed the points found at the Eastport site "Pomranky Points" because they are similar in form to the mortuary points associated with the Red Ocher complex at the Pomranky site in Saginaw County. However, they contended that the points found at Eastport were manufactured for utilitarian purposes rather than mortuary purposes. In contrast, Cleland (2002) links the points found on the Nipissing II terrace at ACNA to a large Late Archaic trade network.

The Woodland Period

The onset of the Woodland period ca. 2500-1500 cal. years BP (Monaghan and Lovis, 1995) in the Eastern Woodlands is traditionally marked by the production of pottery, the adoption of agriculture, and human burial in earthen mounds (Milner, 2004). In northwest Lower Michigan, the manufacture of pottery appears in the record ca. 2000 years ago, more than 500 years after it appears in the southern parts of the state. Therefore, the Early Woodland period is not represented in northwest Lower Michigan. Instead, the onset of the Woodland Period in northwest Lower Michigan begins with a cultural period in the Middle Woodland period known as the Lake Forest Middle Woodland (Brose and Hambacher, 1999), also often referred to as Initial Woodland (Monaghan and Lovis 2005). The Lake Forest Middle Woodland/Initial Woodland is well represented in the archaeological record from both inland (e.g. Portage and Fisher Lake sites) and coastal sites (e.g. Wycamp Creek, Pine River Channel, Fort

Michilimackinac). In general, the coastal sites have higher artifact densities, implying recurring use (Monaghan and Lovis, 2005).

Ceramics from the Woodland period between 2000 and 1500 BP suggest that northwestern Lower Michigan had two distinct regions, the Straits of Mackinac and the Traverse Corridor (Figure 2:7). Groups from these regions had two different cultural affinities. People living in the Straits of Mackinac south to Little Traverse Bay had cultural ties to groups living in the Upper Peninsula, whereas groups using the Traverse Corridor littoral from Little Traverse Bay south had cultural ties to groups living in southern Michigan (Brashler and Holman, 2004). Thus, the Traverse Corridor functioned as a resource-extraction area and perhaps meeting place for groups both north and south of the Corridor (Brashler and Holman, 2004). Ceramics found in the region indicate that both Lake Forest groups and groups from further south were using the area. Brashler (2004) argues that use of the Traverse Corridor was not a necessity for either group, and that neither group resided full time in the corridor.

This scenario fits with the subsistence strategy proposed by Smith (2004) and Monaghan and Lovis (2005). Groups were probably organized in a macroband-microband settlement strategy in which larger groups of several family bands would assemble along the coast in the late spring through early fall in order to harvest spring-spawning fish such as such as Lake Sturgeon and White Sucker. This scenario is represented at the Fisher Lake site (Brose, 1975; Figure 2:7). Bone harpoons associated with bass and sturgeon bones were found at the site. Although other faunal remains such as whitetail deer and wapiti were found at the site as well, the ratio of fish to other faunal remains indicates that fish was of greater dietary importance at the site. Therefore, Fisher

Lake is interpreted to be a small fishing camp utilized in order to take advantage of spring-spawning sturgeon (Brose, 1975).

According to Monaghan and Lovis (2005), groups dispersed into individual family bands in the fall and moved to interior lacustrine environments. Indeed, these interior sites may have been organized into areas resembling family territories. Ceramic decoration may have served as a way to symbolize family band or group identity (Monaghan and Lovis, 2005).

The Late Woodland Period

The Late Woodland period in the northwest Lower Michigan is characterized by a shift to reliance on deep water fishing (Cleland, 1982) as well as a general shift to stronger social/territorial boundaries reflected in the ceramics found at sites (Monaghan and Lovis, 1995; Smith, 2004). This transition is best represented at the Pine River Channel Site (Holman, 1984). Ceramics from this site appear to be transitional between Middle/Initial Woodland Laurel ceramics and early Late Woodland Mackinac phase ceramics (Holman, 1984). In addition, the artifacts and faunal remains found at the site indicate the addition of fall fishing to the subsistence strategy. Cleland (1982) argues that Late Woodland groups relied on the gill net as the foundation of their fall/winter subsistence strategy. The advent of deep-water fishing in the fall resulted in a plentiful food source that could be stored throughout the winter season. He suggests that more relatively permanent settlements are the result of groups congregating at fall-spawning fishing locales to pool their labor for the gathering and preservation of fish. In contrast, Martin (1989) argues that Late Woodland groups did not *add* fall fishing to their subsistence strategy; rather, they *intensified* their use of fall fishing from the Middle Woodland into the Late Woodland. In either case, evidence suggests that the pattern of seasonal mobility appears to have continued from the Middle/Initial Woodland through the Late Woodland period (Holman, 1999). During the spring and summer, family bands migrated to coastal sites and aggregated in larger groups. During the winter, groups again dispersed into small family bands and moved to inland lacustrine environments (Monaghan and Lovis, 2005).

The O'Neil site (Figure 2:7) provides evidence for such a settlement strategy (Lovis, 1990). Two scales of residence are evident here: smaller, activity-specific logistic camps and larger, residential camps, both of which are associated with spring/summer occupations. Ceramics from the early Late Woodland Mackinac phase (800 - 1000 AD) groups and the contemporaneous Skegemog phase suggests that northern groups used the site more intensively and for longer durations than southern groups. However, late Late Woodland Traverse phase (1100 - 1600 AD) and the contemporaneous Juntunen phase indicates that by the late Late Woodland both southern and northern groups were using the site intensively (Lovis, 1990)

Ceramics found at several sites (O'Neil, Skegemog Point, Ponshewaing Point; Figure 2:7) indicate that early Late Woodland social boundaries were rather weak, with groups from the north and south both utilizing the Traverse Corridor/Lake Michigan littoral region (Brashler *et al.*, 2000; Lovis 1973). The biological diversity of the Traverse Corridor made it an attractive resource base for both groups. However, around 1100 A.D., it appears that the boundaries between the Traverse phase people and groups from further north were stronger, although evidence from both groups indicates they shared the territory (Brashler *et al.*, 2000). In addition, ceramics and longhouse-like structures found at the O'Neil and Juntunen sites indicate that a cultural shift, perhaps with identities to the east, occurred 1200-1500 AD (Lovis 1973; McPherron 1967).

Summary

The archaeological record for northwest Lower Michigan extends back approximately 11,000 years. Although evidence for the earliest periods of human history is sparse, archaeologists have been able to infer that the first occupants of the region were nomadic hunter-gatherers. These groups are most recognized by the distinctive fluted projectile points they manufactured. The transition from the Paleo-Indian period to the Archaic is not well understood. Archaic sites may be largely inaccessible to archaeologists because they lie deeply submerged within the lake basin in areas that were subaerially exposed during the Chippewa/Stanley low stand. These areas were subsequently inundated during the Nipissing transgression (Monaghan and Lovis, 2005). It is clear, however, that Archaic groups were hunter-gatherers who may have had ties to more southerly groups through extensive trade networks.

The best understood cultural phase in northwestern Lower Michigan is the Woodland period, which began with the development of ceramics, the use of low level horticulture, as well as the advent of intensive fall season gill net fishing. Ceramics from the Middle and Late Woodland periods lend a better understanding of the settlement and subsistence strategies of these groups, as well as their cultural affiliations with other groups in the region. Throughout this period, groups maintained a seasonal macroband-microband settlement strategy, with summer camps situated along the coast of Lake Michigan and winter camps located around interior lacustrine environments. Throughout the period, groups increasingly intensified their reliance on spring and fall fishing, the latter made possible by addition of the gill net. In addition, ceramic evidence indicates an increasing territoriality of the groups who shared the Traverse Corridor.

Chapter III

Study Area

The study area for this project consists of coastal sand dunes in the Antrim Creek Natural Area (ACNA). ACNA is located in Banks Township in Antrim County, MI, along the coast of Lake Michigan, and is comprised of ~64 hectares of coastline along Grand Traverse Bay (Figure 3:1). The park serves to provide several outdoor recreational activities. Several trails used for hiking, biking, cross country skiing, and snowshoeing run through the park. The park's sandy beaches are a popular swimming locale, and in the fall, hunting is allowed.

History

The public history of the ACNA begins in 1943 when Harry and Eleanor Jones purchased the property from Milfred Tyrell, who had used the property to hunt and camp (Associates, 1996). The Jones family allowed public use of their property; the public were allowed free access to the property for hunting, fishing, swimming, horseback riding, etc. (Associates, 1996). In addition, Melvin Essenberg was allowed to operate a dune buggy company called Spider Creek Dune Rides on the property from 1960-1978 (Associates, 1996).

Figure 3:1 Aerial photo of ACNA, taken in 1998. (photo from http://www.antrimcounty.org/parksandrec.asp)

The Jones family transferred ownership of the property in 1996 to Antrim County, which then founded the Antrim Creek Natural Area (Associates, 1996). After the property's soils, vegetation, and geology were surveyed and documented by White Pine Associates of Bellaire Michigan, the Antrim Creek Natural Area Commission (responsible for managing the park) published the Master Plan for ACNA (Development, 1998).

The mission statement for ACNA as detailed in the Master Plan is as follows: "to manage the site as a natural area, to protect the diversity and fragile natural features found on the property and keep it accessible for recreational and educational use by the public (Development, 1998). Thus, off road vehicles, snowmobiles, and horseback riding were banned from the natural area in order to limit disturbances to the dunes and vegetation communities in the park (Development, 1998). The parking lots, access roads, hiking trails, and signage were built by the Friends of Antrim Creek, the group that is responsible for the maintenance and upkeep of ACNA (Development, 1998).

Geography

The ACNA is bordered to the north by an area of cobbly beach that has low relief. Antrim Creek borders the south end of the park. Old Dixie Highway is the eastern border of the park, and Lake Michigan (177 masl) serves as the western border.

A steep escarpment lies between the coast and the highway (Figure 3:2). This escarpment, at an elevation of approximately 193 m at the top, is a prominent feature at ACNA. In addition, a second terrace stands at approximately 184 masl. The terrace is discontinuous and terminates roughly 472 m north of the park's southern boundary.

At first glance the dunes at ACNA can be divided into two groups: (1) the "open" dunes bordering the southern end of the study area, and (2) the stable, vegetated dunes north of the "open" dunes, terminating roughly 272 m south of Rex Beach Road (Figure 3:2). Both the "open" dunes and stable dunes terminate slightly west of the Nipissing Trail that runs north/south through the park. The study area for this project is confined to the open and stable dunes.

