

## Geology

### Widespread middle Holocene dune formation in the eastern Upper Peninsula of Michigan and the relationship to climate and outlet-controlled lake level

Alan F. Arbogast, Ann G. Wintle and Susan C. Packman

*Geology* 2002;30;55-58

doi: 10.1130/0091-7613(2002)030<0055:WMHDFI>2.0.CO;2

---

**Email alerting services**

click [www.gsapubs.org/cgi/alerts](http://www.gsapubs.org/cgi/alerts) to receive free e-mail alerts when new articles cite this article

**Subscribe**

click [www.gsapubs.org/subscriptions/](http://www.gsapubs.org/subscriptions/) to subscribe to *Geology*

**Permission request**

click <http://www.geosociety.org/pubs/copyrt.htm#gsa> to contact GSA

Copyright not claimed on content prepared wholly by U.S. government employees within scope of their employment. Individual scientists are hereby granted permission, without fees or further requests to GSA, to use a single figure, a single table, and/or a brief paragraph of text in subsequent works and to make unlimited copies of items in GSA's journals for noncommercial use in classrooms to further education and science. This file may not be posted to any Web site, but authors may post the abstracts only of their articles on their own or their organization's Web site providing the posting includes a reference to the article's full citation. GSA provides this and other forums for the presentation of diverse opinions and positions by scientists worldwide, regardless of their race, citizenship, gender, religion, or political viewpoint. Opinions presented in this publication do not reflect official positions of the Society.

---

**Notes**

# Widespread middle Holocene dune formation in the eastern Upper Peninsula of Michigan and the relationship to climate and outlet-controlled lake level

Alan F. Arbogast } Department of Geography, Michigan State University, East Lansing, Michigan 48824-1115, USA

Ann G. Wintle

Susan C. Packman } Institute of Geography and Earth Sciences, University of Wales, Aberystwyth SY23 3DB, UK

## ABSTRACT

Dating of five widely spaced (noncoastal) dunes in eastern upper Michigan by optically stimulated luminescence of quartz establishes that eolian sand was last mobilized between ca. 7 and 5.5 ka in the region. Although this interval corresponds to the drier Altithermal-Hypsithermal period, climate alone may not have been sufficiently arid to cause dune formation in this area. Instead, it appears that dune formation may also be linked to depressed water tables, associated with outlet-controlled low levels in Lakes Michigan and Superior. Following dune stabilization, peat began to accumulate in interdune areas ca. 4.4 ka.

**Keywords:** dunes, Holocene climate, optically stimulated luminescence (OSL) dating, lake levels, peat.

## INTRODUCTION

Dune fields are common in northeastern and central North America; dunes in mesic regions are stabilized by forest (e.g., Grigal et al., 1976), and those in the semiarid Great Plains are anchored by grass (Muhs and Maat, 1993). No consistent cause for mobilization of specific dune fields exists; instead, activation depends on regional environmental factors. Dunes in the Great Plains, for example, activate because of subtle climate fluctuations (Muhs and Maat, 1993). In contrast, forested dunes may require significant environmental changes to mobilize; these include deflation of newly deglaciated or subaerial lacustrine surfaces or devegetation caused by intensive Holocene drought and/or fire.

