Geomorphological History of Massive Parabolic Dunes, Van Buren State Park, Van Buren County, Michigan.(Statistical Data Included).MARTIN VAN OORT, ALAN ARBOGAST, EDWARD C. HANSEN and BEN HANSEN. ***Michigan Academician*** 33.2 (Summer 2001): p175. (4870 words)

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ABSTRACT

Lakeshore erosion along eastern Lake Michigan has exposed a series of buried soils in the massive (up to 45 m high) parabolic dunes at Van Buren State Park, Michigan. For this study, soils were mapped and described along a 300 member stretch of the lake shore. The basal soil in the northern part of the study area is a peat layer that gives way southward to a Spodosol. Radiocarbon dates indicate that peat accumulation began in a wetland at 6170-5750 cal. yr B.P. (2[sigma]) and ended with a influx of windblown sand at 5470-4880 cal. yr B.P. The Spodosol was buried at 5890-5618 cal. yr B.P. A series of buried soils with weakly developed A/C horizonation make up the lower Entisol sequence. These indicate brief intervals of stability during a period of episodic dune growth that ended at 2 150-1970 cal. yr B.P. The lower Entisol sequence is capped by an Inceptisol with an A/[B.sub.s]/C horizonation that represents an extended period of dune stability. This Inceptisol was buried by a remobilization of the dune some time after 500 cal. yr B.P. The upper Entisol sequence indicates that this latter period of dune mobility was episodic until today. The history of the coastal dunes at Van Buren is very similar to the histories of coastal dunes southwest of Holland, Michigan, and at Mt. Baldy in the Indiana National Lakeshore. This suggests that there is a broad regional framework for the history of coastal dunes along the southeastern shore of Lake Michigan.

FIGURE 1. Map of Lower Michigan showing the distribution of coastal dune complexes (black) and the areas referred to in this paper. Modified from Santer (1993) and Farrand and Bell (1982).

INTRODUCTION

The sand dunes along the eastern shore of Lake Michigan (Figure 1) maybe the largest complex of freshwater dunes in the world (Peterson and Dersch 1981). These dunes contain a number of unique ecological communities and are widely recognized as one of the major aesthetic and recreational natural resources of Michigan and northern Indiana. Scientific studies in this complex were critical in the development of the theory of ecological succession (Cowles 1899) and contributed to our understanding of the role of lake level and vegetation in the development of dunes (Olson 1958a,b). The sand that makes up the dunes is also a major economic mineral resource of the state of Michigan (Apres, Lewis, Norris and May, Inc. and Chapman 1978). As a result of their many, often conflicting, uses, a great deal of effort has gone into the management and preservation of these dunes by both governmental regulations established by the Sand Dune Protection and Management Act (Act No. 222 of 1976), and the Michigan Resources and En vironmental Protection Act (Act No. 451, Part 637 Sand Dune Mining), and private organizations, such as Preserve the Dunes Inc., Save the Dunes Council, and the Lake Michigan Federation.

Despite the importance of the well-developed dune fields that exist along the southeastern shore of Lake Michigan, very little was known about their geologic history until recently. These dune fields contain massive (local relief of up to 60 meters) parabolic dunes (the barrier dunes of Buckler 1979) that may be separated from the lake by low foredunes. It is generally recognized that the foredunes are relatively young and develop during periods of low lake levels. Subsequently, the foredunes erode during periods of high lake levels (Scott 1942; Olson 1958a,b). Compared to the foredunes the massive parabolic dunes are quasi-permanent features that more or less reached their present form before the historical period. It is generally assumed that the massive parabolic dunes developed during the high lake levels of the Nipissing period roughly 5000 years ago (Dorr and Eschman 1970). However, radiocarbon dates from basal paleosols in four localities between Manistee and Grand Haven (Figure 1) indicate that, in al l but one case, dune formation began after the Nipissing high stand (Arbogast and Loope 1999).

Very little is known about the period in which the massive parabolic dunes grew to their present size, although the older literature often implies that dune growth was rapid and that the dunes remained essentially unchanged for thousands of years (Dorr and Eschman 1970). In a recent survey of coastal dune growth along the eastern shore of Lake Michigan, Loope and Arbogast (2000) examined radiocarbon ages of buried soils from 32 different localities. They found an extremely active record with numerous episodes of dune growth and migration during the last four thousand years.

