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Iowa's Sand Prairie State Preserves: Anomalous Grain-Size Distributions and Optically Stimulated Luminescence (OSL) Dates

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Grain-size distributions and optically stimulated luminescence (OSL) dates were obtained for the sand from Iowa's five sand prairie state preserves, which are Behren's Ponds and Woodland, Cedar Hills Sand Prairie, Kish-Ke-Kosh Prairie, Marietta Sand Prairie and Rock Island. OSL dates ranged from the late Pleistocene (15,560 years B.P.) to the very late Holocene (as recent as 590 years B.P.), indicating that the late Pleistocene and Holocene Epochs in Iowa have seen multiple episodes of aridity, which is consistent with results from the Nebraska Sand Hills and eolian sand stringers in southeastern Minnesota. The grain-size distributions were anomalous in that, compared with typical eolian deposits, the transition grain sizes between the traction / saltation populations and saltation / suspension populations were shifted toward coarser grains, and the percentage of sand in the suspension population was high. The anomalous grain-size distributions could not be explained by post-depositional weathering or poor sorting in the source region, but were consistent with the eolian transport of sand through grass prior to deposition. It is suggested that the anomalous grain-size distribution could be one of a set of criteria for distinguishing paleo-sand prairies from other buried bodies of eolian sand or sandstone.

INDEX DESCRIPTORS: eolian, grain-size distribution, optically stimulated luminescence, OSL, sand prairie.

The sand prairies of Iowa are generally regarded as originating in eolian sand blown from adjacent river valleys about 4000 years B.P. (Ruhe 1969, Roosa 1984, Prior 1991, Fleckenstein 1992, Prior 1993, Herzberg and Pearson 2001). The eolian origin is based on the proximity of the sand prairies to river valleys and on the NW-SE orientation of the sand dunes, which is consistent with the dominant wind direction (Koch and Walters 2004). The timing is based solely on evidence for a Hypsithermal period ending about 4000 years B.P. (Prior 1991, Anderson 1998). In fact, the sand prairies of Iowa have been little studied geologically aside from studies of wetlands occurring in the sand prairies (Knapp 1983, Thompson et al. 1992).

The sand prairies are geologically interesting for at least two reasons. First, the correct identification of paleosols has recently become an important tool in stratigraphic correlation and petroleum exploration (Ye 1995, McKie et al. 1998, Williams and Krause 2000, Hornung and Aigner 2002). Since grasslands have been a widespread ecosystem since they first appeared during the Eocene Epoch (Retallack 2001), buried sand prairies (buried bodies of eolian sand that formerly hosted grassland ecosystems) have the potential to be a major paleosol in Cenozoic strata. Therefore, it is important to establish a set of criteria for distinguishing between a paleo-sand prairie and any other body of buried eolian sand or sandstone. The first objective of this study was to determine whether grain-size distribution is a distinguishing feature of a sand prairie. Second, non-coastal sand prairies contain important paleoclimatic information in that the sand was deposited at a time when the climate was sufficiently arid for blowing sand. The second objective of this study was to obtain the first set of optically stimulated luminescence (OSL) dates for the sand of the sand prairies of Iowa. OSL dates

refer to the time since quartz grains were last exposed to sunlight, in other words, the time since final burial of sand.

This study was carried out in the five sand prairies that are held in Iowa state preserves, which are Behrens Ponds and Woodland State Preserve (12 ha in Linn County), Cedar Hills Sand Prairie State Preserve (14 ha in Black Hawk County), Kish-Ke-Kosh Prairie State Preserve (7 ha in Jasper County), Marietta Sand Prairie State Preserve (7 ha in Marshall County) and Rock Island State Preserve (7 ha in Linn County) (see Fig. 1 and Table 1). Although sand prairie remnants are found in various cemeteries, railroad rights-of-way and private holdings, there is currently no comprehensive inventory or map of the sand prairies of Iowa. The floral and faunal communities of the sand prairies are discussed by Crum (1972), Menzel and Goellner (1976), Fleckenstein (1992), and Herzberg and Pearson (2001).

METHODS

Nine sand samples for the study of grain-size distribution were collected from each of the five sand prairie state preserves. Sand samples were collected only from the sand prairie portion of each preserve, for example, not from near the pond or in the woodlands of Behren's Ponds and Woodlands State Preserve. Sand samples were collected along two perpendicular traverses that went through the center and covered the length and width of the sand prairie portion of each preserve. Sand samples were collected along a single traverse in Behren's Ponds and Woodland, since the sand prairie portion has a long, linear shape. For each sample, about 2 kg of soil (dry equivalent) was collected between depths 15–30 cm. Care was taken to minimize the visual and environmental impact on the state preserves by removing the intact vegetation with its upper roots, collecting the soil from beneath the root zone, and then replacing the vegetation. In order