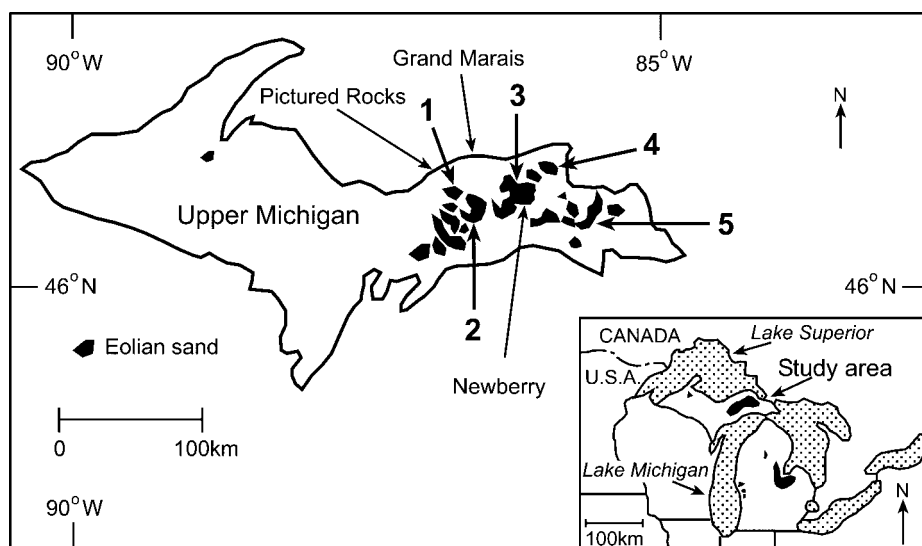
The oldest dunes in northeastern North America are generally those that formed in deglacial environments that were deflated by strong winds theoretically associated with a simulated glacial anticyclone (COHMAP Members, 1988). The earliest recorded period of deglacial dune formation occurred in Connecticut next to Glacial Lake Hitchcock between 12 700 and 12 400 yr B.P. (Thorson and Schile, 1995). As the ice sheet retreated, younger deglacial dunes developed in northern Saskatchewan between ca. 10 000 and 8800 yr B.P. (David, 1981) and in the Saint Lawrence lowland between 10 000 and 7500 yr B.P. (Filion, 1987). Formation of each of these latter dune fields has been attributed to southeasterly anticyclonic winds.

Mobilization of currently forested dunes was also caused by Holocene climate changes. Forested dunes in Minnesota have been investigated at Lake Ann (Keen and Shane, 1990)

and Lake Winnibigoshish (Grigal et al., 1976). Dunes in these fields are parabolic with northwest trends and formed during the more arid Altithermal-Hypsithermal climatic interval ca. 8000 and 5000 yr B.P., when prairie expanded into the region. Subsequently, the dunes stabilized with forest when more mesic conditions returned (e.g., Grigal et al., 1976). To the west, forested dune fields in more arid North Dakota (Minot dune field; Muhs et al., 1997) and southern Manitoba (Brandon dune field; Wolfe et al., 2000) also have northwest trends, but in contrast to the Minnesota dunes (e.g., Keen and Shane, 1990), reactivated several times during the late Holocene because of recurring drought. In a similar vein, dunes east of Hudson Bay in northern Québec formed in

the late Holocene because fire destabilized landscapes during cold and dry periods (Filion et al., 1991).

Although a number of forested dune fields have been investigated, significant spatial gaps remain. Few data exist, for example, from dune fields in the core of the Great Lakes region (Fig. 1; Arbogast et al., 1997). One of these dune fields is the Newberry dune field in eastern upper Michigan, which contains numerous parabolic dunes with arms open to the northwest. Given the regional glacial history, the Newberry dune field may have developed during deglaciation (e.g., David, 1981) because of anticyclonic winds (e.g., Filion, 1987). This simulated circulatory pattern (COHMAP Members, 1988) was apparently present in the region at about this time, as indicated by the southeast-northwest trends of late glacial spits in northern lower Michigan (Krist and Schaetzl, 2001). If this dune-forming scenario occurred, however, the dunes should hypothetically have east trends (e.g., Filion, 1987). Instead, the northwest trends of the dunes suggest a middle Holocene age (e.g., Grigal et al., 1976). These conflicting scenarios present a unique opportunity to test models regarding postglacial landscape evolution in the core of the Great Lakes region. This paper tests the hypothesis that the dune



**Figure 1.** Location of study sites in Newberry dune field (1, Driggs Lake; 2, Seney Quarry; 3, Auger River roadcut; 4, Rainbow Lodge Quarry; 5, Trout Lake Quarry).