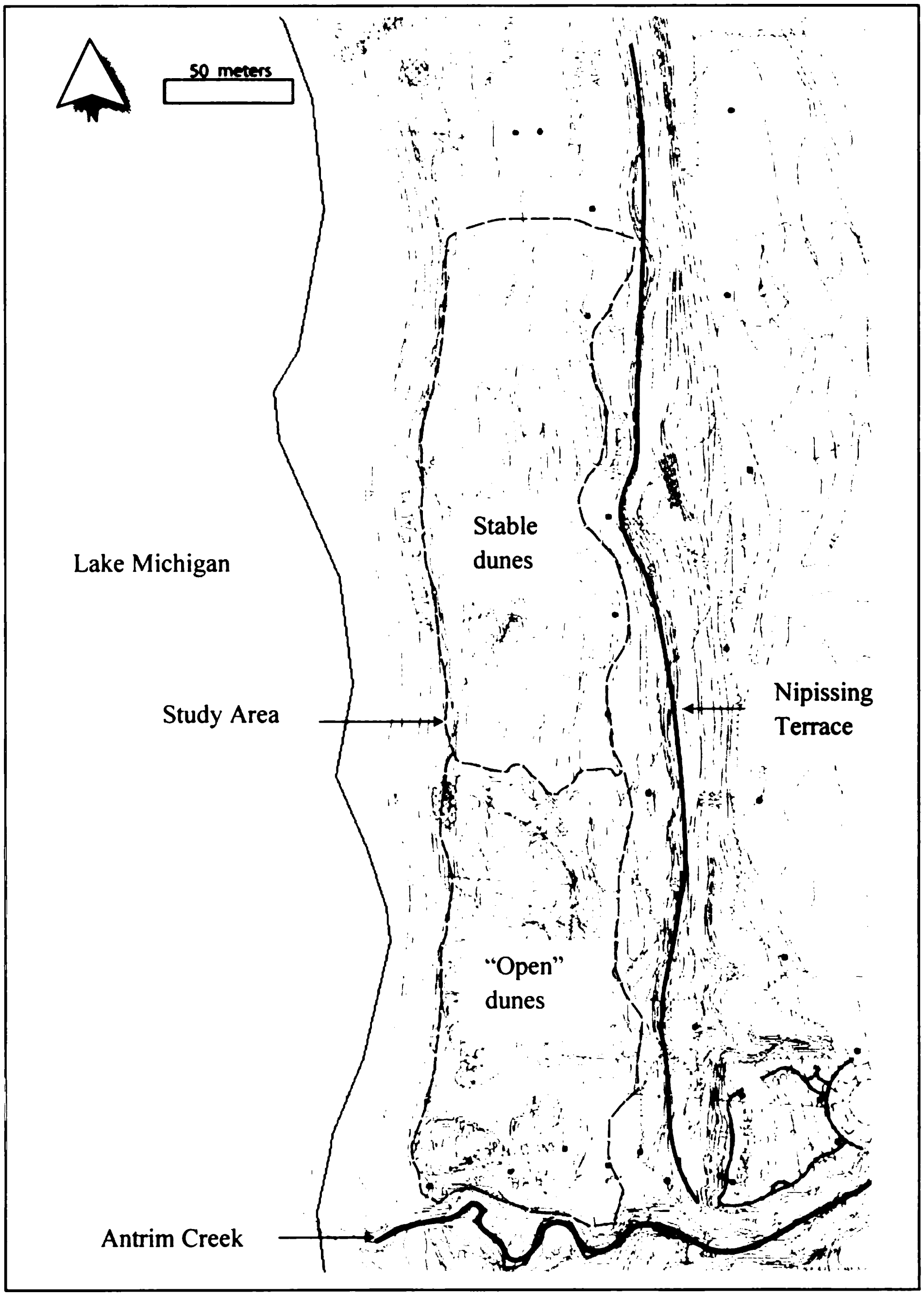

Figure 3:2 Geography of ACNA. Figure adapted from Development (1998).

Climate

Climate data for the ACNA study area were taken from the Soil Survey for Antrim County (Larson and Buchanan, 1978) as recorded at East Jordan for the period of 1946 to 1975. East Jordan is ~27 km east (inland) of ACNA. The climate at ACNA is classified as modified continental, as Lake Michigan moderates the warming and cooling of adjacent land areas. The prevailing winds are westerly or southwesterly.

The average temperature in July is 18.7° C, with the average daily maximum at 25.8 ° C. The average temperature in January is -5.2 ° C, with the average daily minimum temperature of -9.6 ° C. The highest and lowest temperatures on record are 37.8 and -35.0 ° C, respectively.

Average annual precipitation is approximately 309 cm, of which sixty percent (80 cm) occurs as rainfall between April and September. The average relative humidity in the afternoon is approximately 66%. The average humidity is greater during the night, with dawn having the highest, around 85% (Larson and Buchanan, 1978).

Vegetation

ACNA is situated in an ecotone between boreal forest to the north and hardwood forest to the south (Associates, 1996). The Ecological Report of ACNA (Associates, 1996) identified three main vegetation communities in the park: (1) palustrine, (2) palustrine/terrestrial, and (3) terrestrial. Of these communities, only the palustrine/terrestrial and terrestrial are situated within the study area of the park. The palustrine/terrestrial community consists of a wooded dune and swale complex that runs north-south for the length of the dunes in the study area and from the beach to the base of the Nipissing terrace (Associates, 1996). The wetlands are found between the dunes and the Nipissing terrace. The dominant plants of this complex are sugar maple (*Acer saccharum),* basswood, (*Tilia americana),* balsam fir (*Abies balsamea)*, American beech (*Fagus grandifolia),* and white cedar (*Thuja occidentalis).* Other plants found in the complex include marsh fern (*Thelypteris palustris),* sarsaparilla (*Aralia nudicaulis),* lily of the valley (*Maianthemum canadense)*, and poison ivy (*Rhus radicans).* In addition, two protected species occur within this complex: (1) birdeye primrose (*Primula mistassinica),* and (2) red anemone (*Anemone multiflora)* (Associates, 1996).

The terrestrial community consists of several sub-communities. The open dune and the gravel beach are the only sub-communities that occur within the study area. The open dune complex spans the entire length of the western edge of the study area between the open beach and the vegetated dunes as well as between the vegetated dunes and Antrim Creek (Associates, 1996). The dominant plants of this community are dune willow (*Salix cordata),* marram grass (*Ammophilia breriligulata)*, wild rye (*Elymus canadensis)*, wormwood (*Artemesia campestris)*, Bearded wheatgrass (*Agropyron dasystachyum)*, and balsam poplar (*Populus balsmifera)*. Other plants found in the community include silverweed (*Potentilla anserine)*, sand cherry (*Prunus pumila)*, white camas (*Zigadenua glauca)*, and beach pea (*Lathyrus japonicus)*. In addition, two proctected plants are found within the open dune community: (1) pitcher's thistle (*Cirsium pictheri)*, and (2) Lake Huron Tansy (*Tanacetum huronense)* (Associates, 1996).

The sand/gravel beach sub-community runs the length of the coast in the park and includes the lower and middle beach. Silverweed (*Potentilla anserine*) and red-osier dogwood (*Cornus stolonifera*) are the dominant plants. Other plants found in the community include sea rocket (*Cakile edulentum*), and dune evening primrose (*Oenothera qakesiana).*

Soils

Larson and Buchanan (1978) mapped two soil associations at ACNA: (1) Deer Park-Roscommon, and (2) Emmet-Montcalm. Deer Park-Roscommon is mapped in the soils in the dunes at ACNA, with Deer Park being the dominant series. The Deer Park-Roscommon association has excessively drained, poorly drained, and very poorly drained soils on gently sloping to moderately steep sand dunes. Deer Park (mixed, frigid, Spodic Upispamments) makes up 50% of the association and is found on 2 to 20% slopes on dunes. A typical Deer Park pedon ranges from 45 to 137 cm and is excessively drained. The surface soil is light gray sand about 23 cm thick. Roscommon makes up 25 % of the association and is found in depressions between sand dunes on nearly level surfaces. Roscommon (mixed, frigid, Mollic Psammaquents) soils are poorly and very poorly drained with a black A horizon surface soil approximately 13-cm thick. The Emmet-Montcalm association is mapped on and east of the steep escarpment at ACNA. The association has well drained and moderately well drained soils on knolls, ridges, and hills. Emmet (coarse-loamy, mixed, active, frigid Inceptic Hapludalfs) soils comprise about 35% percent of the association and are moderately well drained. Emmet soils formed in calcareous glacial till on 3 to 40% slopes. The surface layer is black sand loam approximately 11 cm thick. Montcalm (Coarse-loamy, mixed, semiactive, frigid Alfic Haplorthods) is well drained and formed in calcareous glacial till on 0 to 40% slopes. The surface layer is gray loamy sand about 8 cm thick.

Summary

ACNA is located in Antrim County, MI along the coast of Lake Michigan. The park is open to the public for recreational purposes such as hiking, skiing, swimming, etc. ACNA encompasses a small dune field that includes both vegetated, stable dunes and largely unvegetated, active dunes. In addition, a steep wave-cut terrace identified as the Nipissing terrace runs the length of the park. Several types of vegetation communities exist in the park, along with a number of species deserving special protection. The dominate soil in the study area is Deer Park, with Roscommon mapped in close association.

Chapter IV

Methods

This chapter reviews the methods that I used to conduct geomorphic research in the Antrim County Natural Area. These methods include both field and GIS techniques that were completed in the summer and fall in 2006.

My first goal was to analyze and characterize the general topography of the study area. In this context, I took stadia rod and eye leveling data to increase the resolution. I set up transects every forty meters, starting at the third blowout on the southern portion of the beach and ending a few meters north of the sixth blowout along the beach (Figure 4:1). Two transects ran from the beach through the open dune section, and five ran through the stable dunes. Although some small dunes are present north of the seventh transect, transect seven marks the general end of the "organized" dunes and the beginning of a hummocky area where the dunes terminate. Transect eight ran through the level terrain north of where the dunes terminate. Elevation points were taken roughly every two meters, although vegetation and other obstacles prevented the two meter spacing to be exact at every location. The elevation points were entered into Excel and plotted on scatter graphs to show the general relief of ACNA dunes as well as the steep bluff to the east of the dunes. All images in this thesis are presented in color.

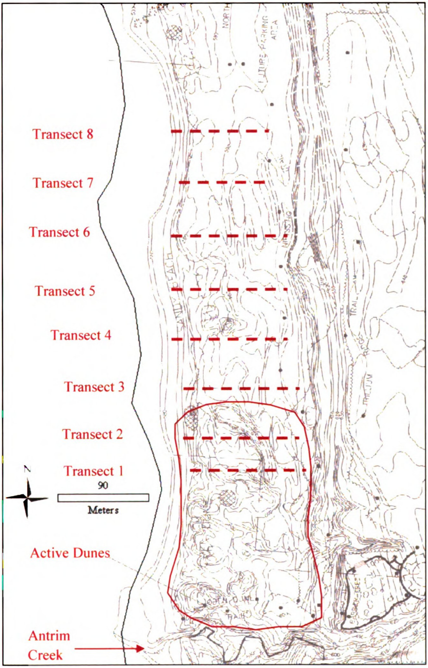

Figure 4:1 Location of stadia rod transects. The GPR study line followed transect 3.

In order to characterize and verify the character of the park soils, I augered along 14 west-east transects, over the dunes, terminating at the Nipissing Trail because dunes are absent east of the trail. Transects were spaced 20 m apart starting from the southern edge of the stable dunes and ending at the northern edge of the stable dunes and hummocky dunes. Each transect contained three auger holes, spaced somewhat randomly, with the goal of hitting at least one summit and one swale per transect. Transect one had five auger holes because this transect crossed the largest of the stable dunes. Each auger hole terminated at the underlying cobbly beach. The thickness of each horizon was measured where possible—some auger holes were too dry and the sand fell out before an approximation of horizonation could be made. At all holes, moist Munsell colors were assessed and recorded. Depth to the cobbly sediment was also recorded for each hole. Two bore holes north of the dunes were augured in order to determine what, if any, differences there were in soil texture and development these soils and the dune soils.

In order to assess the stratigraphy of the dunes, ground penetrating radar (GPR) was used. One transect was run across the dunes at auger transect three (Figure 4:1) using a pulse EKKO 100 system. Measurements were collected at 25, 50, 100, and 200 MHz antenna frequencies, but the 100 MHz antenna gave the clearest results.

In order to determine the age of ACNA dunes, I collected three samples for optical stimulated luminescence (OSL) dating along a transect that follows the largest stable dunes (Figure 4:2). OSL dating is an estimate of the last time a mineral grain was exposed to sunlight. Quartz and feldspar absorb ionized radiation emitted from other minerals during burial. Exposing the quartz to blue or green light causes the stored radiation to be released at a certain rate that is compared to a laboratory rate (i.e. an associated gamma sample). The rate is measured to determine the time since burial, which implies the date that sand last accumulated at the sample depth (Murray and Wintle, 2000). Figure 4:2 shows the approximate locations of the OSL collection points. Sample 1 was taken on the second vegetated dune from lake at a depth of 1.25 m. Sample 2 was taken from the dune directly east of the first dune at a depth of 1.35 m. Sample 3 was taken from the shoulder of the dune directly east of the second dune at a depth of 1.30 m. Samples 2 and 3 were taken using a bucket auger and black tarp to block out the light, while sample 3 was taken in a pit. I used a 4 cm diameter pipe for the OSL samples and quart sized Ziploc bags for the gamma sample.