In a detailed study of the history of a stretch of coastal dunes south of Holland, Michigan (Figure 1), Arbogast et al. (1999) also found an active and complex history. The basal buried soil in these dunes is developed on lake plain sediments and buried by eolian sand. Charcoal collected from this soil has a radiocarbon date of 5550 ([+ or -]150) cal. yr. B.P., indicating that dune growth began during the Nipissing high stand in lake level.

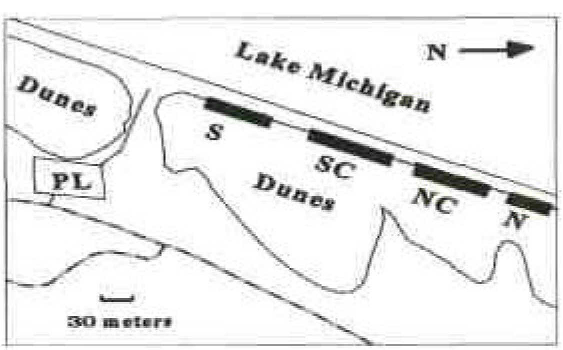


FIGURE 2. Sketch map of a portion of Van Buren Park showing the approximate positions of the dune sections shown in Figures 2 and 3. S = south section; SC = south central section; NC north central section; N = north section; PL = south parking lot.

Subsequently, the dunes grew episodically with several brief periods of stability marked by thin Entisols (A/C horizonation). Radiocarbon dates on six of these soils indicate at least four periods of active dune growth and migration between 4,640 ([+ or -] 190) and 2525 ([+ or -]195) cal. yr B.P. In the upper part of the stratigraphic sequence there is an Inceptisol (A/[B.sub.s]/Chorizonation) containing buried tree trunks. Such soils typically require more than a thousand years to develop (Barrett and Schaetzl 1992). Hence, the Inceptisol indicates an extended period of dune stability under a forest. This soil is buried by a thin unit of eolian sand on which the modern dune soils are developed. Radiocarbon dates on the Inceptisol indicate that this new period of dune activity began as early as 965 (+ or -]175) cal. yr B.P. in one dune and as late as 145 ([+ or -]145) cal. yr B.P. in another.

Hints of a similar history of dune growth and migration can be found around Mount Baldy in the Indiana Dunes National Lakeshore, 120 kilometers to the south of Holland (Figure 1). Radiocarbon dates on buried soils in this area indicate that dune growth began sometime after 5500 years ago, that a soil developed under forest vegetation sometime after 3300 yr B.P., and that this soil was buried by a fresh influx of eolian sand around 310 yr B.P. (Gutshick and Gonsiewski 1976). Our examination of this forest soil indicates that it is an Inceptisol much like the one seen in the dunes near Holland.

These similarities in the timing of eolian activity at Holland and the Indiana Dunes National Lakeshore raise the intriguing question of whether the dunes along the southeastern shore of Lake Michigan share a common history of growth and migration. To address this question we undertook a study of the geological history of coastal barrier dunes in Van Buren State Park, near South Haven, Michigan.

GEOGRAPHIC SETTING

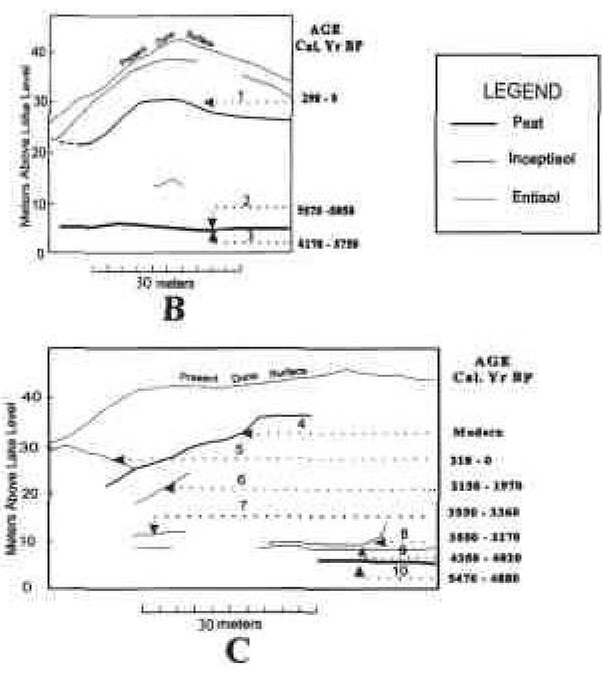
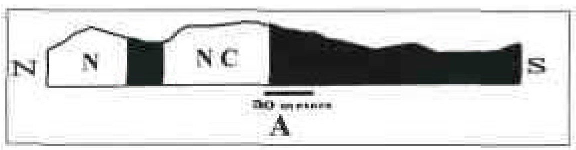