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●   Sand Prairie State Preserve
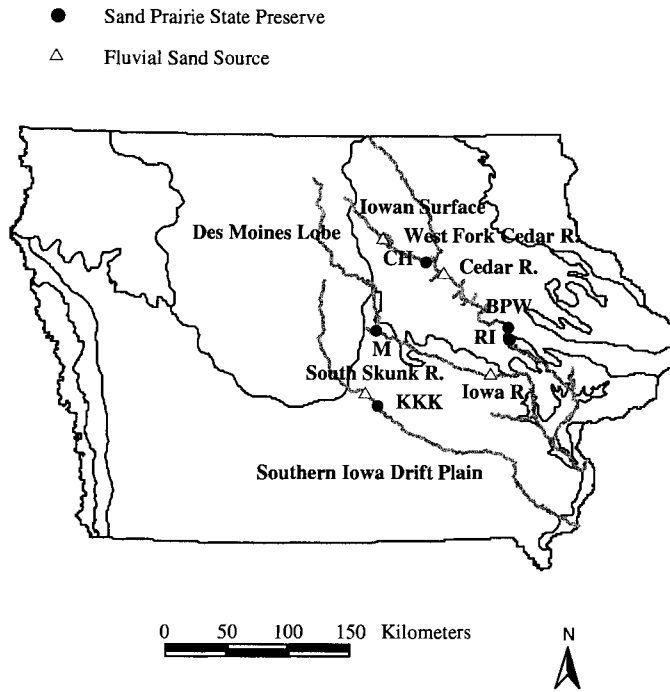
△   Fluvial Sand Source

Fig. 1. Iowa's five sand prairie state preserves in relation to fluvial sand sources and landform regions (Prior 1991). BPW = Behrens Ponds and Woodland, CH = Cedar Hills Sand Prairie, KKK = Kish-Ke-Kosh Prairie, M = Marietta Sand Prairie, RI = Rock Island.

to de-flocculate the clay-sized particles, the samples were blended with Calgon (60 g/L) at a ratio of 1 mL Calgon to 4 g of field-moist soil. The clay and silt were then removed by washing the samples through a 0.063 mm sieve. After drying the sand at 90°C for four hours, the sand samples were passed through 18 sieve sizes using an electric sieve shaker.

Sand samples for OSL dating were collected in opaque plastic tubes at depths 48 cm and 110 cm in Behren's Ponds and Woodland, depth 32 cm in Kish-Ke-Kosh Prairie, depth 56 cm in Marietta Sand Prairie, and depths 40 cm and 114 cm in Rock Island. OSL dating was carried out at the Research Laboratory for Archaeology and the History of Art, University of Oxford, according to procedures described in Stokes and Swinehart

(1997). During sample collection, it became apparent that there was some mixing of sand horizons by burrowing animals. We were careful not to sample near visible burrows. In addition, up to 100 aliquots were dated from each sample, younger and older outliers were rejected, and the mean was calculated from the remaining dates. (Both younger and older outliers can occur as burrowing animals can move sand both up and down.) For no sample were more than 10% of aliquots rejected as outliers. An additional 13 samples collected for OSL dating from the above preserves have not yet been analyzed.

The grain-size distributions were represented graphically by plotting the cumulative weight percentage of sand on a probability scale as a function of phi ϕ, where $\phi = -\log_2$ (grain diameter in mm) (see Fig. 2). The advantage of a probability scale is that normally distributed data fall on a straight line so that it is easy to recognize distinct normally-distributed populations. A classic paper by Visher (1969) showed that from such plots conclusions can be drawn regarding the depositional environment of a sand deposit. Visher (1969) showed that log-probability plots of grain-size distributions fit well to three connected straight lines. Visher (1969) interpreted the straight line for the coarse grains (small ϕ) as the sand population transported by traction. The straight line for the fine grains (large ϕ) corresponds to the sand population transported by suspension. The straight line for the intermediate grain sizes corresponds to the sand population transported by saltation. Visher (1969) examined thousands of sand samples from a wide variety of depositional environments and found that the depositional environment could be related to (1) ϕ_{TS}, the grain size that marks the transition between traction and saltation, (2) ϕ_{SS}, the grain size that marks the transition between saltation and suspension, and (3) P_{TR}, P_{SA} and P_{SU}, the percentages of the sand sample in the traction, saltation and suspension populations, respectively (see Fig. 2). Since the publication of Visher's (1969) paper, further studies have applied his methodology to determine the depositional environments of unconsolidated sands and sandstones (e.g., Glaister and Nelson 1974). Middleton (1976) and Sagoe and Visher (1977) have investigated the theoretical basis for the transition grain sizes. The Folk-Ward parameters of mean grain size, standard deviation (sorting), skewness and kurtosis, all of which are expressed in ϕ units and assume a log-normal distribution (Boggs 1992), were also calculated. Alternative fits to grain-size distributions include the log-hyperbolic distribution (Bagnold and Barndorff-Nielsen 1980) and the skew log-Laplace distribution (Fieller et al. 1984). However, the advantage of the log-normal distribution lies in its ease of physical

Table 1. Soil series, soil classification, and nearest distance to probable fluvial sand source (Fleckenstein 1992, Smith 1996) for Iowa's sand prairie state preserves (BPW = Behrens Ponds and Woodland, CH = Cedar Hills Sand Prairie, KKK = Kish-Ke-Kosh Prairie, M = Marietta Sand Prairie, RI = Rock Island).