All samples were sent to the Dr. Mark D. Bateman at Sheffield Centre for International Drylands Research, Department of Geography, University of Sheffield. The samples were dated using a single-aliquot regenerative-dose protocol (SAR). Laboratory irradiated samples introduce a level of "noise" in that they emit one or more other irradiation signals that confuse lifetimes of the samples. To remove these unwanted signals, the samples are heated up prior to measurement. However, this introduces another source of error as heating times and temperatures can vary. SAR protocol helps to eliminate additional signal rates without having to heat the sample (Murray and Wintle, 2000).

Summary

Several types of data were collected to characterize the dunes at ACNA. Field work was completed in the summer and fall of 2006. Auger-hole and GPR data were taken to assess the stratigraphy of the soils in the dunes. Stadia rod data were taken in order to characterize and represent the topography of the study area. OSL samples were taken to date the accumulation of the dunes at ACNA.

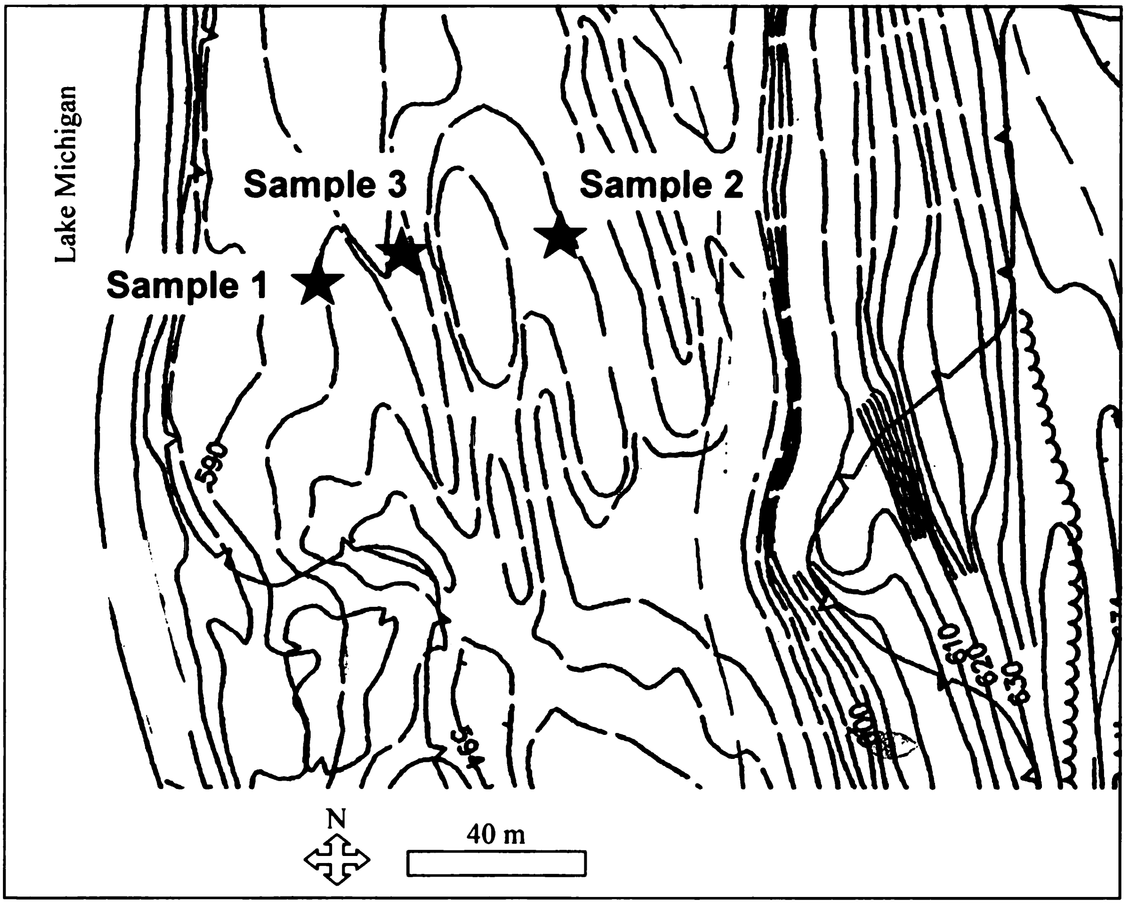

Figure 4:2 Location of OSL samples.

Chapter V

Results and Discussion

This chapter summarizes the geomorphology and evolution of the dunes at Antrim Creek Natural Area and places them within a geoarchaeological context. The first section presents the topographic relationships in the park. Subsequently, the dune stratigraphy and character of surface soils in the study area are generally described. Following this discussion, the next part of the chapter focuses on the chronology of dune evolution using OSL dates and lake-level records. The fourth section of the chapter reviews the archaeology of the dunes at ACNA. Finally, the last part of the chapter places the study within a geoarchaeological context and proposes a model that associates the age of archaeological remains in similar dune fields along the coast.

Topographic Analysis

The topographic transects provide a good representation of the landforms at ACNA. Beginning in the southern end of the park, transects 1 and 2 (Figure 5:1) illustrate the prominent Nipissing I bluff that borders the western side of the study area. The top of this bluff lies is at an elevation of ~193 meters above sea level (masl). Another prominent feature at the eastern side of these transects is a smaller terrace at an elevation of 188 masl (Figure 5:2). The area of unstable dunes begins abruptly at the base of this secondary bluff and continues as hummocky and largely unvegetated terrain toward the lake on the west side of the transect (Figure 5:3).

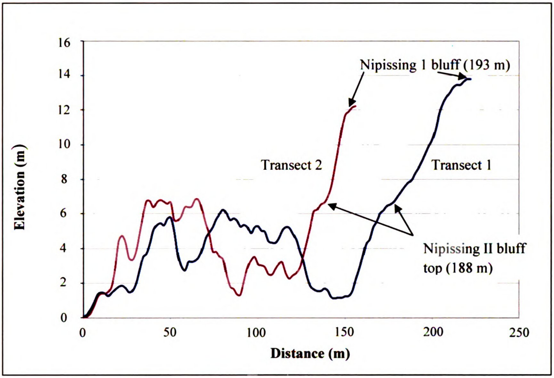

Figure 5:1 Stadia rod transects 1 and 2. Baseline elevation of the transect is the base of the most lakeward dune.

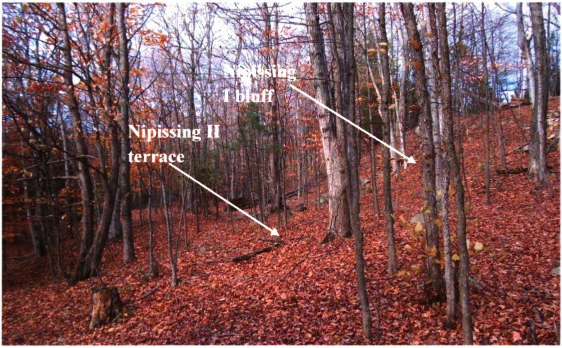

Figure 5:2 Photo of Nipissing I bluff and Nipissing II terrace.

Figure 5:3 Photo of a blowout located in the unstable dunes of the park. The cobbly beach sediments underlying the dunes are visible in the photo (arrow).

As in the first pair of transects, both the Nippising I bluff and the Nipissing II terrace are the baseline topographic features on the east side of the park in both transects 3 and 4 (Figure 5:4), which are the southernmost study lines in the vegetated part of the dune field. Examination of these transects reveals that a pair of well-defined ridges occurs between the base of the Nipissing II terrace and the lake. These ridges range in elevation from 185 m to 186 masl, are ~ 4 m in height, and are separated by a prominent swale (Figure 5:5).

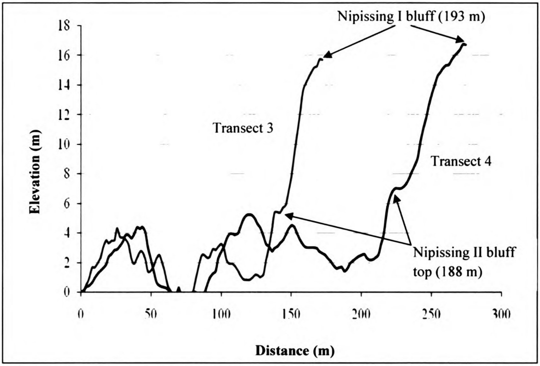

Figure 5:4 Stadia rod transects 3 and 4. Baseline elevation of the transect is the base of the most lakeward dune. The ridge and swale topography of these dunes is evident in the transects.

Figure 5:5 Photo of deep swale between ridges in transects 3 and 4.

Inspection of transects 5 – 7 (Figure 5:6), toward the north end of the park, reveals the same topographic relationships observed elsewhere in the study area. The most prominent features are again the bluffs on the east end of the park. In this part of the park, however, the bluff line becomes progressively closer to the beach toward the north. In addition, the second lake terrace becomes increasingly narrow around transect 7. As with the sites to the south, dunes flank the base of the bluff and continue westward to the beach. In contrast to the distinct ridge and swale topography of transects 3 and 4 (Figure 5.4), the surface of transects 5–7 is far more hummocky and less linear (Figure 5:6). As a result, the distinct ridge and swale topography observed farther south is absent. North of transect 7, the dunes end and the terrain becomes essentially level. At transect 8 the steep bluff is the only prominent landform in that part of the study area (Figure 5:7).

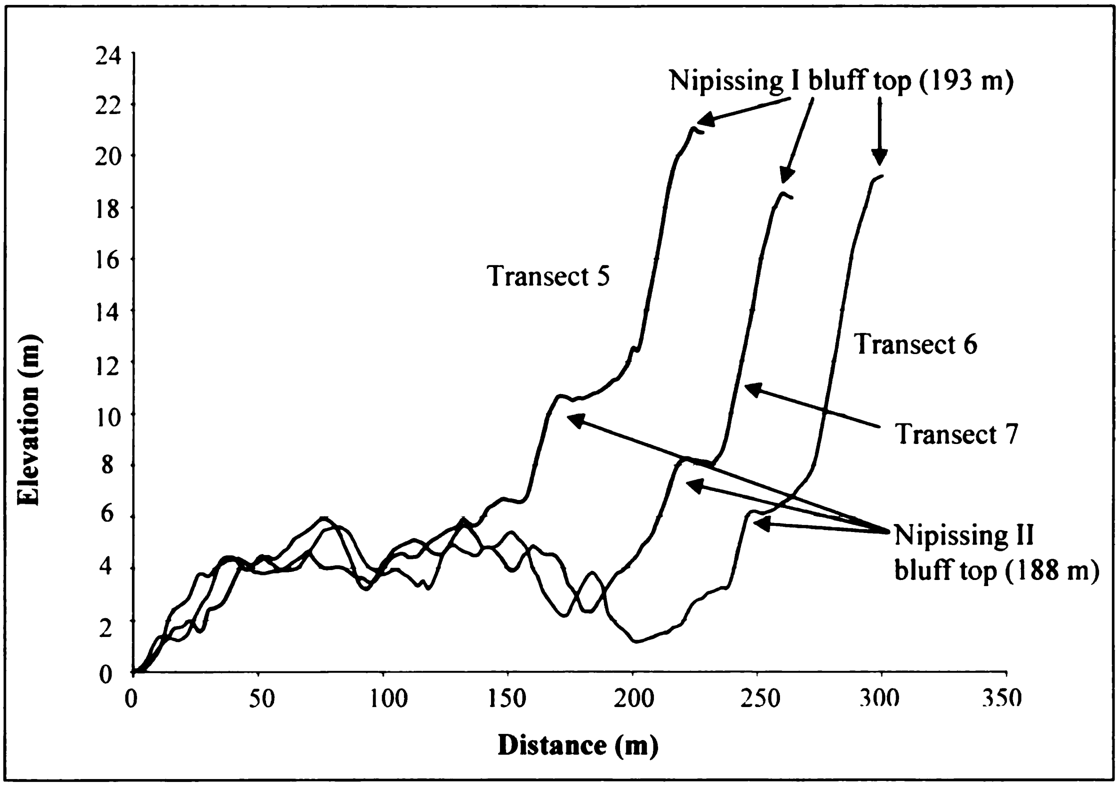

Figure 5:6 Stadia rod transects 5, 6, and 7. Baseline elevation of the transect is the base of the most lakeward dune.