FIGURE 3. Dune sections for the northern part of the study area. Ages of the soils are given in calendar years before present along the right edge of the diagrams. The numbers above the dotted lines refer to the sample numbers in Table 1. 3A-Profile of the dune ridge illustrating the locations of the sections shown in this figure; N = north segment; NC = north central segment. 3B: Section of the north segment showing the exposures of buried soils and the location of samples. 3C: Section of the north central segment showing the exposures of buried soils and the location of

samples

Van Buren State Park is 7 km to the south of the city of South Haven, 43 km south of the dunes near Holland, and 75 km north of Mount Baldy in the Indiana National Lakeshore (Figure 1). Along the southeastern shore of the lake massive parabolic dunes are found only in places where sandy lake plain sediments are exposed along the coast (Leverert 1911; Farrand and Bell 1982). These areas are separated by regions in which the shoreline consists of till or glacial outwash and where coastal dunes are relatively small or absent. The dunes at Van Buren are separated from those south of Holland by a broad region where the Lake Border Moraine intersects the shoreline. Fifteen kilometers south of Van Buren Park the dunes are again interrupted as the Lake Border Moraine approaches the shore. Our study focuses on a section of this dune complex (Figure 2) that begins roughly 30 meters north of the walkway leading from the main parking lot to the shore and extends for approximately 300 meters to the north. Coastal dunes i n this area have merged to form a nearly continuous ridge that exceeds 45 meters above present lake level at its highest point. Undercutting by waves and subsequent erosion has stripped the vegetation from the lakeward face of much of the ridge, exposing numerous buried soils.



RESEARCH METHODS

The positions of outcrops of buried soils were mapped along the dune face using a plane table and alidade. Shallow pits were dug in each soil in several places and their orientations (strikes and dips) were recorded with a Brunton compass. At the same time the thickness of each horizon was measured and its color characterized by a Munsell soil chart. Once the mapping and descriptions were finished, samples of organic matter from the A-horizons of buried soils were collected for radiocarbon analyses. Nine samples were analyzed by Beta Analytic labs in Miami, Florida, while an additional seven were analyzed at the Institute for Arctic and Alpine Research (INSTAAR) at Boulder, Colorado. The majority of samples were analyzed by AMS (accelerator mass spectrometry), although a few were assayed by conventional radiocarbon analyses when large samples could be collected. All dates are reported at 2[sigma] and were calibrated to the tree-ring curve of Stuiver et al. (1998) to provide calendar age estimates. The radioc arbon dates in buried dune soils give the time at which the organic material in the soil was cur off from exchange with the atmosphere presumably by an influx of windblown sand.

RESULTS

For the purpose of description it is convenient to divide the area into four segments. The positions of buried soils in these segments are shown in Figures 3 and 4 as sections projected from our maps. The sixteen radiocarbon ages obtained from organic material in the buried soils are given in Table 1 and displayed on Figures 3 and 4 as calendar years before present (B.P.).