Preserve	Soil Series and Classification	Distance to Source
BPW	Chelsea loamy fine sand, fine, mixed, mesic Alfic Udipsamments[1]	1400 m, Cedar R.
CH	Sparta loamy fine sand, sandy, mixed, mesic Entic Hapludolls[2]	3500 m, West Fork Cedar R.
KKK	Chelsea loamy fine sand, fine, mixed, mesic Alfic Udipsamments[3]	1600 m, South Skunk R.
M	Dickinson fine sandy loam, coarse-loamy, mixed, mesic Typic Hapludolls[4]	2000 m, Iowa R.
RI	Chelsea loamy fine sand, fine, mixed, mesic Alfic Udipsamments[1]	1200 m, Cedar R.

[1]Schermerhorn and Highland (1975)
[2]Fouts and Highland (1978)
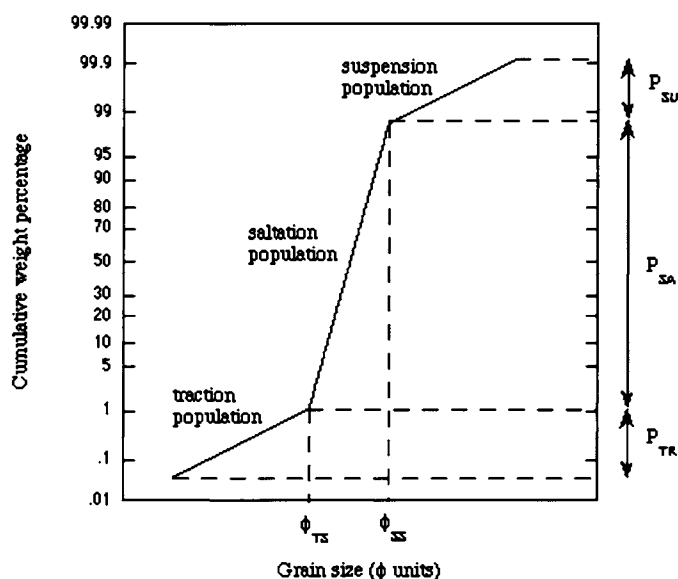[3]Nestrud and Worster (1979)
[4]Oelmann (1981)

Fig. 2. Visher plot in which cumulative weight percentage as a function of grain size (ø units) shows three connected straight lines corresponding to the traction, saltation and suspension populations. The Visher parameters are $ø_{TS}$ = transition grain size between traction and saltation populations, $ø_{SS}$ = transition grain size between saltation and suspension populations, P_{TR} = percentage of sand in traction population, P_{SA} = percentage of sand in saltation population, and P_{SU} = percentage of sand in suspension population.

interpretation and the fact that the very large data set analyzed by Visher (1969) makes it possible to compare the Visher parameters of a given grain-size distribution with the range of values that exist for a wide variety of depositional environments.

RESULTS

When the cumulative weight percentages for the individual sand samples are plotted as a function of grain size (ø units), they show the three connected straight lines found by Visher (1969) (see Figs. 3a–e). For clarity, only four or five samples are shown for each preserve, but the samples shown display the full range of values found for each preserve. Note that the effect of averaging the individual samples for each preserve would be to smooth the grain-size distribution and blur the three straight lines.

Two of the preserves, Behrens Ponds and Woodland and Rock Island, show average $ø_{TS}$, grain size for the transition between traction and saltation, that is coarser (smaller ø) than is typical for eolian sands (see Table 2). (Note that Visher (1969) reported the total range of values, rather than average ± standard error.) With the exception of Kish-Ke-Kosh Prairie, which has no suspension population in the sand fraction, all of the preserves show average $ø_{SS}$, grain size for the transition between saltation and suspension, that is coarser than is typical for eolian sands (see Table 2). In general, for the sand prairies, the grain sizes that mark the traction / saltation and saltation / suspension transitions are shifted toward coarser grains. In other words, a sand grain so coarse that it could only creep in the formation of a typical eolian deposit could bounce in the formation of the Iowa sand prairies. Moreover, a sand grain so coarse that it could only bounce in the formation of a typical eolian deposit could be carried in

suspension in the formation of the Iowa sand prairies. All of the preserves show P_{TR}, percentage of sand within the traction population, within the range found for typical eolian sands (see Table 2). However, four of the preserves show P_{SU}, percentage of sand in the suspension population, to be considerably higher than is typical for eolian sands (see Table 2). The only exception is Kish-Ke-Kosh Prairie, which has no suspension population.

In contrast to the Visher parameters, the sand prairies show Folk-Ward parameters that are largely consistent with those found for eolian sands (see Table 3). The mean grain sizes found in the sand prairies are slightly coarser than the range of 2.0–3.0 ø units (125–250 μm) found by Ahlbrandt (1979) for 291 coastal dune samples and 175 inland dune samples. The standard deviation (sorting) for the sand prairies is very similar to the average of 0.53 ø units found by Goudie et al. (1987) for 1289 desert dune samples. The range of 0.50–0.70 ø units is regarded as moderately well sorted (Boggs 1992). Only the sand from Kish-Ke-Kosh Prairie falls into the range of moderately sorted (0.70–1.00 ø units.) Most eolian sands show slight positive skewness, meaning that the grain-size distribution differs from an ideal log-normal distribution in that there is an excess of fine particles (Livingstone and Warren 1996). Again, only Kish-Ke-Kosh Prairie is an exception. Values of kurtosis for eolian sands are highly variable (Livingstone and Warren 1996).