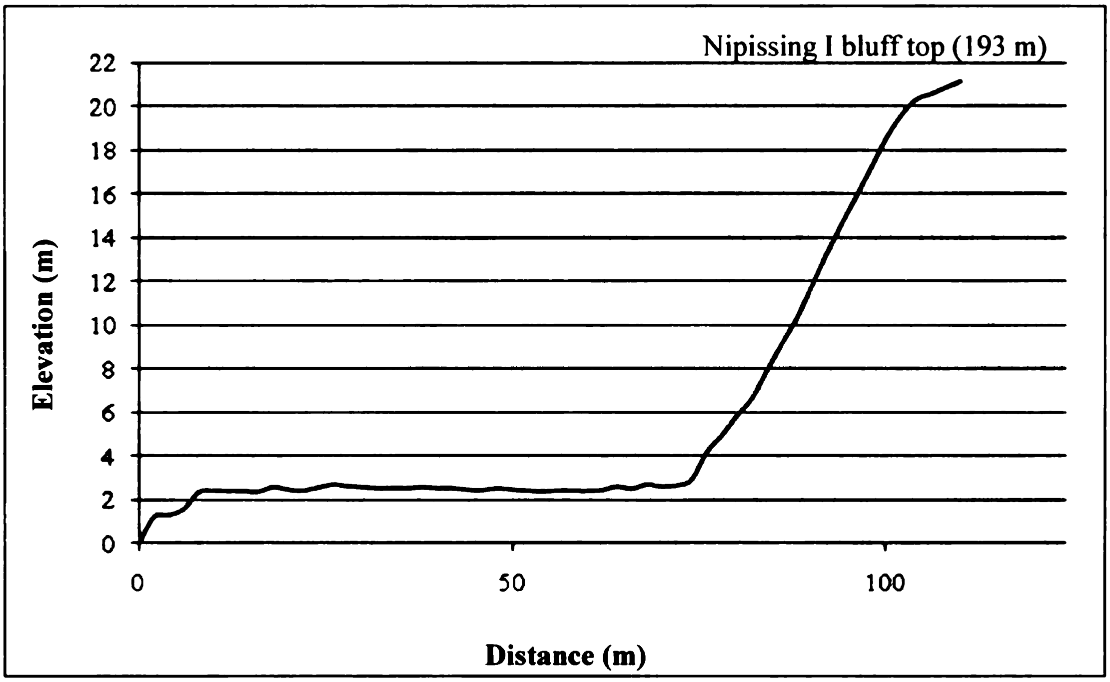

Figure 5:7 Stadia rod transect 8.

In summary, the topographic relationships in the park are nicely demonstrated in the stadia rod transects (Figure 5:8). In all transects the dominant features on the eastern edge of the park are the Nipissing I bluff and Nipissing II terrace. The variations in the dune topography are easily discernable when all eight transects are examined. The transition from hummocky, unstable dunes to linear dunes is apparent between transects 1-2 and transects 3-4. The dunes transition back to a more hummocky, less linear topography in transects 5-7. By transect 8, no dunes are present and the terrain is thus relatively level.

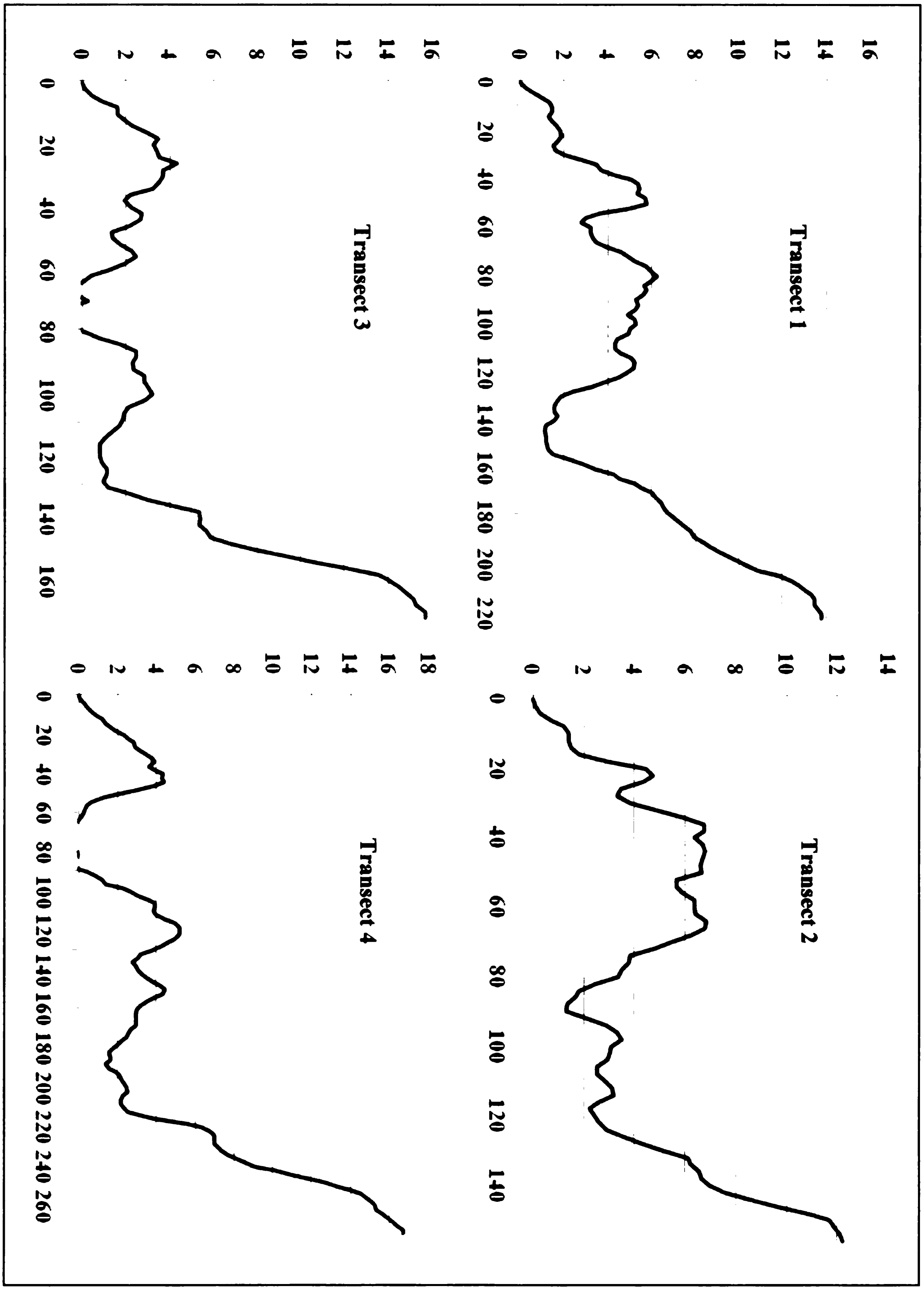

Figure 5:8 Stadia rod transects 1 through 8. Distance (m) is plotted on the x-axis, elevation on the y-axis.

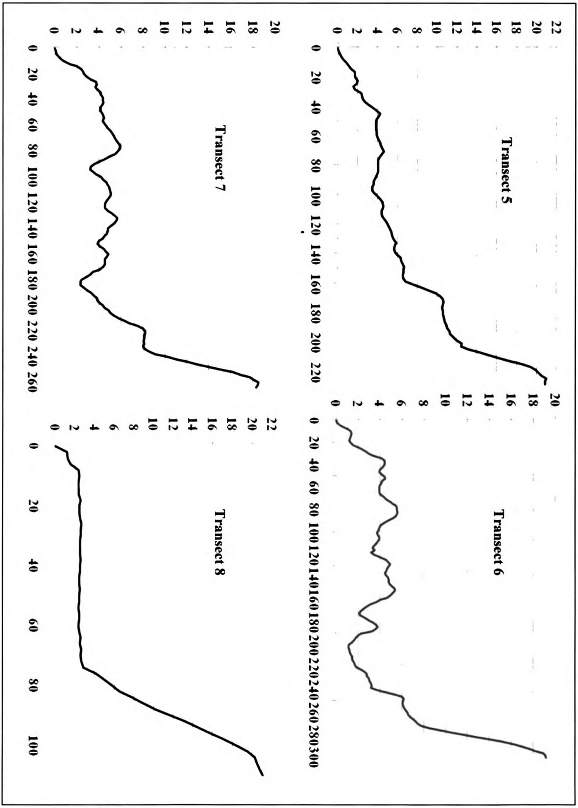

Figure 5:8 (cont'd.)

Stratigraphy and Soils

As noted in Chapter III, a primary goal of the study was to assess the stratigraphic relationships of dunes as they relate to the underlying deposits at ACNA. In addition to this assessment, a secondary focus was to examine the degree of soil development within the dunes. Although the dune soils at ACNA are entirely mapped within the Deer Park series (Larson and Buchanan, 1978), the initial soils investigation in the area may have been so limited because of the scale of the county that any potential spatial variation may have been missed. If such variation does occur, it may shed some light on the relative age of dunes in the park (e.g., Barrett, 2001). This part of the chapter discusses the dune stratigraphy and morphology at ACNA and the results of an empirical investigation of the surface soils.

Dune Stratigraphy

I investigated the dune morphology and stratigraphy and the nature of surface soils in a series of fourteen transects running east-west across the dune field. Overall, the stratigraphy consists of aeolian sands that overlie beach cobbles. The thickness of aeolian sand ranges from ~2.5-3.3 m in the dune ridges to an average of about 1.6 m in the swales. A special effort was made to locate buried soils because a potential paleosol was identified in an archeological investigation by Goatley (2004). Although I augered a total of 48 holes in this study, no buried soils were identified in the dunefield.

In an effort to supplement the augering component of the project and to assess stratigraphic relationships more broadly, the dunes were investigated with ground penetrating radar in spring, 2008. This effort consisted of running a line in the vicinity of transect 3 (Figure 4:1) across the dune field. The line extended from the Nipissing II terrace on the east side of the study area to Lake Michigan on the west.

The GPR data collected at ANCA support the auger investigations of dune stratigraphy. At a coarse scale (Figure 5:9) the most prominent features in the GPR data are the beach gravels that underlie the dunes and some possible lacustrine sedimentary structures in the basal deposits near the lake. A larger scale examination of the GPR data, centered on the deep swale, (Figure 5:10) illustrates the nature of the dune/beach gravel contact in more detail. This contact is represented by a generally horizontal line that crosses the image, one that ranges in depth from ~ 3 m in the dune ridges to ~1 m in the swale. The GPR data also indicate that well-developed sedimentary structures are not present in the aeolian sands and that a buried soil is not present in this part of the dune field.