TABLE 1. OPTICALLY STIMULATED LUMINESCENCE (OSL) DATA

Sample number	Sample depth (m)	$\alpha$ count rate (counts/ks·cm <sup>2</sup> )	K (%)	U (ppm)	Th (ppm)	$\beta$ dose rate (Gy/k.y.)	$\gamma$ dose rate (Gy/k.y.)	Cosmic-ray dose rate (Gy/k.y.)	Total dose rate (Gy/k.y.)	D <sub>e</sub> (Gy)	OSL age (ka)
30/Mic1	5.0	0.132 ± 0.002	1.88	0.60 ± 0.06	1.71 ± 0.21	1.44 ± 0.09	0.58 ± 0.04	0.12 ± 0.04	2.13 ± 0.10	14.42 ± 2.36	6.8 ± 1.2
30/Mic2	1.5	0.167 ± 0.003	1.81	0.86 ± 0.08	1.83 ± 0.25	1.42 ± 0.09	0.60 ± 0.04	0.17 ± 0.02	2.19 ± 0.10	14.95 ± 1.63	6.8 ± 0.8
30/Mic3	1.0	0.146 ± 0.003	2.11	0.57 ± 0.08	2.23 ± 0.24	1.60 ± 0.10	0.66 ± 0.04	0.19 ± 0.02	2.44 ± 0.11	15.06 ± 1.66	6.2 ± 0.7
30/Mic4	7.0	0.156 ± 0.003	2.00	0.65 ± 0.08	2.21 ± 0.27	1.54 ± 0.10	0.64 ± 0.04	0.09 ± 0.05	2.27 ± 0.11	11.60 ± 2.81	5.1 ± 1.3
30/Mic5	4.0	0.151 ± 0.003	2.63	0.80 ± 0.07	1.56 ± 0.22	1.98 ± 0.12	0.77 ± 0.04	0.13 ± 0.03	2.88 ± 0.13	16.35 ± 3.48	5.7 ± 1.2
30/Mic6	4.0	0.151 ± 0.003	2.71	0.69 ± 0.08	1.96 ± 0.25	2.03 ± 0.12	0.80 ± 0.05	0.13 ± 0.03	2.96 ± 0.14	16.89 ± 2.50	5.7 ± 0.9
30/Mic18	1.5	0.188 ± 0.003	1.64	0.94 ± 0.09	2.14 ± 0.28	1.32 ± 0.08	0.59 ± 0.04	0.17 ± 0.02	2.08 ± 0.09	13.88 ± 2.32	6.7 ± 1.2
30/Mic19	5.0	0.176 ± 0.003	1.62	0.84 ± 0.09	2.14 ± 0.27	1.29 ± 0.08	0.57 ± 0.04	0.12 ± 0.03	1.97 ± 0.09	13.05 ± 1.96	6.6 ± 1.0

landscape in upper Michigan developed during the middle Holocene by reconstructing the geomorphic history of the Newberry dune field.

## STUDY AREA

The Newberry dune field mantles the Glacial Lake Algonquin surface (Larsen, 1987) and is currently stabilized by a mixed hardwood-coniferous forest including sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), beech (*Fagus grandifolia*), and jack pine (*Pinus banksiana*). In many places, interdune depressions contain swamps or bogs that are forested by black and white spruce (*Picea mariana* and *P. glauca*), northern white cedar (*Thuja occidentalis*), and tamarack (*Larix laricina*; Whitney, 1992). The dunes provide the only lake-plain relief, ranging from 4 to 8 m in height.

Given the proximity of the Great Lakes, the regional climate is categorized as humid, continental, short-season variety. Mean daily high temperatures range from -4 °C in January to 25 °C in July. Annual precipitation is ~86 cm, most of which accumulates as lake-effect snow. Although modern winds are multidirectional, the present annual winds are largely from the northwest (Eichenlaub et al., 1990).

## METHODS

Extensive reconnaissance of the dune field stratigraphy was conducted by Crozier (1999). He discovered only 4 exposures (at quarries) and thus explored the dune stratigraphy at 37 sites with a bucket auger. No buried soils were identified, either in the dunes or at the eolian-lacustrine contact. On the basis of this previous work, we collected samples for determining the age of dunes at five widely spaced sites (Fig. 1).