In contrast to the earlier assumption that the sand of the sand prairies was deposited during the Hypsithermal Period (4000 years B.P.) (Fleckenstein 1992), the OSL data show dates of sand deposition ranging from the late Pleistocene (15,560 years B.P.) to the very late Holocene (as recent as 590 years B.P.) (see Table 4). Therefore, the late Pleistocene and Holocene Epochs in Iowa have seen multiple episodes of aridity. This is consistent with the findings of Ahlbrandt et al. (1983), Stokes and Swinehart (1997), Loope and Swinehart (2000), Forman et al. (2001), Goble et al. (2004) and Mason et al. (2004) who used radiocarbon and OSL data to report multiple episodes of eolian activity throughout the Holocene in the Great Plains and Rocky Mountains. A comparison of the OSL dates from the Iowa sand prairies with the most recent compilation of OSL dates from the Nebraska Sand Hills (Goble et al. 2004) shows that the Iowa dates of 590 ± 50 and 3290 ± 300 years B.P. correspond to clusters of Nebraska OSL dates of 470 ± 90 and 3560 ± 340 years B.P., respectively. The Iowa date of 5860 ± 420 years B.P. could correspond to possible clusters of Nebraska dates (based on only a single locality) of either 5730 ± 710 or 6180 ± 370 years B.P. (Goble et al. 2004). Late Pleistocene OSL dates have not been reported from the Nebraska Sand Hills. On the other hand, late Pleistocene thermoluminescence (TL) dates (15,000–11,000 years B.P.) have been reported from eolian sand stringers in southeastern Minnesota (Zanner et al. 1996). (TL dates refer also to the time since quartz grains were last exposed to sunlight (Livingstone and Warren 1996)).

DISCUSSION

The only remote alternative to an eolian origin for the sand prairies is that they are remnants of sand bars that were abandoned by the widespread stream downcutting that occurred during the Holocene (Prior 1991). Such an alternative is unlikely in that all of the sand prairies show $ø_{TS}$ much larger (finer grain size) than is typical for fluvial sands (see Table 2). However, aside from the OSL dates, the chief new result of this study is that the grain-size distributions for the sand prairies of Iowa are not typical of eolian sands. The suspension population is much larger than is typical and the transition grain sizes between traction /
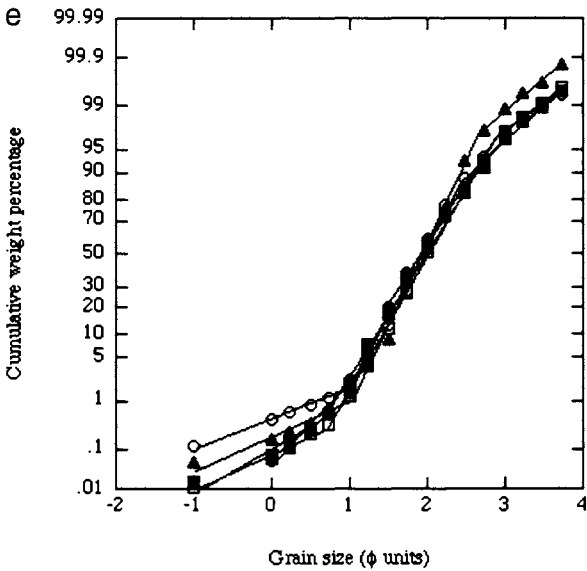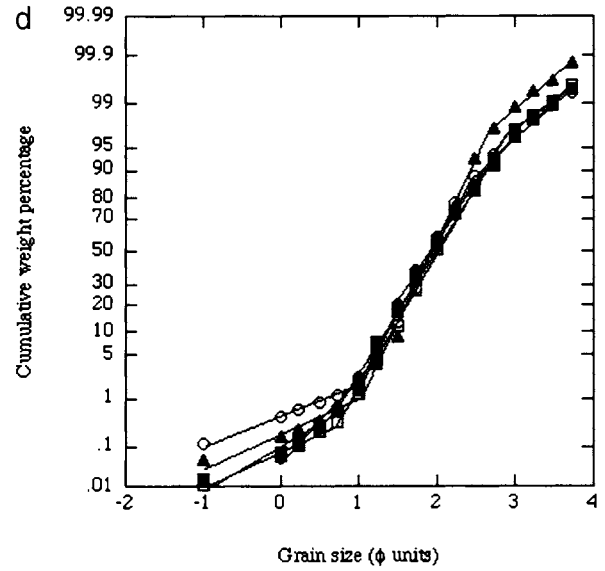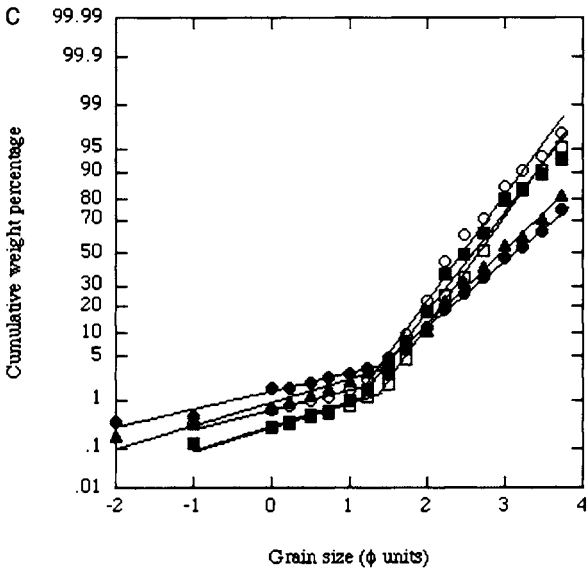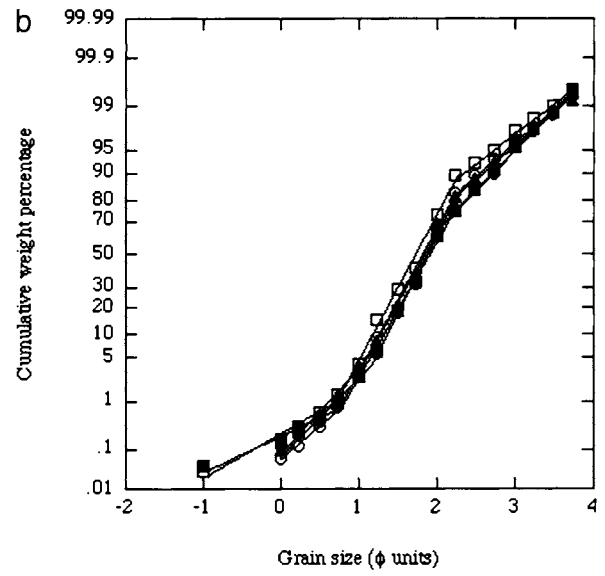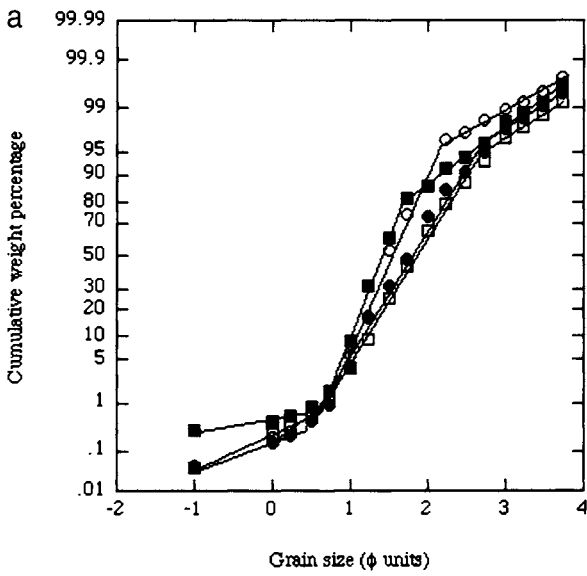
Table 2.   Comparison of average Visher parameters for Iowa's sand prairie state preserves with results from Visher (1969) for eolian and fluvial sands (BPW = Behrens Ponds and Woodland, CH = Cedar Hills Sand Prairie, KKK = Kish-Ke-Kosh Prairie, M = Marietta Sand Prairie, RI = Rock Island, E = eolian, F = fluvial, ϕ_{TS} = transition grain size (ϕ units) between traction and saltation populations, ϕ_{SS} = transition grain size (ϕ units) between saltation and suspension populations, P_{TR} = percentage of sand in traction population, P_{SA} = percentage of sand in saltation population, P_{SU} = percentage of sand in suspension population).