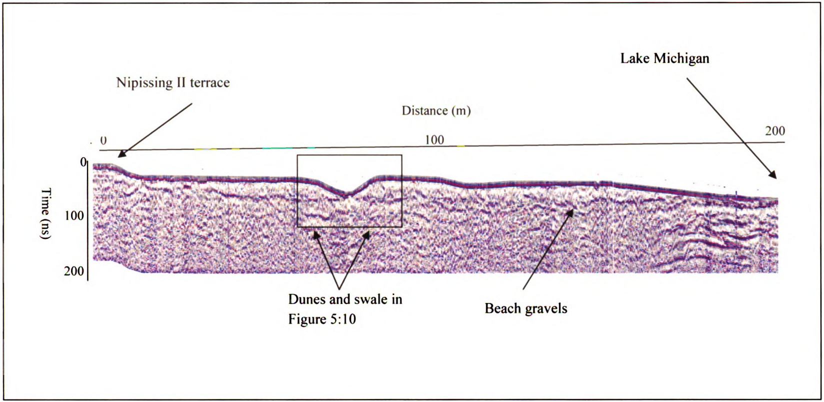

Figure 5:9. Diagram (looking south) showing GPR data at Transect 3 (see Figure 4:1; from van Damm, personal communication).

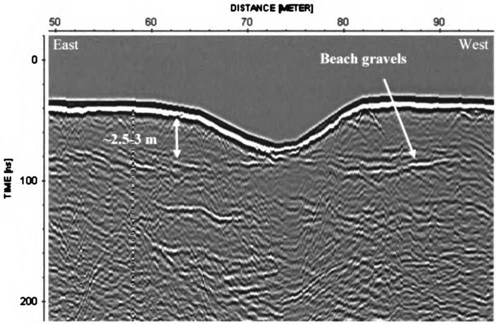

Figure 5:10. Diagram detailing the stratigraphy of the dunes at ACNA. The location of this study box is shown in Figure 5.9. The layer of beach gravel is evident at a depth of ~2.5-3.0 m. No distinct sedimentary structures between the surface of the dunes and the beach gravels are present (from van Dam, personal communication).

In addition to the examination of dune stratigraphy, I also assessed the general character of the surface soils in the auger holes (Table 5:1). Although the soils in the dune field are mapped exclusively within the Deer Park series (Larson and Buchanan, 1978), this investigation indicates that some subtle variation in development occurs, based mainly on landscape position.

Table 5:1 Soil horizonation for auger holes located in the dunes at ACNA.

	A Horizon Color (moist)	E Horizon Color (moist)	Bw Horizon Color (moist)	Bs Horizon Color (moist)	C Horizon Color (moist)	Depth to Beach (m)
Transect 1						
Auger 1	10YR 3/1	10YR 6/1	n/a	n/a	10YR 6/2	1.38
Auger 2	10YR 2/1	10YR 6/2	10YR 4/4	n/a	10YR 6/1	2.78
Auger 3	10YR 2/1	n/a	n/a	n/a	2.5Y 6/2	0.83
Auger 4	10YR 2/1	n/a	n/a	n/a	10YR 6/1	0.80
Auger 5	10YR 3/1	10YR 6/1	n/a	7.5YR 3/4	10YR 6/3	2.00
Transect 2						
Auger 1	10YR 2/1	10YR 6/1	n/a	10YR 3/6	10YR 6/2	3.10
Auger 2	10YR 2/1	n/a	10YR 4/3	n/a	10YR 6/1	2.68
Auger 3	10YR 2/1	n/a	n/a	n/a	10YR 6/1	2.70
Transect 3						
Auger 1	10YR 2/1	n/a	n/a	n/a	10YR 6/1	2.90
Auger 2	10YR 2/1	n/a	n/a	n/a	2.5Y 6/2	0.75
Auger 3	10YR 2/1	10YR 6/1	n/a	10YR 3/6	10YR 6/2	2.80
Transect 4						
Auger 1	10YR 2/1	n/a	n/a	n/a	10YR 6/1	2.90
Auger 2	10YR 2/1	n/a	n/a	n/a	2.5Y 6/2	0.89
Auger 3	10YR 2/1	n/a	10YR 4/3	n/a	10YR 6/3	3.00
Transect 5						
Auger 1	10YR 2/1	n/a	n/a	n/a	10YR 6/1	3.10
Auger 2	10YR 2/1	n/a	n/a	n/a	2.5Y 6/2	0.90
Auger 3	10YR 2/1	n/a	10YR 4/3	n/a	10YR 6/3	2.90
Transect 6						
Auger 1	10YR 3/1	n/a	10YR 4/3	n/a	10YR 6/3	3.00
Auger 2	10YR 2/1	n/a	n/a	n/a	2.5Y 6/2	0.95
Auger 3	10YR 2/1	n/a	n/a	n/a	10YR 6/2	2.90
Transect 7						
Auger 1	10YR 3/1	n/a	10YR 4/4	n/a	10YR 6/3	3.30
Auger 2	10YR 2/1	n/a	n/a	n/a	2.5Y 6/3	0.80
Auger 3	10YR 2/1	n/a	10YR 4/3	n/a	10YR 6/2	3.10
Transect 8						
Auger 1	10YR 2/1	n/a	n/a	n/a	10YR 6/3	2.90
Auger 2	10YR 2/1	n/a	10YR 4/3	n/a	10YR 6/3	3.00
Auger 3	10YR 2/1	10YR 6/1	n/a	10YR 3/6	10YR 6/2	3.30
Transect 9						
Auger 1	10YR 2/1	n/a	10YR 4/3	n/a	10YR 6/2	3.00
Auger 2	10YR 2/1	n/a	n/a	n/a	2.5Y 6/3	1.10
Auger 3	10YR 2/1	10YR 6/1	n/a	10YR 3/6	10YR 6/3	3.20
Transect 10						
Auger 1	10YR 2/1	n/a	n/a	n/a	10YR 6/3	3.10
Auger 2	10YR 2/1	n/a	n/a	n/a	2.5Y 6/2	0.90
Auger 3	10YR 2/1	10YR 6/1	n/a	10YR 3/6	10YR 6/3	3.00
Transect 11						
Auger 1	10YR 2/1	n/a	n/a	n/a	10YR 6/3	2.80
Auger 2	10YR 2/1	n/a	n/a	n/a	2.5Y 6/1	0.95
Auger 3	10YR 3/1	n/a	10YR 4/3	n/a	10YR 6/3	3.00
Transect 12						
Auger 1	10YR 3/1	n/a	n/a	n/a	10YR 6/2	3.00
Auger 2	10YR 2/1	n/a	10YR 4/3	n/a	10YR 6/3	3.30
Auger 3	10YR 2/1	10YR 6/2	n/a	10YR 3/6	10YR 6/3	3.00
Transect 13						
Auger 1	10YR 2/1	n/a	n/a	n/a	10YR 6/2	2.90
Auger 2	10YR 2/1	n/a	10YR 4/3	n/a	10YR 6/3	3.30
Auger 3	10YR 3/1	10YR 6/1	n/a	7.5YR 3/4	10YR 6/2	3.00
Transect 14						
Auger 1	10YR 2/1	n/a	n/a	n/a	10YR 6/3	3.10
Auger 2	10YR 3/1	n/a	10YR 4/3	n/a	10YR 6/3	3.30
Auger 3	10YR 2/1	n/a	10YR 4/3	n/a	10YR 6/2	3.00

At a fundamental level, the best developed soils occur on the dune crests, whereas the least developed soils are found in the dune swales. Soils in the dune swales were remarkably uniform, with A/Cg horizonation (Figure 5:11). The A horizon in these swale soils was generally about 28 cm thick and was usually 10YR 2/1 (Black) in color. The Cg horizon in swale soils extended from the base of the A horizon to the beach gravels at the base of the deposit. The color of the Cg horizon ranged from 2.5Y 6/2 (Light Brownish Gray) to 2.5Y 6/3 (Light Yellowish Brown). Roscommon soils are mapped in association with Deer Park soils in the dunes at ACNA (Larson and Buchanan, 1978). The typical pedon for a Roscommon soil have A/Cg/C horizonation. A horizons have a hue of 10YR or 7.5YR, a value of 2 or 3, and a chroma of 1 or 2. The C horizons have a hue of 10YR to 5Y, a value of 4 to 6, and a chroma of 1 to 3. The textures for both the A and C horizons range from loamy very fine sand to sand (NRCS, 2008). The characteristics of the soils in the swales fall within the accepted range of characteristics for the Roscommon soil series.

In contrast to the soils on dune swales, the soils on the dune crests were generally better developed. Soils on the dune crests also exhibited more variability across the landscape, with a positive relationship in development observed from the lakeshore to the most interior dune crest. Soils in the most lakeward dunes tended to have A/C profiles.

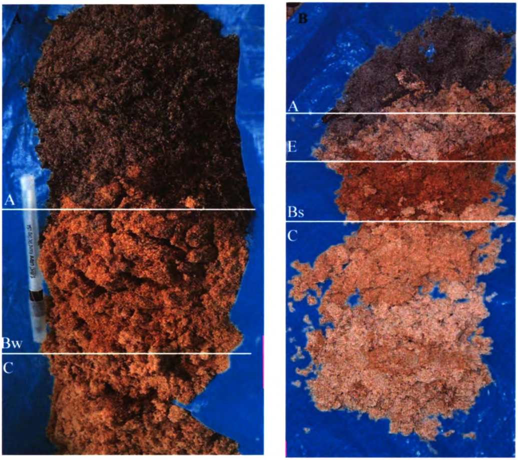

Figure 5:11 A: Example of soil development in middle dune. Notice the lack of an E and Bs horizon. B: Example of dune development in inner dune with A/E/Bs/C horizonation. Notice the contrast in development between the soil in the middle dune and the soil in the inner dune.

In contrast to the weakly developed soils in swales, the crest soils in the central part of the park generally have A/Bw/C horizonation (Table 5:1) The A horizon color was most commonly 10YR 2/1 (Black) and ranged in thickness from ~5 to ~20 cm. Bw horizons were usually 10YR 4/3 (Brown) and ranged in depth from ~5-28 cm. Soils in the dunes adjacent to the bluff were the most developed, often having A/E/Bs/C horizons (Figure 5:11; Table 5:1). A horizon color was usually 10YR 2/1 (Black) and ranged in thickness from ~5-22 cm. Where present, E horizons were predominately 10YR 6/1 (Gray) and ranged in depth from 22-94 cm. Bs horizons were 7.5YR 3/4 (Dark Brown) and 10YR 3/6 (Dark Yellowish Brown) and ranged in depth ~42-65 cm. The soils in the dunes at ACNA have been mapped as Deer Park (Larson and Buchanan, 1978). The typical Deer Park pedon has A/E/Bs1/Bs2/C horizonation (NRCS, 2008). In all horizons, the texture is sand or fine sand. The A horizon has a hue of 10YR or 7.5YR, a value of 2 or 3, and a chroma of 1 to 3. The E horizon has a hue of 7.5YR or 10YR, a value of 2 or 3, and a chroma of 1 or 2. The B horizons have a hue of 7.5YR or 10YR, a value of 4 to 6, and a chroma of 3 to 6. The C horizon has a hue of 10YR or 7.5YR, a value of 5 or 6, and a chroma of 3 or 4 (NRCS, 2008). The characteristics of the soils in the dunes at ACNA generally fall within the accepted range of characteristics for the Deer Park soil.

Optical Stimulated Luminescence Ages

In order to determine the absolute chronology of the dunes at ACNA, I obtained three OSL samples (Table 5:2) from the ridges along a transect across the most prominent set of stable dunes (Figure 4:2). Sample 1 was acquired from the crest (~185 masl) of the dune closest to the lake with a bucket auger at a depth of 1.25m. This sample returned a date of 1300 ± 110 ka (Shfd06141). Sample 2 was located on the shoulder (~185 masl) of the middle dune and taken from a depth of 1.35 m at the base of a soil pit. This sample returned a date of 2170 ± 50 ka (Shfd06142). Sample 3 was obtained from the crest (186 masl) of the dune adjacent to the secondary lake terrace at a depth of 1.3m. This latter sample returned a date of 1950 ± 180 ka (Shfd07001).

Table 5:2 Summary of OSL data for the dunes at ACNA.