Overall, 10 samples were collected to establish chronostratigraphic control. Eight sand samples were collected for optically stimulated luminescence (OSL) dating (Aitken, 1998). Six of these sands were obtained from excavations protected from exposure by an opaque plastic sheet, and the remaining two were collected from a bucket auger that was similarly covered. The OSL measurements from 180–212  $\mu$ m quartz grains were taken with the single-aliquot regenerative-dose (SAR) procedure

(Murray and Wintle, 2000), which has provided an OSL age of  $20 \pm 10$  yr for sand from an active parabolic dune crest (Bailey et al., 2001) and OSL ages that correlate with calibrated radiocarbon ages for the past 5000 yr (Murray and Clemmensen, 2001). Values of the equivalent dose (D<sub>e</sub>), concentrations of K, U, and Th, and measured dose rates are given in Table 1, together with the OSL ages. In addition, two organic samples were processed for dating via accelerator mass spectrometry (AMS) at the Institute for Arctic and Alpine Research in Boulder, Colorado (see Table DR1 in GSA Data Repository<sup>1</sup>).

## RESULTS

### Driggs Lake Site

The Driggs Lake site is located in the northwestern part of the dune field, southwest of Grand Marais (Fig. 1). An OSL sample was collected near the base of an ~2-m-deep soil pit and provided an age of  $6.7 \pm 1.2$  ka (30/Mic18; Fig. 2). To test whether more than one eolian unit is present, even though there was no obvious unconformity, the lower part (~5 m deep) of the dune was also sampled for OSL dating via bucket auger and yielded a date of  $6.6 \pm 1.0$  ka (30/Mic19). The nearly identical ages from both depths suggest that all eolian sand within the dune accumulated in a relatively short period of time.

### Seney Quarry

The Seney Quarry is located on the western side of the dune field (Fig. 1). Exposed here is ~8 m of dune sand that mantles an ~10-cm-thick deposit of truncated lacustrine silt (unit III; Fig. 2). Humic acids from this silt provided a calibrated AMS radiocarbon age of 5887–5587 yr B.P. (NSRL-3334;  $4940 \pm 60$  yr B.P.).

There are two eolian stratigraphic units at the Seney Quarry. The lowermost eolian unit (unit II) consists of ~7 m of laminated sands that dip ~27° to the southeast. An OSL age of  $6.8 \pm 1.2$  ka (30/Mic1) was obtained for a sample collected from this unit. The upper-

most part of unit II is horizontally truncated and buried by unit I, which contains horizontally laminated sands (~1.1 m thick) that provided an OSL age of  $6.8 \pm 0.8$  ka (30/Mic2). These ages for units II and I indicate rapid sand accumulation. Inversion of the OSL ages for the eolian units and the basal AMS age from the lacustrine unit is most likely explained by the influx of contaminating organic acids from the groundwater into the basal silt.

### Rainbow Lodge and Trout Lake Quarries

The Rainbow Lodge Quarry and Trout Lake Quarry are located in the northeastern and southeastern corners, respectively, of the dune field (Fig. 1). Each of these sites exposes a single unit of eolian sand, ~7 m thick (Fig. 2), from which OSL samples were obtained. At the Rainbow Lodge Quarry, the deposits are horizontally laminated and provided an OSL age of  $5.7 \pm 1.2$  ka (30/Mic5). At the Trout Lake Quarry, the sediments dip steeply (~33°) to the southeast and gave an OSL age of  $5.7 \pm 0.9$  ka (30/Mic6).

### Auger River Roadcut

The Auger River roadcut is located in the central part of the dune field (Fig. 1), ~10 km north of the town of Newberry. Here, interdune depressions are filled with sphagnum bogs. Although the exposure is ~7 m high (Fig. 2), only the upper 2 m could be OSL dated because the lower deposits are disturbed by off-road traffic. To test whether sand of more than one age exists at the site, the lower part of the dune was sampled for OSL dating via a bucket auger. This probing extended ~7 m deep and indicated that bog peat does not extend under the dune. In order to determine the chronologic relation between the dune and the bog, a sample was collected from the deepest part (~1.10 m) of the bog for AMS dating.

These investigations reveal information about the central part of the dune field. The lower sample gave an OSL age of  $5.1 \pm 1.3$  ka (30/Mic4), whereas the upper sample (1 m deep) gave an age of  $6.2 \pm 0.7$  ka (30/Mic3). The error margins of both ages overlap and suggest that the Auger River roadcut contains sand of a single age, one that accumulated ca.  $6.0 \pm 0.6$  ka. After the dune stabilized, peat

<sup>1</sup>GSA Data Repository item 2002005, Radiocarbon ages from the Newberry dune field, is available from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, editing@geosociety.org, or at www.geosociety.org/pubs/ft2002.htm.