DISCUSSION

The Basal Soils and the Initiation of Dune Growth

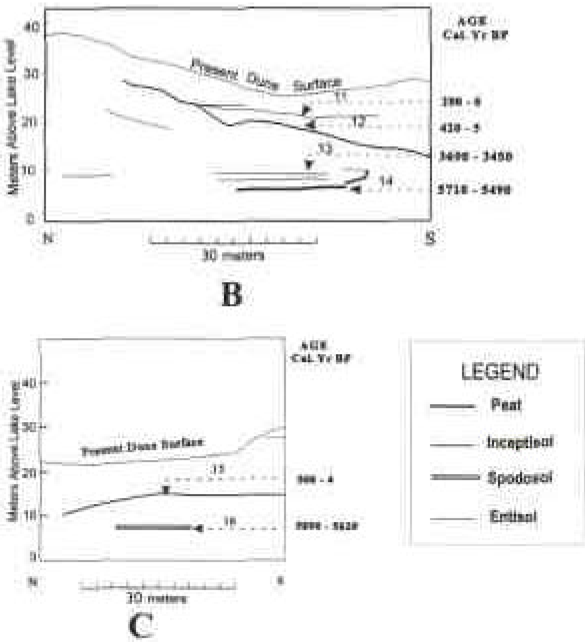


FIGURE 4: Dune sections for the southern part of the study area. Ages of the soils are given in calendar years before present along the right edge of the diagram. The numbers above the dotted lines refer to the sample numbers in Table 1. 4A: Profile of the dune ridge showing the locations of the sections shown in this figure: S = south segment, SC = south central segment. 4B: Section of the south central segment showing the exposures of buried soils and location of samples. 4C: Section of the south segment showing the exposures of buried soils and location of samples.

The basal soil throughout most of the study area (Figure 3B, 3C, 4B) is a horizontal peat layer containing abundant plants remains which are predominantly grasses (Tim Evans, Hope College, personal communication). This peat crops out between 6 and 7 meters above current lake level and is generally between 10 and 30 cm thick. It can be traced for 700 meters north beyond our study area and has a total outcrop length of 1 kilometer. At the southern edge of its exposure (Figure 4B) the peat ends in an oxidized Spodosol which climbs several meters up the dune. As this soil gains elevation on the paleoslope the A horizon disappears and a 3-5 cm thick, dark-red, slightly cemented [B.sub.s1] horizon directly overlies reddish yellow sand ([B.sub.s2] horizon). To the south the horizontal basal soil is a Spodosol containing a dark brown, 2-cm thick A horizon, a 30-cm thick, light gray, E horizon, and a brown B horizon.

A sample collected from the base of the peat in the north segment (Figure 3B) gave an age between 6170-5750 cal. yr B.P. Another sample collected at the base of the peat layer somewhat further south (Figure 4C) provided a slightly younger age of between 5710-5490 cal. yr B.P. A sample collected from the top of the peat in the north section (Figure 3B) yielded a date of between 5570-5050 cal. yr B.P., whereas sample collected from the top of the peat in the north-central section (Figure 3C) gave a date of 5470-4880 cal. yr B.P. Taken together these dates suggest that the peat accumulated for a considerable period of time (hundreds of years). This organic accumulation probably occurred in a wetland possibly formed behind a beach ridge or dune ridge banier (e.g., Thompson and Baedke 1997). The southern edge of this wetland is exposed in the central portion of our study area, and apparently extended for at least 1.5 kilometers to the north. At the southern edge of the former wetland the peat changes to a mineral Spodosol with increased elevation probably because it was well drained on the slope of what may have been a low foredune or dune ridge. Further south (Figure 3B) the basal soil is a Spodosol at about the same level as the peat layer and provided an age (5890-5620 cal. yr B.P.) essentially contemporaneous with the accumulation of the peat layer. The radiocarbon ages obtained from the top of the peat indicate burial between 5570-5050 and 5470-4880 cal. yr B.P. which are slightly younger than the burial time (5890-5620 cal. yr B.P.) indicated for the basal Spodosol in the southern segment. These dates reveal that dune growth in this area began at about 5,500 years ago during the Nipissing high stand.

The Lower Entisol Sequence and the Period of Early Dune Growth

In the northern and central segments of the study area the basal soils are overlain by eolian sands that contain Entisols, which are in turn capped by a moderately developed Inceptisol. The soils between the basal peat and the Inceptisol comprise the lower Entisol sequence. These poorly developed soils consist of thin (0.5 to 8 cm thick) brown to dark brown A horizons. Most of the color is due to coatings on sand grains although small fragments of organic mater (including charcoal) are also present. In the north-central and southcentral segments (Figures 3C, 4B) 1 to 2 meters of eolian sand lie between the peat and a gently dipping to horizontal Entisol. Such low, gently dipping to horizontal surfaces now occur where low foredunes merge to form dune platforms (Buckler 1979) and this was apparently the landscape present in the early part of dune evolution at Van Buren State Park. The radiocarbon date on this soil from the north central segment indicates that these low dunes were buried by a fresh influx of eo lian sand between 4350-4020 cal. yr B.P.