Location	Lab Code	Depth (cm)	Total N Aliquots Measured	Usable Aliquots	Dose Rate (μGy/a^{-1})	OSL Age (ka)
ACNA Dune 1	shfd06141	125	24	16	990±53	1300±110
ACNA Dune 2	shfd07001	135	24	16	995±54	2170±50
ACNA Dune 3	shfd06142	130	24	14	980±53	1950±180

Archaeology of the dunes at ACNA

Two archaeological excavations were conducted at ACNA. The first excavations were carried out by a team of local volunteers led by Charles Cleland from Michigan State University between July 2000 and September 2001. The Cleland excavations at ACNA determined that dozens of sites are present in the park, ranging from the Archaic Period through European settlement. Of all of these sites, however, only two are located within the study area in this investigation. These sites are the *Nipissing II Terrace Site* (10AN54) and the *Antrim Creek Site* (10AN22).

The older of the two sites preserved in this study area is apparently the *Nipissing II Terrace Site*, which is located on the Nipissing II terrace. (Figure 5:12). Excavations at this site consisted of one test pit dug to a depth of 74 cm. According to Cleland (2002), diagnostic artifacts found in the pit imply that the site is from the Archaic Period. Norwood chert debitage and projectile point bases that are stylistically indicative of the Late Archaic period were found throughout the site in the shovel tests as well. Similar points, called Pomranky Points (Papworth and Binford, 1963) have been found in the nearby *Eastport Site*. These points were likely produced at the *Nipissing II Terrace Site*

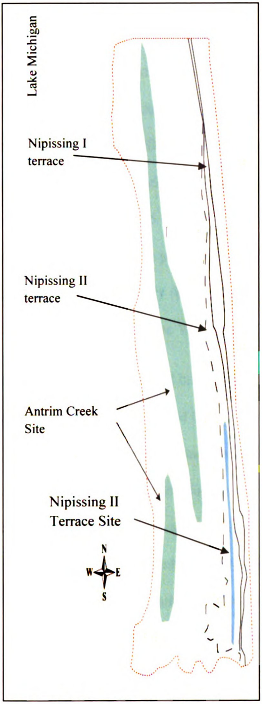

Figure 5:12 Location of Nipissing II Terrace Site and Antrim Creek Site. Figure adapted from Cleland, 2002 (Not to scale).

and the *Eastport Site* and exported to other parts of the state via a Late Archaic trade network (Cleland 2002).

Unlike the *Nipissing II Terrace Site*, more extensive excavations were conducted at the *Antrim Creek Site* (Figure 5:12). These excavations consisted mainly of shovel testing and 11 small pit excavations (Cleland, 2002). The test pits and shovel tests yielded an extensive, probably repeated, occupation of the dunes at ACNA. Flint chips and fire-cracked rock were found in the upper 25 cm of test pit 1. Several body sherds were found lower in the pit. Unfortunately, these pottery sherds could not be used to assign a cultural period to the site, except to imply (based on the paste and temper) that the sherds may have been produced during the Late Woodland (Cleland, 2002).

Only one lithic artifact was found that could be used to tentatively assign the site a cultural period. One side scraper, made of Norwood Chert, was found that is stylistically like scrapers manufactured in the Woodland Period (Cleland, 2002). The large amount of sherds recovered at the site suggests that it was occupied extensively. Cleland (2002) suggested that the site represents a series of Late Woodland occupations (900-1650 AD). Excavations at ACNA were resumed in 2004 under the direction of Dan Goatley from the Michigan State University Department of Anthropology (Raviele, 2006). The 2004 excavations were conducted primarily within the *Nipissing II Terrace Site*. 33 pits were excavated at the site. Numerous lithic artifacts, including flakes, bifaces, and hammerstones were found at the site. Raviele (2006) interpreted the site to be a logistic task sit, used for the reduction of chert (obtained from the nearby Pi-wang-go-ing Quarry) into bifaces.

One radiocarbon date was obtained from the site and returned a date of 1390±40 years (Raviele, 2006). Previously, Cleland (2002) had interpreted the site to be from the Late Archaic period; however, based upon the radiocarbon date, Raviele (2006) believes the site also has a Late Woodland component

Unlike the Nipissing II Terrace Site, the 2004 excavations at the Antrim Creek Site were less extensive. Test pits (11) and shovel tests were conducted over a two week period. Only lithic artifacts were found at the site during the 2004 investigations. Raviele (2006) assumed the site to be a Late Woodland Site.

In addition to the artifacts found in the pits, an organic horizon was uncovered in pit 1 at a depth of 95 cm (Figure 5:13). The horizon was discontinuous in the pit It is possible that this horizon is an organic midden created by the people who occupied the dune. Another possible scenario is that this horizon is a buried soil. If the feature is indeed a soil, it appears to consist of a thin A horizon over a C horizon (Figure 5:14), suggesting that the dune stabilized for a brief period of time as it formed. In an effort to learn more about this stratigraphic marker, I systematically searched for it during my auger investigations. Unfortunately, this organic horizon was not identified in any of the auger sites, nor was it identified in the GPR line.

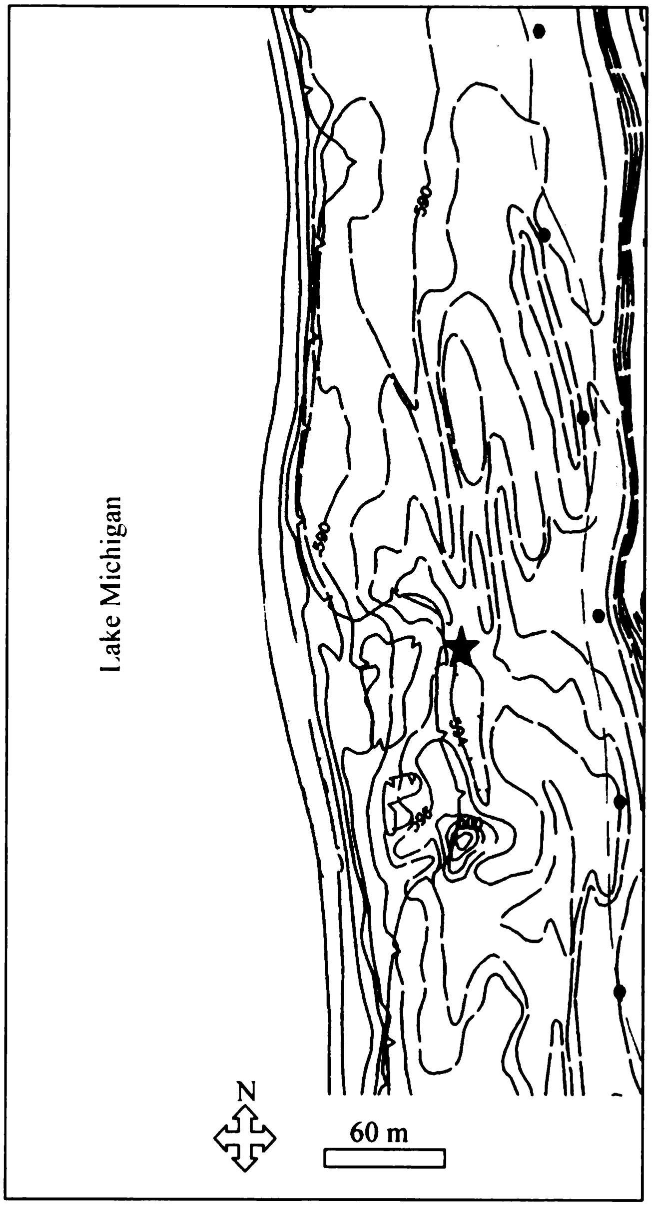

Figure 5:13 Location of test pit 1.

Figure 5:14 Organic horizon found during Goatley's archaeological excavation. Photo courtesy of Antrim County Nature Society, MSU Department of Anthropology, and the MSU Museum.

Discussion

Chronology of the Dunes at ACNA

Results from this study provide a chronology for landscape evolution and related archaeology at the Antrim Creek Natural Area. The following discussion outlines this chronology and is based on the combined evidence of topographic relationships, soils information, OSL ages derived from the dunes, and apparent geoarchaeological relationships.

The landscape at ACNA appears to have first begun to evolve during the Nipissing stage of ancestral Lake Michigan, which occurred between 5.5 ka and 4.0 ka (Larson and Schaetzl, 2001). This lake phase occurred as the North Bay outlet rose due to isostatic rebound (Larson and Schaetzl, 2001). By the end of this time, the lake reached an elevation of ~ 190 m at ACNA, which is about 13 m higher than present (Larsen, 1985b; Cleland 2002). As a result of this high lake phase, a prominent bluff, the Nipissing I bluff, was cut that borders the study area on the east (Figure 3:2). Subsequently, erosion of the Port Huron outlet resulted in falling lake-levels (Monaghan and Lovis, 2005). Lake-levels dropped to around 178 m before rising to 180 m during the Nipissing II transgression between 4185 and 3800 years BP (Larsen, 1985b). Another wave-cut bluff (the Nipissing II) formed during this high stand, one that lies immediately west of the more prominent Nipissing bluff.

After the Nipissing II phase, continued erosion of the Port Huron outlet resulted in falling lake-levels. However, lake-levels rose briefly ~3200 years ago, resulting in the Algoma phase (Larson and Schaetzl, 2001). At ACNA, this lake phase most likely caused deposition of the beach gravels that underlie the dunes. When downcutting of the Port Huron outlet subsequently resumed, lake-levels began to fall once again ~2500 cal. yrs. BP (Monaghan and Lovis, 2005). At ~1700 cal. years BP, another brief period of high lake-levels occurred in the basin, after which lake-levels began fluctuating in a range similar to that of the historical record (Thompson and Baedke, 1997).

The elevation data (Figure 5:8) and OSL dates (Table 5:2) collected at ACNA indicate that the dunes in the study area formed and stabilized after the Algoma phase of Lake Michigan at ~2500 cal. yrs. BP. Given this chronology, coupled with the ridge and swale topography of the landscape, the dunes appear to be ancient foredunes. In that context, the dunes likely formed in a manner consistent with Olson's (1958b) foredune model as lake-level fell from the Algoma high stand. According to this model, a foredune begins to form when the lake falls sufficiently to expose beach sands that can be subsequently blown by the wind. The foredune subsequently continues to grow as vegetation begins to colonize the dune, which further traps wind-blown sand.

Assuming the ACNA dunes are foredunes, the oldest dune ridge should theoretically be the most easterly (nearest the bluff), with progressively younger foredunes toward the modern beach (e.g., Olson, 1958b). Unfortunately, the first pair of dates provides somewhat conflicting evidence for the timing of dune formation at the central and easternmost ridges. This comparison reveals that the OSL age from the central foredune is ~2170±50 ka, whereas the age obtained from the easternmost dune is ~1950±180 ka. In the context of Olson's (1958b) model, these ages are topographically inverted because the middle foredune theoretically should have formed after the more easterly dune ridge as lake-level progressively fell from the Algoma high.

The conflicting age evidence can be explained in two scenarios. The first scenario incorporates the buried organic horizon found during the archaeological excavations (Raviele, 2006). Assuming for a moment that this horizon formed pedogenically, it reflects a period of prehistoric landscape stability that presumably occurred everywhere in the dune field. As a result, the soil should be fairly common in the study area (e.g., Arbogast et al., 2001). I did not encounter this soil during the auger investigations nor during the GPR investigations, however, suggesting that it was stripped at other locations during a later period of erosion. Such erosion would have reset the OSL clock in the eroded sediments by exposing them to light. If some of those sediments were subsequently deposited on the easternmost dune, they would have resulted in topographically inverted ages if I happened to sample them.