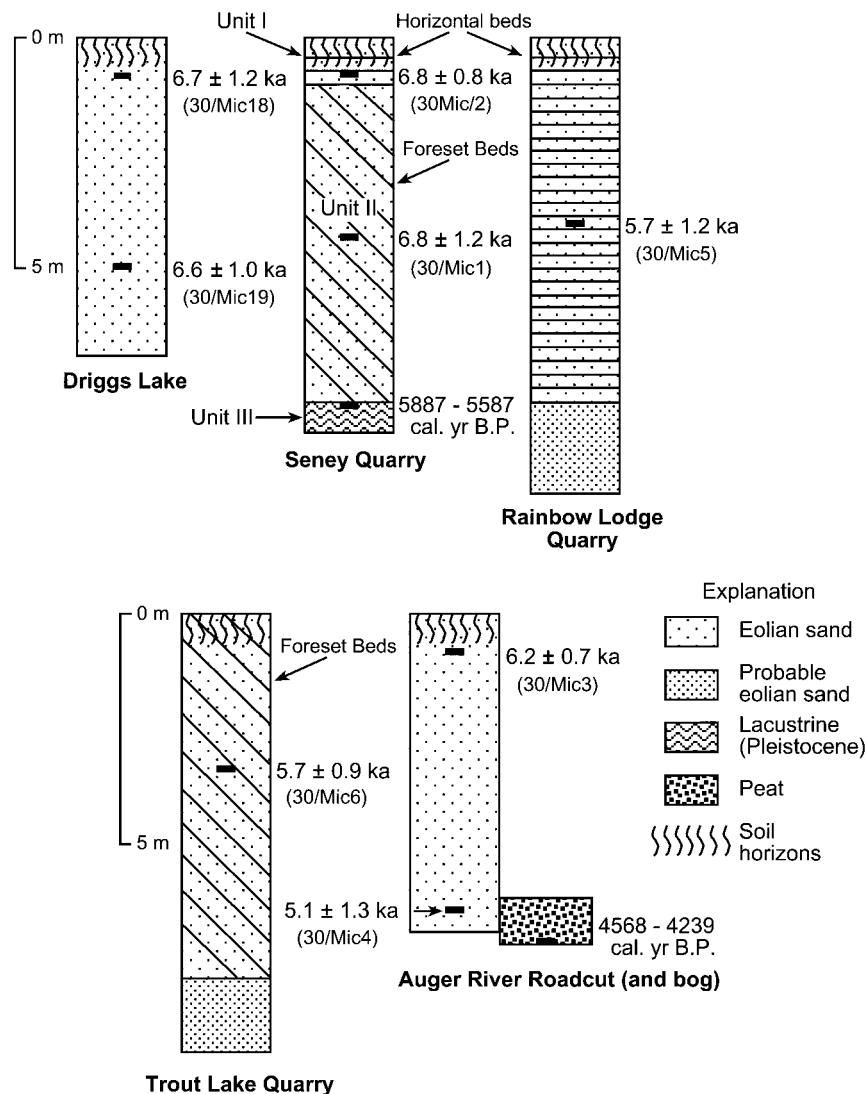


Figure 2. Chronostratigraphy at study sites in Newberry dune field.

began to accumulate in the interdune area, which, according to AMS dating, occurred between 4568 and 4239 yr B.P. (NSRL-10341;  $3960 \pm 50$  yr B.P.).

## DISCUSSION

Geomorphic investigations in the Newberry dune field yield a record of eolian-sand mobilization in noncoastal dunes in eastern upper Michigan. Although dunes may have formed shortly after Glacial Lake Algonquin receded ca. 10 100 yr B.P. (Larsen, 1987), there is currently no evidence for this scenario. Instead, our data indicate that modern dunes developed between ~7 and 5.5 ka (Fig. 3). Given that no buried soil occurs at the lacustrine-dune contact (Crozier, 1999), it appears that sandy lake sediments were the primary source of eolian sand and that vegetation was relatively sparse when the dunes formed. This hypothesis is supported by data from western upper Michigan indicating that outwash deposits were less densely vegetated than adjacent (loamy) tills during the middle Holocene

(Brubaker, 1975). Furthermore, this lack of evidence for organic deposits being buried by eolian sand suggests that wetlands were not present in the study area while the dunes formed, as they apparently were in other parabolic dune fields (e.g., the Nebraska Sand Hills; Loope et al., 1995). Dune orientations and azimuths of high-angle foreset beds indicate that the prevailing winds were northwesterly.