TABLE 1. Radiocarbon Ages of Selected Soils

Dune	Sample	Description	Lab	Radiocarbon Age	Calibrated Age
North	1	Inceptisol	Colorado	16 ± 30	290–0
North	2	Top of Peat	Beta	4620 ± 60	5570–5050
North	3	Base of Peat	Beta	5160 ± 60	6170–5750
North Central	4	Inceptisol	Beta	Modern	
North Central	5	Entisol	Beta	200 ± 50	310–0
North Central	6	Entisol	Beta	2090 ± 40	2350–1970
North Central	7	Entisol	Beta	3220 ± 40	3550–3360
North Central	8	Entisol	Beta	3190 ± 50	3550–3270
North Central	9	Entisol	Beta	3800 ± 40	4350–4020
North Central	10	Top of peat	Beta	4550 ± 80	5470–4880
South Central	11	Entisol	Colorado	155 ± 30	290–0
South Central	12	Inceptisol	Colorado	235 ± 35	4205
South Central	13	Entisol	Colorado	3320 ± 45	3690–3450
South Central	14	Base of Peat	Colorado	4890 ± 45	5710–5490
South	15	Inceptisol	Colorado	300 + 60	500–5
South	16	Spodosol	Colorado	5030 + 40	5890–5620

The next higher soil in the sequence varies from a horizontal to gently dipping soil about 9 meters above present day lake level (Figures 30, 4B), to a soil which climbs at least five meters up the dune while dipping steeply (30[degrees]) to the northwest (Figure 3C). The steep dip angles indicate that this surface was a former slip face and gives the first evidence of the development of dunes with significant topographical relief. The radiocarbon burial date obtained from material collected at the northern exposure of this soil (Figure 20) is 3550-- 3270 cal. yr B.P., while the date obtained from material collected near its southern exposure (Figure 4B) is 3690-3450 cal. yr B.P. Short segments of Entisols, dipping at angles close to the angle of repose for dune sand, crop out higher in the dunes (Figures 3B, 30, 4B). Each of these paleosols represents a small portion of a slip face of a former dune and by this time the dunes had apparently obtained fairly high topographic relief. The highest of these soils gives a burial age between 2150-1970 cal. yr B.P. (Figure 30).

In summary, the lower Entisol sequence represents a period of active dune growth which began about 5500 years ago and lasted for approximately 3500 years. The first dunes to grow were apparently low foredunes which merged to form a dune platform. These dunes were eventually buried in an episodic way by significant deposits of eolian sand. Each Entisol represents a brief period of stability in which the dunes were vegetated and the surfaces stabilized. The outcrop pattern of the Entisols is fragmentary especially in the upper portions of the sequence. Thus, it is likely that the record is incomplete and that some periods of stability during this growth stage are not represented by soils. These soils may still be covered by dune sand or they may have been destroyed by erosion during dune migration.

The Inceptisol and the Period of Extended Stability

Capping the Entisol sequence is an Inceptisol that is exposed in the upper portion of every dune section (Figures 3 and 4). This soil consists of a brown to very dark grayish brown A layer up to 20 cm thick that overlies a yellowish brown [B.sub.S] horizon between 1 and 1.5 meters thick. The A horizon contains abundant plant remains including buried tree trunks. In the northern segment (Figure 3B) the Inceptisol first dips to the south east and then steeply (23[degrees] to 32[degrees]) to the north west, climbing to an elevation of 30 meters above current lake levels before leveling. Following a covered interval, the same soil is exposed once again in the north central segment (Figure 3C) where it dips steeply (21[degrees] to 28[degrees]) to the north and climbs 11 meters to 33 meters above current lake level before becoming horizontal. The dip then reverses to the south in the south central segment (Figure 3B) and the soil descends to 9 meters above current lake level before the exposure is lost. These rela tionships suggest that the outcrop of the buried soil crosses the crests of former dunes twice and that these dunes reached a height of at least 33 meters above the current lake level. In the southern segment of the study section (Figure 3C) the Inceptisol is exposed at between 10 to 15 meters above current lake level and dips 22[degrees] to 25[degrees] to the east, This suggests that these outcrops represent a portion of the back (landward) slip face of the former dune.