Although the above erosional scenario for the age inversion is possible, a second scenario more likely explains the apparently inverted dates. This second scenario focuses on how the ages should be interpreted given their probability distributions at two standard deviations. At this level of statistical analysis the ages overlap in time by 240 years (from 2310 – 2070 ka; Figure 5:15; Table 5:2). According to Olson (1958b), foredunes grow in 30-year cycles that are associated with lake-level fluctuations. Therefore, it is entirely possible that the dunes formed too close together to be differentiated using OSL dating alone. In this context, the overlap in the probability distributions of the oldest pair of OSL ages at ACNA can be interpreted to mean that the middle dune formed after the easternmost ridge in a manner consistent with Olson's (1958b) foredune model. Given the simplicity of this argument, it is favored to explain the apparent age discrepancy between the middle and easternmost dune ridges.

The differences in soil development between the easternmost and middle dunes also support this interpretation. The dunes at ACNA represent a chronosequence (Barrett, 2001). In a chronosequence, four of the five (climate, organisms, landscape, parent material, time) soil forming factors are held constant. Chronosequences in foredunes have been recognized in other locations along Lake Michigan (Lichter, 1995, 1998; Petty *et al.*, 1996; Barret, 2001). Lichter (1998; Figure 2:2) used radiocarbon dating and tree-ring cores to determine that the beach-ridge/foredune couplets at Wilderness State Park formed ~35 years. Lichter continued his research of the dunes at

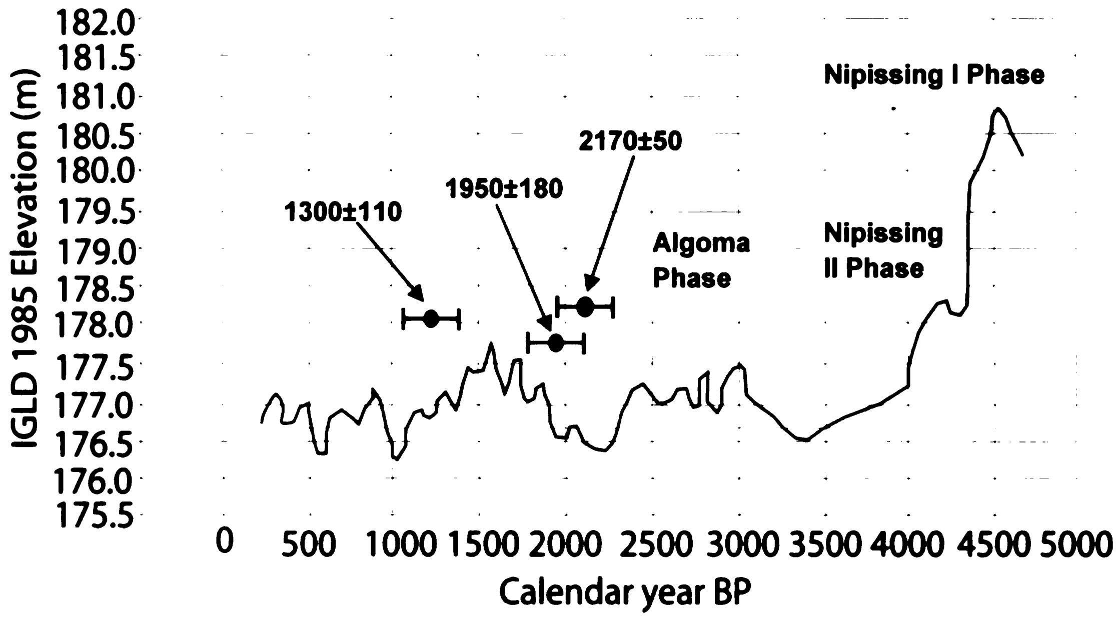

Figure 5:15 OSL dates from this study versus lake-levels. Figure adapted from Thompson and Baedke (1997).

Wilderness State Park in 1998, this time focusing on soil development among the dunes. He found that younger dunes, closest to the lake, had less developed soils, whereas older dunes, further from the lake, had more developed soils that had undergone a greater degree of podzolization. Barrett (2001) studied a strandplain by Naubinway, MI. This dunefield had previously been studied by Petty *et al.* (1996), who found that the dunes formed ~72 years, and increased in age with distance from the beach. Barrett, (2001) focused on soil development rates within the strandplain. She found that as the soils in the dunes increased in age, so did the appearance of recognizable E and Bs horizons.

Although the foredune field at ACNA is smaller than fields at other sites, the dunes at ACNA appear fit the patterns observed elsewhere. Given the dunes' close proximity at ACNA, it is logical to assume that climate, organisms (i.e. vegetation), landscape, and parent material are the same, suggesting that time is the major factor in determining the differences in soil development between the dunes. If this is indeed the case, the dune with the most developed soil should be the oldest dune. At ACNA, the easternmost dune has the most developed soil (A/E/Bs/C) which supports Olson's (1958b) foredune model in that the oldest dune should be the dune furthest from the beach.

In the context of these age rationales, it is possible to compare the formation of the ACNA foredunes to Thompson and Baedke's (1997) lake-level curve (Figure 5:15) to relate periods of dune growth with distinct lake phases. OSL ages from the most eastern and middle dune ridge suggest that the most recent accumulation of aeolian sand in the oldest foredunes occurred after the Algoma phase, sometime around 2100 years ago. This period of time correlates reasonably well with a low-lake phase in a manner that is generally consistent with the Olson (1958b) model. Following a period of higher lake-level about 1700 years ago, the most lakeward foredune formed during a period of dropping lake-level about 1300 years ago.

The OSL ages of the dunes at ACNA provide a means to refine the cultural period that was assigned to the *Antrim Creek Site* during the Cleland (2002) investigations. Cleland (2002) has suggested the site was from the Late Woodland period, although no diagnostic artifacts were found that could definitively date the site. During the Goatley (Raviele, 2006) investigations, an organic midden was found in a test pit located within the middle dune (~2170±50). If the site is indeed a Woodland site as Cleland (2002) proposed, the organic midden was most likely deposited during the Middle Woodland (2500-1500 cal. years BP).

In summary, the topographic, stratigraphic, and age data derived from ACNA provide a chronology for the evolution of the landscape in the park. The elevation (193 m) of the top of the easternmost bluff suggests that it is the Nipissing I bluff that formed due to wave erosion when lake-levels were higher than present around 5500 cal. yrs. BP (Larson and Schaetzl, 2001). The elevation of the secondary bluff and terrace in the park suggests that it formed during the Nipissing II transgression around 4000 cal. yrs. BP. Lake-level subsequently fell, only to rise again during the Algoma phase about 3200 years ago. Following the Algoma high stand, lake-level slowly fell about 1 m (Larsen, 1985b). At the lowest point of this regression, about 2100 years ago, a pair of foredunes apparently formed fairly quickly at ACNA. These dunes remained in place through a subsequent high stand that occurred about 1700 years ago. As lake-level fell from this high stand, another foredune formed about 1300 years ago. Since this period of time the lake has fluctuated slightly around the historic average and any further foredune development would have been focused in the nearshore environment.

Geoarchaeology of the Dunes at ACNA and its Relationship to Nearby Sites

Based on the geomorphic reconstruction described in this study, the archaeological sites at ACNA can be placed within a definable geoarchaeological framework. This framework is intimately tied to the history of lake-level fluctuations in Lake Michigan and the evolution of foredunes in the park. Because of these distinct relationships, the results derived from this study can be further applied to other archaeological sites, such as *Wycamp Creek* and *Inwood Creek*, where cultural remains have been retrieved from similar landscapes.

Archaeological remains from two cultural periods have been found at ACNA (Cleland, 2002). The oldest site is the *Nipissing II Terrace Site*, which is a Late Archaic site confined to the Nipissing II terrace. Nearby sites (i.e. the *Eastport Site*) contain Late Archaic deposits as well, suggesting that groups were using the area at least seasonally. Because the Late Archaic predates the Algoma phase of Lake Michigan, it is extremely unlikely that any evidence from this period would be found on elevations lower than the Nipissing II terrace (i.e. the dunes at ACNA) because those sites would have been eroded during more recent higher lake phases such as the Algoma.

In addition to the Late Archaic site on the Nipissing II terrace, an extensive Late Woodland site occurs within the dunes at ACNA (Cleland, 2002). Unlike the earlier Archaic period, which occurred during the highest lake-levels in the Holocene, the Late Woodland period occurred in the post-Algoma period when lake-levels were much lower (Table 5.3). Topographic data and OSL dates obtained in this study have confirmed that the ACNA dunes formed after the Algoma highstand and prior to the Late Woodland period. As a result, the dunes at ACNA were available to be occupied by Late Woodland people, as Cleland's (2002) study indicated.

Table 5:3 Cultural periods, timeline, and corresponding Lake Michigan geologic period. Adapted from Monaghan and Lovis (2005).

<table>
<tr><th colspan="2">Cultural Periods</th><th>Timeline</th><th>Lake Michigan Geologic Events</th></tr>
<tr><td colspan="2">Glaciated</td><td>13 ka</td><td>Port Huron Advance, high lake-levels</td></tr>
<tr><td colspan="2">Paleo-Indian</td><td>11-12 ka</td><td>Glacial Lake Algonquin, high lake-levels</td></tr>
<tr><td rowspan="3">Archaic</td><td>Early</td><td>10 ka</td><td>Chippewa-Stanley low phase</td></tr>
<tr><td>Middle</td><td>7-8 ka</td><td rowspan="2">Nipissing/Algoma Transgression (5.0-3.5 ka) high lake-levels</td></tr>
<tr><td>Late</td><td>5 ka</td></tr>
<tr><td rowspan="3">Woodland</td><td>Early</td><td>2.55 ka</td><td>Low lake-levels</td></tr>
<tr><td>Middle</td><td>2.0 ka</td><td>High lake-levels</td></tr>
<tr><td>Late</td><td>1.5 ka</td><td>Low lake-levels</td></tr>
</table>

Similar geoarchaeological relationships to those reconstructed in this study have been observed in a pair of sites, *Wycamp Creek* and the *O'Neil Site* (Figure 5:16), located in small foredune fields along the northwest shore of Lake Michigan. The *Wycamp Creek Site* is located on a small dune field at the base of the Nipissing Terrace on the north bank of Wycamp Creek (Figure 5:16). A small portion of the site was excavated in 1967 by a group led by Cleland at Michigan State University (Lovis, unpublished). From this initial excavation, several occupations of the site were evident, spanning over a ~ 1000-year period. Three radiocarbon dates taken from the site bracket the occupation to between 1320 ± 120 years BP and 400 years BP. Because such a small portion of the site was excavated (estimated to be less than 1% of the total area of the site), little about the use of the site can be conclusively determined. However, Lovis (unpublished) proposed that the site was used somewhat continuously throughout the entire 1000-year period from the Late Middle Woodland through the Late Woodland period.

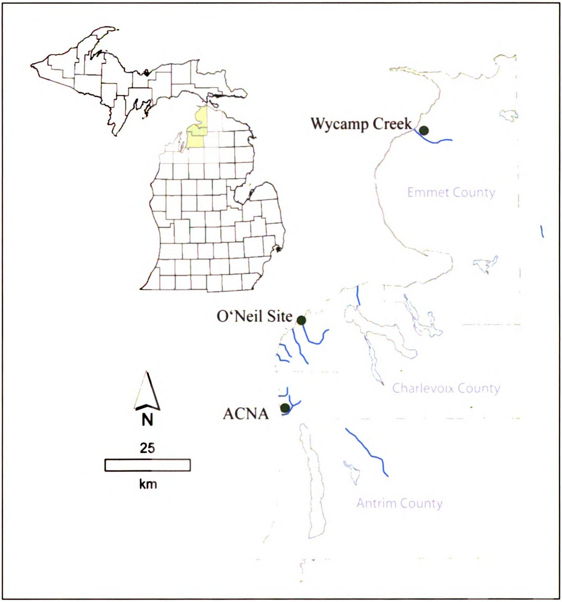

Figure 5:16 Location of the Wycamp Creek Site, the O'Neil Site, and ACNA.