Preserve	ϕ_{TS}	ϕ_{SS}	P_{TR}	P_{SA}	P_{SU}
BPW	0.61 ± 0.06[1]	2.3 ± 0.2	0.9 ± 0.2	91 ± 4	8 ± 4
CH	0.9 ± 0.1	2.2 ± 0.5	1.7 ± 0.8	74 ± 5	24 ± 5
KKK	1.36 ± 0.06	–[2]	2.5 ± 0.6	97.9 ± 0.5	–
M	1.1 ± 0.1	2.75 ± 0.08	4 ± 2	90 ± 2	6 ± 1
RI	0.4 ± 0.1	2.1 ± 0.2	0.9 ± 0.5	78 ± 9	21 ± 10
E	1.0–2.0	3.0–4.0	0–2	97–99	1–3
F	−1.5−−1.0	2.75–3.50	varies	65–98	2–35

[1]Value ± standard error
[2]Blank space (–) indicates no suspension population.

saltation and saltation / suspension are shifted toward coarser grains. The differences cannot be due to the short distance between the source area and site of deposition (see Table 1), because Visher's (1969) data set included many coastal dunes, which were also very close to their source area. Three possible explanations for the difference between the grain-size distribution for sand prairies and typical eolian sands are considered.

1. *Post-depositional soil-forming processes in the sand prairies have altered the grain-size distribution.*

Soil-forming processes should not affect the sizes of quartz grains, but only labile minerals such as feldspars or micas. The hypothesis could be tested by using appropriate acid treatments to dissolve all but the quartz grains and measuring the resulting grain-size distribution of quartz grains. However, the effect of weathering of a sand sample can easily be shown graphically. If weathering processes are uniform within a volume of labile grains, all grains will lose the same diameter within a given amount of time. (For example, 2.0-mm grains might be reduced to 1.9 mm, 1.5-mm grains will be reduced to 1.4 mm, etc.) Figure 4 shows the grain-size distribution for a sand sample from Behren's Ponds and Woodland compared with the grain-size distribution for the same sand sample with all grain diameters reduced by 0.1 mm. (Note that reducing all grain diameters by 0.1 mm causes some grains to be removed from the sand fraction.) The effect of weathering is to cause ϕ_{TS} and ϕ_{SS} to shift toward larger ϕ (finer grains) and P_{SU} to decrease, all of which is opposite to the intended result. Therefore, the explanation based on post-depositional soil-forming processes cannot be correct.