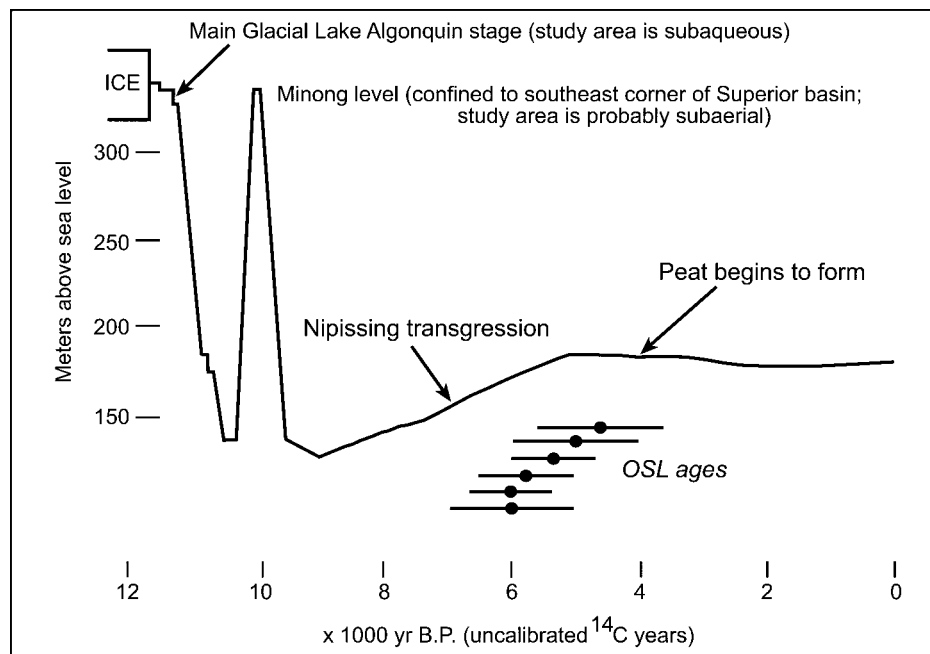
An unresolved issue is the paleoenvironmental variable(s) that initiated dune formation. The simplest explanation is a change toward increased temperatures and/or aridity that would remove stabilizing vegetation. Middle Holocene dune formation determined in this study correlates with dune formation in Minnesota during the more arid Altithermal-Hypsithermal between 8000 and 5000 yr B.P. (e.g., Grigal et al., 1976). Our OSL ages, equivalent to uncalibrated radiocarbon ages of ca. 6000–4000 yr B.P. (Fig. 3), appear to correlate best with the end of dune formation in Minnesota. During this period, July tempera-

ture is inferred to have been ~2 °C higher in Minnesota than it is today (~20 °C), mean annual precipitation could have been ~100 mm less (modern = 660 mm), and prairie expanded into the eastern part of the state (Keen and Shane, 1990).

A simple interpretation is that the Newberry dune field formed for similar reasons as the Minnesota dune fields (e.g., Grigal et al., 1976). However, the middle Holocene climate of upper Michigan appears not to have been sufficiently arid to cause mobilization of eolian sand. For example, pollen data from Pictured Rocks National Lakeshore, ~25 km northwest of the Driggs Lake site (Fig. 1), indicate that mean annual temperature was only ~1.0 °C warmer than modern temperatures and annual precipitation was ~9% less (Davis et al., 2000). Thus, upper Michigan was evidently more mesic (100 mm greater annual precipitation) in the middle Holocene than northeastern Minnesota is now, where dunes are currently stable (e.g., Grigal et al., 1976). We therefore reject climate change as a sole cause for dune activity in eastern upper Michigan. It is possible that fire frequencies increased during the middle Holocene, which may have contributed to dune formation (e.g., Filion et al., 1991), but there is no evidence (e.g., charcoal concentrations, burned wood) that this occurred.