Unlike the *Wycamp Creek Site*, more extensive excavations have been completed on the *O'Neil Site*, located on the north bank of Inwood Creek (Figure 5:16). The Nipissing terrace is situated above the site at an elevation of 186 m, with dunes located on the Algoma beach up to the Nipissing terrace. The site was excavated in three blocks and yielded both diagnostic artifacts and radiocarbon dates. Both the artifacts and the dates bracket occupation of the site to the Woodland Period. The radiocarbon dates indicate that the site was occupied by at least 1200 cal. yrs BP, and was probably occupied repeatedly throughout the Woodland period on a seasonal basis. In addition, the occupation at the *O'Neil Site* indicates that groups were utilizing the area rather intensively throughout the Woodland Period.

The chronology of dune formation at ACNA can be extrapolated to the dunes at both Wycamp Creek and Inwood Creek. Absolute dating from the three sites shows that the dunes formed and stabilized after the Algoma highstand, probably via Olson's (1958b) model of foredune formation. Because of the age of the dunes at these sites, it is not surprising that the only archaeological remains found in the dunes date to the Late Woodland period. Any archaeological sites predating the Late Woodland are likely to be found only at higher elevations

Geoarchaeological Model for Small Foredune Fields along Lake Michigan

Evidence from ACNA, the *Wycamp Creek Site*, and the *O'Neil Site* suggests a model (Figure 5:17) of archaeological site preservation along the northeastern coast of Lake Michigan. Archaic and Late-Archaic sites must be confined to the Nipissing I and II terraces because topographically lower surfaces were submerged at this time. Although Late Woodland sites may also occur on these elevated surfaces sites, they can also be found in the foredunes that occur between Nipissing bluffs and the modern beach where the dunes post-date the Algoma lake phase. Such sites have already been found at ACNA, Wycamp Creek, and Inwood Creek. In this context, Late-Woodland sites may also be present in the dunes south of Elk Rapids and the dunes at Cross Village.

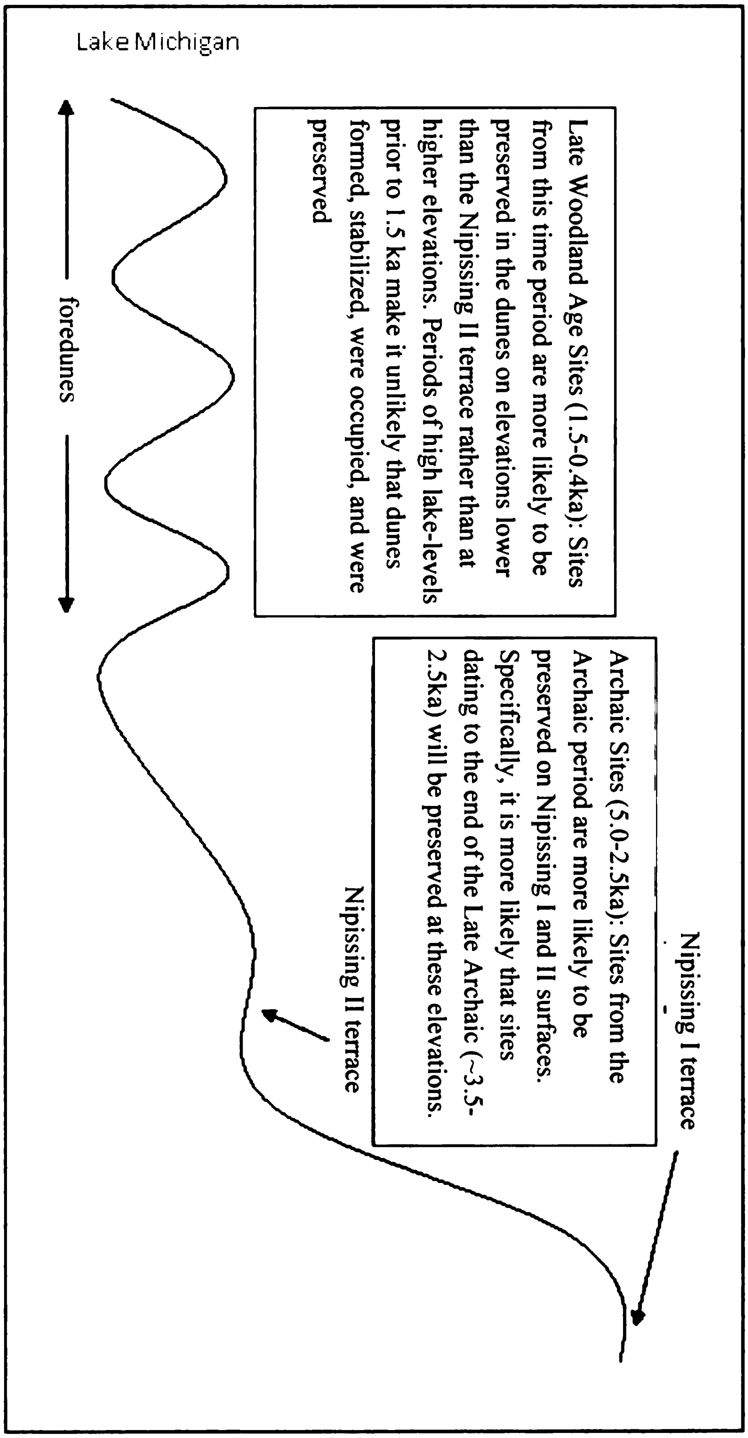

Figure 5:17 Representative diagram of geoarchaeological model.

In summary, the topographic and OSL data from ACNA provide a chronology for the evolution of the dunes at ACNA and place them within a geoarchaeological context. The dunes apparently formed after the Algoma highstand during periods of falling lake-levels via the Olson (1958b) model. Archaeological evidence from the dunes indicates that they were occupied successively by groups during the Late Woodland period. When combined with evidence from other nearby sites, a model of archaeological site preservation emerges. Sites from earlier periods of higher lake-levels, such as the Late Archaic, are most likely to be found at higher elevations like the Nipissing I and II terraces. Sites dating to periods of lower lake-levels, like the Late Woodland, are more likely to be found in small dune fields like those at ACNA.

Chapter VI

CONCLUSIONS AND FUTURE RESEARCH

The goal of this research was to reconstruct the geomorphic evolution of a small dune field along the northwestern shore of Lake Michigan and to place it within a geoarchaeological context. The study focused on dunes within the Antrim Creek Natural Area (ACNA) because archaeological investigations were previously conducted at this location. To meet the study goals, I derived a variety of topographic, stratigraphic, and absolute age data to help ascertain the evolution of the dunes. Archaeological evidence from ACNA, as well as nearby sites at Wycamp Creek and Inwood Creek, were subsequently combined with the geomorphic evidence to propose a model of site preservation for small coastal dune fields along the northwestern shore of Lower Michigan.

Geomorphology of ACNA

Geomorphic research conducted at ACNA suggests that the evolution of the landscape is directly tied to the history of late Holocene lake-level fluctuations in Lake Michigan. The landscape began to evolve during the Nipissing Great Lakes between ~5.5 and 4.0 ka. During the Nipissing I transgression, lake-levels at ACNA reached ~190 masl, about 13 m higher than present. A steep wave-cut bluff was formed at this time. After the Nipissing transgression, lake-levels fell to about 178 m before rising to 180 m during the Nipissing II transgression ~4000-3800 cal. years BP. At ACNA, this high stand cut another bluff and terrace that are topographically lower than the Nipissing I landforms. Subsequently, lake-levels again fell before rising briefly (~185.0 masl) during the Algoma highstand ~3.2 to 2.5 ka. During this latter high lake stage, beach gravels were deposited at ACNA in about a 150-m wide zone between the Nipissing II bluff and the modern beach. After the Algoma highstand, lake-levels fell about one m before rising about 1.5 m at approximately 1700 cal. yrs. BP. Since that time, lake-levels fell to modern levels (177 m) and began to fluctuate in a narrow range comparable to the historical record.

The formation of dunes at ACNA is apparently related to lake-level fluctuations since the Algoma high stand ~ 3.2 – 2.5 ka. In a crossection of the study area, the dunescape consists of three well-defined ridges, which are about four-m in height, that are separated by distinct swales. This ridge and swale topography, along with other characteristics, indicates that the dunes are foredunes that formed according to Olson's (1958b) model. In this scenario, the dunes would have formed during periods of low lake-level, with the easternmost dune being the oldest, with progressively younger dunes toward the coast.

OSL ages from ACNA provide a mixed chronology for foredune development. Some inconsistency with Olson's (1958b) model is apparent because the middle and easternmost dune returned topographically inverted dates of ~2170 ±180 and ~1950 ±50 ka, respectively. Taken at face value, these ages imply that the easternmost ridge is the youngest of the pair. Although this chronology is possible, it is more likely that both dunes formed at about the same time.. Regardless, it appears that both dunes formed during a low lake stage, which fits within the Olson's (1958b) model. After formation of these dunes, the lake rose again at about 1700 cal. yr B.P. Following this high lake stage, the lake dropped again, resulting in formation of the most western foredune at about 1300 ka.

Geoarchaeology of ACNA and Surrounding Areas

In addition to reconstructing the geomorphic history of ACNA, a secondary goal was to integrate the evolution of landforms with the archaeological record from the park and to create a geoarchaeological model. Archaeological investigations of ACNA were completed in 2001 by Dr. Charles Cleland of Michigan State University. Two archaeological sites were found within the study area at ACNA. The oldest site is the *Nipissing II Terrace Site.* This site, which is confined to the Nipissing II terrace, consists of a late-Archaic lithic scatter that may have been used to manufacture projectile points for export. The other archaeological site in the study area is the *Antrim Creek Site,* which is a large site located in the dunes of the study area. One diagnostic artifact was found at the site, a lithic scraper that was stylistically indicative of the Woodland period. In addition, the paste and temper of pottery sherds found there imply that the site is from the Late Woodland.

The archaeological information from the *Nipissing II Terrace Site and the Antrim creek Site* correlates well with information found at Wycamp Creek and Inwood Creek, nearby sites in small coastal dune fields. Incorporating the information from these sites with the geomorphic information at ACNA provides a model of site preservation for small coastal dune fields in northwest Lower Michigan. Sites predating the Late Woodland should be preserved on topographically high surfaces, such as the Nipissing I and II terraces, because topographically lower surfaces were submerged during the

Nipissing and Algoma lake phases. In contrast, sites dating to the Late Woodland can be found on lower elevations, such as dunes that mantle the Algoma surface, because these landforms developed after ~ 2.5 ka.

Future Research

The results of this study provide a direction for future research regarding site preservation in small coastal dune fields along Lake Michigan. This model should be tested against un-excavated dune fields in northwest Michigan. Two such dune fields, at Elk Rapids and Cross Village, could provide suitable locations for testing. whether the findings in this study are truly applicable to other small dune fields along the coast.

As in this study, chronological dating techniques should be used to definitively bracket dune ages and the sites within the dunes. Although elevation data provide relative ages for the evolution of landscapes, dating the dunes and the archaeological sites provides necessary information for testing the model. This approach would not only confirm both the ages of the dunes and the evolution of the landscape, but also test whether the sites preserved in the dunes conform to the proposed model.

Another area for future research involves the origin of buried organic horizons in archaeological sites in coastal dune fields. During the Cleland excavations a buried organic horizon was identified in a test pit. In the context of my research, I speculated that this horizon was actually a buried soil with an A/C profile. This marker was not found in any of the stratigraphic investigations in this study, however, making it unlikely to be a buried soil. An alternative interpretation is that the marker is a cultural midden. If this hypothesis is correct, it means that dune stratigraphy elsewhere may be misinterpreted because buried organic horizons may be thought to represent periods of prehistoric landscape stability when, in fact, they merely reflect short-term human occupation. Investigating how these organic horizons form would add a significant contribution to understanding how archaeological sites are preserved in coastal dune fields and an indirect impact that prehistoric people had on coastal dunes.

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