Radiocarbon dates were determined from organic material collected from 4 separate places within the Inceptisol. The 2[sigma] age ranges for these samples overlap and all lie in the range of 500-0 cal. yr B.P. The burial date on the soil just below the Inceptisol in the north central segment is between 2145-1 955 cal. yr B.P., suggesting at least 1,500 years for the development of the moderately developed soil above it. Thus, the buried Inceprisol at Van Buren would appear to indicate a relatively long period of dune stability during which the dunes were forested. This interpretation is supported by the more extensive development of soil horizons in the Inceptisol compared to the Entisols.

The Upper Entisol Sequence and the Period of Remobilization

Entisols lie above the Inceptisol in every section (Figures 3 and 4) although they are not very extensive in the south segment. These soils comprise the upper Entisol section, which is capped by the present dune surface. The soils in this sequence represent brief periods of stability in the period of dune growth and migration that began with the burial of the Inceptisol. Radiocarbon ages on the

Inceptisol indicate that dune remobilization occurred within the last 500 years. The resolution of the radiocarbon dates is insufficient to give us a detailed chronology of the burial of the Inceprisol. However, the geological evidence indicates that the burial was a complex process occurring at different times across the dunes. These relationships indicate that in the north central section (Figure 3C) the burial of the Inceptisol began along the northern flank and was interrupted by a brief period of stability during which an Entisol formed. The orientation of this Entisol suggests that the burial was due to the late ral expansion of the dune to the north. In the south central segment (Figure 3B) the burial of the Entisols evidently began along the southern flank and was interrupted by two brief periods of stability marked by two Entisols. Radiocarbon analyses of the highest of these horizon gives a burial age of 290-0 cal. yr B.P. In the southern section (Figure 3C) the Inceptisol was buried as the dune began migrating inland covering the eastward facing slip face. The period of dune mobility marked by the upper Entisol sequence is continuing today. One consequence of this is the erosion which has exposed the buried soils. Along the central segments this erosion has been accompanied by the migration of the dunes inland, the development of incipient blowouts, and the burial of the forest along the eastern flank of the dune.

Regional Implications

The geomorphological history of the massive parabolic dunes at Van Buren State Park is very similar to the history of those dunes south of Holland (Arbogast et al. 1999). In both cases episodic dune growth began during the Nipissing high stand and was followed by a long period of dune growth marked by a lower Entisol sequence. In both places this was followed by a period of extended dune stability, marked by an Inceptisol. The onset of this period of stability may have been somewhat earlier in Holland: the youngest soil in the lower Entisol sequence gives an age of 2720-2330 cal. yr B.P. in Holland compared to 2150-1970 cal. yr B.P. for Van Buren State Park. In both localities the period of extended stability was followed by a new period of instability during which the Inceptisol was buried. In both places the remobilization occurred in different parts of the complex at different times. The onset of this new period of mobility may have occurred earlier near Holland where the oldest burial age of the Inceptis ol is 1140-790 cal. yr B.P. All of the burial ages of the Inceptisol at Van Buren are within the last 500 years. In both Van Buren and Holland this period of dune mobility is continuing today and is now influenced by anthropogenic factors. Dune growth at Mount Baldy in the Indiana Dunes National Lakeshore also began at about the same time (Gutschick and Gonsiewski 1976) and an Inceptisol in this area also marks a period of extended dune stability which ended about 300 years ago. It appears that the barrier dunes throughout the southeastern shore of Lake Michigan may share the same basic geomorphological history. One particularly significant element of this history is a long period of dune stability that preceded the current era of dune mobility.