We propose that isostatically driven water-level fluctuations in Lake Michigan and Lake Superior (Fig. 3) are an important cause of dune activity in the interior of upper Michigan. Following regression from the Glacial Lake Algonquin stage 10 100 yr B.P., lake levels dropped ~10 m to the Houghton stage in Lake Superior and ~100 m to the Chippewa stage in Lake Michigan. These regressions maximized ~9500 yr B.P. and occurred because isostatically depressed outlets opened to the east at Sault Ste. Marie for Lake Superior and at North Bay for Lake Michigan (Larsen, 1987). We hypothesize that groundwater levels within the study area also dropped in response to this base-level decrease. Given that depth to bedrock is as much as 50 m in the Newberry region (Soller, 1998), a significant water-table decline could have occurred because the overlying Quaternary sediments are dominantly sands and gravels (Soller, 1998) that are easily drained (e.g., Brubaker, 1975). Thus far, there is no direct evidence for the extent or timing of this hypothetical water-table response. However, if an outlet-driven groundwater decline occurred in combination with the slightly warmer and drier middle Holocene climate, dune formation could have been initiated by the moisture stress on stabilizing vegetation. An additional factor is that sand was transported by westerly winds,





**Figure 3.** Correlation of dune activity (optically stimulated luminescence [OSL] dates), long-term lake fluctuations (solid line), and peat formation in study area (modified from Farrand and Drexler, 1985). OSL ages have been adjusted by using INTCAL 98 (Stuiver et al., 1998), but maintain their original percentage limits.

which, according to the COHMAP Members (1988), were stronger than they are today.

Evidence indicates that the Newberry dune field stabilized ca. 5.5 ka (ca. 4800 yr B.P.). This time of stabilization correlates closely with the peak of the Nipissing transgression in the Great Lakes (Fig. 3), which began ca. 9000 yr B.P. as the North Bay outlet rebounded (Larsen, 1987), and a return to a slightly more mesic climate (e.g., Davis et al., 2000). We thus hypothesize that the combined effects of more precipitation and an isostatically controlled water-table rise caused dunes to stabilize. This overall increase in effective moisture culminated with interdune bog development as seen at the Auger River roadcut at 4.4 ka, which has continued to the present day.

#### ACKNOWLEDGMENTS

We thank Xiomara Cordoba for her assistance in the field. Randy Schaetzl helped both in the field and with an earlier draft of the manuscript. Daniel Muhs, Curtis Larsen, and an unnamed reviewer made constructive comments that greatly improved this paper. Funding was provided by National Science Foundation grant ATM-9809322.

#### REFERENCES CITED

- Aitken, M.J., 1998, *An introduction to optical dating*: Oxford, Oxford University Press, 280 p.
- Arbogast, A.F., Scull, P., Schaetzl, R.J., Jameson, T.P., Harrison, J., and Crozier, S., 1997, Concurrent stabilization of some interior dune fields in Michigan: *Physical Geography*, v. 18, p. 61–76.
- Bailey, S.D., Wintle, A.G., Duller, G.A.T., and Britton, C.S., 2001, Sand deposition during the last millennium at Aberffraw, Anglesey, North Wales, as determined by OSL dating of quartz: *Quaternary Science Reviews*, v. 20, p. 701–704.
- Brubaker, L.B., 1975, Postglacial forest patterns associated with till and outwash in north-central upper Michigan: *Quaternary Research*, v. 5, p. 499–527.
- COHMAP Members, 1988, Climatic changes of the last 18000 years—Observations and model simulations: *Science*, v. 241, p. 1043–1052.
- Crozier, S.D., 1999, A preliminary record of Holocene eolian activity in Michigan's eastern Upper Peninsula [M.A. thesis]: East Lansing, Michigan State University, 109 p.
- David, P., 1981, Stabilized dune ridges in northern Saskatchewan: *Canadian Journal of Earth Sciences*, v. 18, p. 286–310.
- Davis, M., Winkler, M.G., Flakne, R., Douglas, C., Calcote, R., and Cole, K.L., 2000, Holocene climate in the western Great Lakes National Parks and Lakeshores: Implications for future climate change: *Conservation Biology*, v. 14, p. 968–983.
- Eichenlaub, V.L., Harman, J.R., Nurnberger, F.V., and Stolle, H.J., 1990, *The climatic atlas of Michigan*: Notre Dame, Indiana, University of Notre Dame Press, 165 p.
- Farrand, W.R., and Drexler, C.W., 1985, Late Wisconsinan and Holocene history of the Lake Superior basin, in Karrow, P.F., and Calkin, P.E., eds., *Quaternary evolution of the Great Lakes*: Geological Association of Canada Special Paper 30, p. 17–32.
- Filion, L., 1987, Holocene development of parabolic dunes in the central St. Lawrence lowland, Québec: *Quaternary Research*, v. 28, p. 196–209.
- Filion, L., Saint-Laurent, D., Despons, M., and Payette, S., 1991, The late Holocene record of ae-