2. *The sand source for the eolian dunes studied by Visher (1969) was well-sorted beach sand, while the sand source for the sand prairies was poorly-sorted glacial outwash or fluvial sand.*

If sorting of the source sand were a major factor in the grain-size distribution of the deposited sand, it should be reflected in relative poor sorting in the deposited sand. However, as mentioned above, the standard deviation (sorting) of the sand from the sand prairies is not atypical for eolian sands. Only the sand from Kish-Ke-Kosh Prairie is not at least moderately well sorted, which is also the only sand prairie that does not show anomalous Visher parameters. Moreover, it is not clear why poor sorting in the source area should affect the transition grain sizes or the percentage of suspension population. Therefore, the explanation based on poor sorting in the source area is also probably not correct.

3. *The sand of the sand prairies was transported through grass prior to deposition (Emerman et al., 2002).*

The effect of grass will be both to trap blowing sand within the grass and to increase the turbulence of the wind above the grass (Thom 1971, Jackson 1981, Raupach 1991, Livingstone and Warren 1996, Arens et al. 2002). Saltating grains within the grass will be trapped and deposited, but some of those grains that saltate above the grass will be transferred to the suspension population. As a result, the grain size for transition between saltation and suspension will be shifted toward coarser grains (smaller ϕ) and the percentage of grains in the suspension population will increase. It can also be argued that grass will cause the grain size for transition between traction and saltation to be shifted toward coarser grains (smaller ϕ). Traction will be impeded by clumps of grass. Coarse grains will accumulate on the windward side of grass clumps until the impact of an unusually large number of descending saltating grains causes the accumulated grains to be forced over the grass clump. The effect will be to force grains that would normally creep due to their size into a manner of "pseudo-saltation," thus shifting the transition

Fig. 3a.   The dependence of cumulative weight percentage on grain size (ϕ units) for sand samples from the sand prairie at Behren's Ponds and Woodland. For clarity, results from only four of nine samples are shown. (See Table 2 for Visher parameters.).
Fig. 3b.   Cedar Hills Sand Prairie (five of nine samples shown).
Fig. 3c.   Kish-Ke-Kosh Prairie (five of nine samples shown).
Fig. 3d.   Marietta Sand Prairie (five of nine samples shown).
Fig. 3e.   Rock Island (four of nine samples shown).

Table 3. Folk-Ward parameters (expressed in ∅ units) for Iowa's sand prairie state preserves (BPW = Behrens Ponds and Woodland, CH = Cedar Hills Sand Prairie, KKK = Kish-Ke-Kosh Prairie, M = Marietta Sand Prairie, RI = Rock Island).

Preserve	Mean Grain Size	Standard Deviation (Sorting)	Skewness	Kurtosis
BPW	1.66 ± 0.09[1]	0.52 ± 0.03	0.7 ± 0.1	70 ± 10
CH	1.89 ± 0.04	0.537 ± 0.009	0.50 ± 0.05	90 ± 5
KKK	2.7 ± 0.1	0.74 ± 0.06	−0.9 ± 0.3	100 ± 20
M	1.97 ± 0.02	0.520 ± 0.008	0.2 ± 0.1	120 ± 10
RI	1.66 ± 0.05	0.63 ± 0.02	0.1 ± 0.3	33 ± 6

[1]Value ± standard error

from traction to saltation toward coarser grains. There is no direct evidence that such a process actually occurs.

The most likely explanation for the anomalous grain-size distribution of the sand prairies is that sand was transported through grass prior to deposition. Such a scenario should actually be expected. Sand was mobilized from river valleys during the multiple episodes of Holocene aridity. As the climate became moister, grass became established in eolian sand deposits. Blowing sand was trapped by grass until the moistening of the climate and the spread of grass caused eolian transport of sand to cease. This upper layer of trapped sand was the substrate upon which the sand prairie appeared and it is this upper layer of trapped sand that was sampled during this study.

CONCLUSIONS

The first result of this study, that sand from the sand prairies has an anomalous grain-size distribution, could be one of a set of criteria for distinguishing between a paleo-sand prairie and any other buried body of eolian sand or sandstone. The hypothesis must be tested by measuring sand grain-size distribution as a function of depth and verifying that the anomalous grain-size distributions occur only in the present-day soil and paleosols. Other possible diagnostic criteria for paleo-sand prairies include abundant fine root traces, small crumb peds, stable carbon isotope ratios characteristic of the C$_4$ photosynthetic pathway (Retallack 2001), and lignin signatures that are characteristic of grassland soils (McSween et al. 2003). Ideally, it may be possible to use grain-size distribution to separate individual soils from a welded or composite soil (Ruhe and Olson 1980, Goble et al. 2004). The second result is that Iowa has seen multiple episodes of aridity and eolian activity from the late Pleistocene until the very late Holocene. Due to the amount of bioturbation observed in the

Table 4. Optically stimulated luminescence (OSL) dates for Iowa's sand prairie state preserves.