The factors that lead to periods of dune migration or dune stability are not yet completely understood. Olson (1958b) demonstrated that broad beaches lead to the development and growth of foredunes. Foredunes are built as wind sweeps over the beach, picking up sand and depositing it further inland: the broader the beach, the greater the sand supply. In such a situation much of the sand may be stored in foredunes in front of the massive parabolic dunes. It is therefore not clear that broad beaches will lead to migration or growth of massive parabolic dunes. Anderton and Loope (1995) proposed that the growth of dunes perched on high lake bluffs along Lake Superior occurred during periods of high lake levels. In their model dune growth is a consequence of sand supplied by collapsing lake bluffs. This collapse occurs when waves reach and undercut the base of the bluff. Loope and Arbogast (2000) successfully applied this model to perched dunes along the eastern shore of Lake Michigan. Observations in Allegan and Ottawa counties made during periods of high lake levels over the last two decades (1980-2000) suggests a similar situation for the massive parabolic dunes along the southeastern shore of the lake. As waves reach the base of these dunes they apparently undermine them, causing the vegetated dune face to collapse and exposing the bare sand beneath. Onshore wind blowing over the unvegetated faces begins to move the sand inland often funneling it into incipient blowouts. The crest of these blowouts frequently grows higher as they move inland, increasing the height of the dune. Thus, periods of dune mobility tend to be correlated with narrow beaches and the absence of foredunes. Conversely broad beaches and foredunes protect the massive parabolic dunes from wave erosion and hence might be expected to lead to plant colonization and enhanced dune stability. Lower storm frequency or intensity could also lead to less wave erosion and therefore enhance dune stability. Broad beaches can be caused either by low lake level s or by high sediment supply to the beach. According to the lake level curves of Thompson and Baedkle (1997), the period of extended stability represented by the Inceptisol spanned several periods of highly variable lake level. Thus, lake level alone cannot explain this period of stability. It is possible that during the period of stability the massive parabolic dunes were protected by broad beaches nourished by large amounts of sand brought in by long shore currents.

ACKNOWLEDGMENTS

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REFERENCES

ANDERTON, J. B., AND W. L. LOOPE. 1995. Buried soils in a perched dunefield as indicators of late Holocene lake level change in the Lake Superior basin. Quaternary Research 44:190-99.

APRES, LEWIS, NORRIS AND MAY INC. AND M. J. CHAPMAN. 1978. An Economic Study of Coastal Sand Dunes Mining in Michigan: Report of Investigation 20. Lansing, MI: Geological Survey Division, State of Michigan.

ARBOGAST, A. F., AND W. L. LOOPE. 1999. Maximum-limiting ages of Lake Michigan coastal dunes: their correlation with Holocene Lake level history. Inter. Jour. of Great Lakes Res. 29: 372-82.

ARBOGAST, A. F., M. D. VAN CORT, AND E. C. HANSEN, B. E. BODENBENDER, J. P. BUCKINCHAM, AND M. J. INGERSOLL. 1999. Reconstructing the geomorphic chronology of massive lake-terrace dunes along Lake Michigan. Abst. W/Prog. G.S.A. 1999 Annual Meeting, 50.

BARRETT, L. R., AND R. J. SCHAETZL. 1992. An examination of podzolization near Lake Michigan using chronofunctions. Canadian J. of Soil Sci. 72:527-A 1.

BUCKLER W. R. 1979. Dune Type Inventory and Banier Dune Classification Study of Michigan's Lake Michigan Shore. Report of Investigation 23, Geological Survey Division State of Michigan, Department of Natural Resource, 20 pp.

COWLES, H. C. 1899. The ecological relations of the vegetation of the sand dunes of Lake Michigan. Bot. Gaz. 17 95-117, 167-202, 281-308, 361-91.

DORR, J.A., JR., AND D. F. ESCHMAN. 1970. Geology of Michigan. Ann Arbor MI: University of Michigan Press.

FARRAND, W. R., AND D. L. BELL. 1982. Quaternary geology (map) of southern Michigan with surface water drainage divides. 1:500,000 scale. Ann Arbor MI: Dept of Geological Sciences, University of Michigan.

GUTSCHICK, R. C. AND J. GONSIEWSKI. 1976. Coastal geology of the Mount Baldy Area, Indiana Dunes National Lakeshore. In Coastal Sedimentation and Stability in Southern Lake Michigan, ed. W. L. Wood, 38-90. Kalamazoo MI: Western Michigan University.