- olian and fire activity in northern Québec, Canada: *The Holocene*, v. 1, p. 201–208.
- Grigal, D.F., Severson, R.C., and Goltz, G.E., 1976, Evidence of eolian activity in north-central Minnesota 8000 to 5000 yr ago: *Geological Society of America Bulletin*, v. 87, p. 1251–1254.
- Keen, K.L., and Shane, L.C.K., 1990, A continuous record of Holocene eolian activity and vegetation change at Lake Ann, east-central Minnesota: *Geological Society of America Bulletin*, v. 102, p. 1646–1657.
- Krist, E., Jr., and Schaetzl, R.J., 2001, Paleowind (11 000 BP) directions derived from late spits in northern Michigan: *Geomorphology*, v. 38, p. 1–18.
- Larsen, C.E., 1987, Geological history of Glacial Lake Algonquin and the upper Great Lakes: U.S. Geological Survey Bulletin 1801, 34 p.
- Loope, D.B., Swinehart, J.B., and Mason, J.P., 1995, Dune-dammed paleovalleys of the Nebraska Sand Hills: Intrinsic versus climatic controls on the accumulation of lake and marsh sediments: *Geological Society of America Bulletin*, v. 107, p. 396–406.
- Muhs, D.R., and Maat, P.B., 1993, The potential response of eolian sands to greenhouse warming and precipitation reduction on the Great Plains of the U.S.A.: *Journal of Arid Environments*, v. 25, p. 351–361.
- Muhs, D.R., Stafford, T.W., Jr., Been, J., Mahan, S.A., Burdett, J., Skipp, G., and Rowland, Z.M., 1997, Holocene eolian activity in the Minot dune field: *Canadian Journal of Earth Sciences*, v. 34, p. 1442–1459.
- Murray, A.S., and Clemmensen, L., 2001, Luminescence dating of Holocene aeolian sand movement, Thy, Denmark: *Quaternary Science Reviews*, v. 20, p. 751–754.
- Murray, A.S., and Wintle, A.G., 2000, Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol: *Radiation Measurements*, v. 32, p. 57–73.
- Soller, D.R., 1998, Map (I-1970B) showing the thickness and character of Quaternary sediments in the glaciated United States east of the Rocky Mountains—northern Great Lake States and central Mississippi Valley States, The Great Lakes, and southern Ontario (80°31' to 93° west longitude): U.S. Geological Survey Miscellaneous Investigations Series Map, scale 1:100 000.
- Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., Van der Plicht, J., and Spurk, M., 1998, INTCAL98 radiocarbon age calibration, 24 000–0 cal. BP: *Radiocarbon*, v. 40, p. 1041–1083.
- Thorson, R.M., and Schile, C.A., 1995, Deglacial eolian regimes in New England: *Geological Society of America Bulletin*, v. 107, p. 751–761.
- Whitney, G.D., 1992, *Soil survey of Chippewa County, Michigan*: Washington, D.C., U.S. Government Printing Office, 391 p.
- Wolfe, S.A., Muhs, D.R., David, P.R., and McGeehin, J.P., 2000, Geochronology and geochemistry of late Holocene eolian deposits in the Brandon Sand Hills, Manitoba, Canada: *Quaternary International*, v. 67, p. 61–74.

Manuscript received April 19, 2001

Revised manuscript received August 27, 2001

Manuscript accepted September 12, 2001

Printed in USA