State Preserve	Depth (cm)	OSL Date (years before 2000 AD)
Behren's Pond and	48	3290 ± 300[1] (YR)[2]
Woodland	110	10,710 ± 710 (YR)
Kish-Ke-Kosh	32	590 ± 50 (OR)
Marietta Sand Prairie	56	15,560 ± 950 (YR)
Rock Island	40	1,240 ± 130 (OR)
	114	5,860 ± 420 (OYR)

[1]Value ± standard error
[2]YR = younger outliers rejected, OR = older outliers rejected, OYR = older and younger outliers rejected

upper meter of the sand prairies, that result must be confirmed by additional OSL dates at more depths and replication of depths. Further research will be conducted along the above lines.
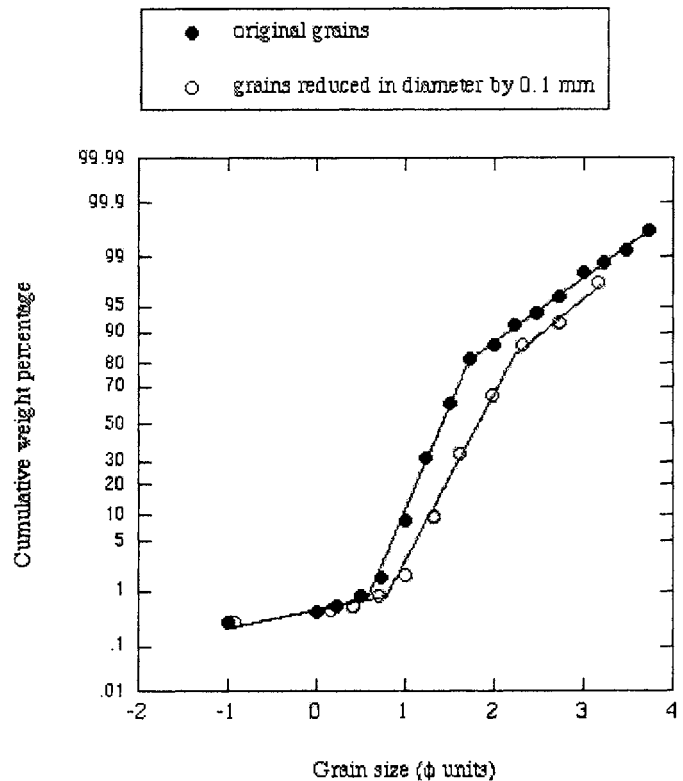
Fig. 4. Grain-size distribution for a sand sample from Behren's Ponds and Woodland compared with the grain-size distribution for the same sand sample with all grain diameters reduced by 0.1 mm. The effect of weathering is to shift ∅$_{TS}$ and ∅$_{SS}$ toward larger ∅ (finer grains) and to reduce P$_{SU}$.

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A Note on the Status of the Endangered Red-backed Vole (*Clethrionomys gapperi*) in Iowa

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The red-backed vole, *Clethrionomys gapperi*, is an endangered species in Iowa that has only been found in a small area in the north-central portion of the state. An extensive survey in 1967 suggested that *C. gapperi* was once abundant in that area, but work in 1982 suggested that its abundance had dramatically declined. In April 2000, we sampled areas in Pilot Knob State Park where *C. gapperi* was found in 1982 to determine the current status of the population. During 1080 trapnights of effort at 5 locations, no *C. gapperi* were captured. The most abundant small mammal collected during sampling was the white-footed mouse, *Peromyscus leucopus*. Although we captured no *C. gapperi*, greater sampling effort and sampling during summer months or fall months are necessary before concluding that *C. gapperi* is extinct in Iowa.

INDEX DESCRIPTORS: *Clethrionomys gapperi*, endangered, Iowa, population, red-backed vole, small mammal.

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The red-backed vole, *Clethrionomys gapperi*, is an arvicoline rodent generally associated with wooded, mesic habitats (Merritt 1981). The geographic range of *C. gapperi* stretches across most of Canada and northern portions of the United States, and extends south along mountain ranges in the eastern and western United States (Merritt 1981). *Clethrionomys gapperi* probably was widespread in Iowa prior to European settlement (Bowles et al. 1998). From 1961 to 1966, Blagen (1967) sampled 17 counties in Iowa and found *C. gapperi* only at Pilot Knob State Park and five wooded areas located within 8 km of the park. Later, Lampe (1982) revisited these sites and concluded that only one population remained, located within the confines of Pilot Knob State Park. This population was separated from the nearest populations in Minnesota by approximately 65 miles of agricultural land that probably prevents migration (Blagen 1967, Hazard 1982).

The status of the only known relict population of *C. gapperi* in Iowa has not been examined since the study of Lampe (1982). We examined areas within Pilot Knob State Park where *C. gapperi* was found during past sampling efforts (Blagen 1967, Lampe 1982) to document the current status of this population. Additionally, data regarding other small mammal species within the park was also obtained.