LAKE MICHIGAN FEDERATION. 2001. [less than]http://www.lakemichigan.org[greater than]

LEVERETT, F. 1911. Map of the Surface Formations of the Southern Peninsula of Michigan. Lansing MI: Geological Survey of Michigan.

LOOPE W. L., AND A. F. ARBOGAST. 2000. Dominance of a - 150-year cycle of sand-supply change in Late Holocene dune-building along the eastern shore of Lake Michigan. Quaternary Research 54:414-22.

MICHIGAN STATE LEGISLATURE, PUBLIC ACTs. 1976 and 1994.. Sand Dune Protection and Management Act: Act No. 222, Public Acts of 1976.

MICHIGAN STATE LEGIsLATURE. 1994. Michigan Resources and Environmental Protection Act: Act No. 45 1, Public Acts of 1994. Part 637 Sand Dune Mining.

OLSON, J. S. 1958a. Lake Michigan dune development 2. Plants as agents and tools in geomorphology. J. Geol 66: 345-51.

_____. 1958b. Lake Michigan dune development 3. Lake-level, beach, and dune oscillations. J. Ceol. 66: 473-83.

PETERSON, J. M., AND E. DERSCH. 1981. A Guide to Sand Dune and Coastal Ecosystem Functional Relationships. Extension Bulletin E-1529, MICHU-SG-81-501, 18 pp.

PRESERVE THE DUNES INC. 2001. [less than]http://daac.com/sosdunes/index.html[greater than]

SANTER, R. A. 1993. Geography of Michigan and the Great Lakes Basin. Dubuque, Iowa: Kendall/Hunt Publishing.

SAVE THE DUNES COUNCIL. 2001. [less than]http://www.savedunes.org[greater than]

SCOTT, I. D. 1942. The dunes of Lake Michigan and correlated problems, 44th Annual Report of the Michigan Academy of Science, Arts and Letters, 53-61. Ann Arbor MI: University of Michigan Press.

STUIVER, M., P. J. REIMER, E. BARD, ,J. W. BECK, G.S. BURR, K. A. HUGHEN, B. KROMER, F. G. MCCORMAC, J. V. D. PLICHT, AND M. SPURK. 1998. INTCAL98 Radiocarbon age calibration 24,000-0 cal. YR B.P. Radiocarbon 40:104-83.

THOMPSON, T. A., AND S. J. BAEDKE. 1997. Strand-plain evidence for late Holocene lake-level variations in Lake Michigan. GEOL. Soc. America Bull. 109: 666-82.

TABLE 1

Radiocarbon Ages of Selected Soils

Dune	Sample	Description	Lab	Radiocarbon Age
North	1	Inceptisol	Colorado	16 [+ or -] 30
North	2	Top of Peat	Beta	4620 [+ or -] 60
North	3	Base of Peat	Beta	5160 [+ or -] 60
North Central	4	Inceptisol	Beta	Modern
North Central	5	Entisol	Beta	200 [+ or -] 50
North Central	6	Entisol	Beta	2090 [+ or -] 40
North Central	7	Entisol	Beta	3220 [+ or -] 40
North Central	8	Entisol	Beta	3190 [+ or -] 50
North Central	9	Entisol	Beta	3800 [+ or -] 40
North Central	10	Top of peat	Beta	4550 [+ or -] 80

South Central	11	Entisol	Colorado	155 [+ or -] 30
South Central	12	Inceptisol	Colorado	235 [+ or -] 35
South Central	13	Entisol	Colorado	3320 [+ or -] 45
South Central	14	Base of Peat	Colorado	4890 [+ or -] 45
South	15	Inceptisol	Colorado	300 + 60
South	16	Spodosol	Colorado	5000 + 40

Dune	Calibrated Age
North	290-0
North	5570-5050
North	6170-5750
North Central	
North Central	310-0
North Central	2150-1970
North Central	3550-3360
North Central	3550-3270
North Central	4350-4020
North Central	5470-4880
South Central	290-0
South Central	4205
South Central	3690-3450
South Central	5710-5490
South	500-5
South	5890-5620

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