METHODS

Pilot Knob State Park is a 283-ha park located in Hancock and Winnebago Counties in the northern portion of central Iowa. Within Pilot Knob, five sites were sampled. Because of the extensive survey of the region by Blagen (1967), habitats within the park that historically did not contain *C. gapperi* were not examined in this effort (Blagen, pers. comm., Lampe 1982). Three sites, the amphitheater, the knoll, and the lake, were sampled with trapping grids with 10-m spacing between traps to estimate small mammal density (see Orrock 2000 for more details). An 8 × 8 sampling grid was established at the amphitheater site, located southeast of the amphitheater at the east end of the park, along a north-facing hillside. Trees at

the amphitheater site consisted mostly of oak (*Quercus* spp.) and ash (*Fraxinus* spp.). The knoll site was located north of the highest point in the park, the 'knoll', where the lookout tower is situated (Orrock 2000). The 8 × 8 trapping grid was established along a hillside just north of the horse trail, with a small bog located in the northeast corner. The knoll site was characterized by oak (*Quercus* spp.) and Hickory (*Carya* spp.), but also included hackberry (*Celtis occidentalis*) and aspen (*Populus* spp.). The lake site was located in a portion of forest due east of Deadman's Lake. The 9 × 9 trapping grid began on the north side of the road through the park, and extended to the other side of the road. Tree species at the lake site consisted of oak (*Quercus* spp.) and ash (*Fraxinus* spp.) in the overstory and dogwood (*Cornus* spp.) and ironwood (*Ostrya virginica*) in the understory.

Sampling was conducted from 10–16 April 2000. All sites were sampled over the same time period to eliminate temporal bias among sites and facilitate comparison of sampling results among sites. We used live traps to reduce the potential impact on extant *C. gapperi* populations (Blagen, pers. comm.). One 8 × 9 × 23 cm Sherman live trap (H. B. Sherman Traps, Inc., Tallahassee, FL) was at each trap station within a grid. Leaf litter was removed to facilitate trap placement directly on the ground, and traps were placed in areas where rodent activity was likely to be high (e.g., along downed woody debris). Traps were baited with whole oats scented with peanut butter. Cotton bedding material was placed in traps to provide bedding material and warmth for captured rodents. Traps were pre-baited for two days and then opened for five consecutive days. Traps were checked daily for captures and rebaited as necessary. Animals were marked with an ear tag (National Band and Tag Co., Lexington, KY), and species, sex, age, and weight recorded before release. Trapping methods followed established guidelines (American Society of Mammalogists 1998; ISU Committee on Animal Care # 3-0-4488W-1; Iowa DNR Permit SC 97 0001) to ensure safe and humane treatment of captured rodents.

In addition to the three trapping grids, two additional sites were sampled less intensively during the effort by placing traps within likely capture areas. The 'campground' site consisted of 8 traps set

for two nights in aspen forest along the road to the campground, and the 'picnic' site consisted of 10 traps set for two nights in a strip of aspen across from a picnic area.

RESULTS AND DISCUSSION

Evidence collected during this study suggests that the relict population of *Clethrionomys gapperi* within Pilot Knob State Park may be locally extinct: in 1081 trapnights at 5 sites from 12–16 April 2000, no *C. gapperi* were caught. During this time, 35 individuals representing four species and 76 total captures were recorded. Captures were dominated by white-footed mice, *Peromyscus leucopus* (30 individuals), but chipmunks, *Tamias striatus* (2 individuals), meadow voles, *Microtus pennsylvanicus* (2 individuals), and a red squirrel, *Tamiasciurus hudsonicus,* were also captured. While the dispersal ability of *M. pennsylvanicus* is well-known (Reich 1981), a noteworthy capture of one adult male meadow vole occurred in the small bog within the knob site, approximately 400 meters from a field, the nearest suitable habitat.

Although habitats sampled were selected based upon the locations of previous captures of *C. gapperi* (Blagen 1967, Lampe 1982), we cannot be certain that red-backed voles are locally extinct. There was a full moon and clear skies during the sampling period, both of which are known to reduce capture success of small mammals in Pilot Knob (Blagen 1967). Additionally, while *C. gapperi* is active all year, population size tends to be lowest just prior to the onset of spring and subsequent reproduction (Merritt 1981). These climatic and temporal factors may have prevented detection of *C. gapperi* during the sampling effort, and more sampling (e.g., the Iowa NatureMapping Program) is warranted to fully document the existence and status of *C. gapperi* at Pilot Knob State Park and elsewhere in Iowa (Blagen 1967).

An examination of previous work suggests that *C. gapperi* populations within Pilot Knob have been declining. Miller (1954, 1955) reports that 21 *C. gapperi* were captured in a single night at the knob using 100 snap traps in August 1953, whereas we failed to capture *C. gapperi* in the same area using 320 trapnights of effort with livetraps. Furthermore, when Blagen (1967) sampled Pilot Knob with snap traps, he captured 98 *C. gapperi* at twenty locations within the park and concluded that *C. gapperi* was a dominant member of the small mammal community in suitable habitats. When Lampe (1982) later sampled Pilot Knob from 28 June–30 July 30, 1982, he only found 18 *C. gapperi* among five sites within the park. The reduced size of the Pilot Knob population in 1982 would increase the probability of extinction due to stochastic events and also may lead to

reduced heterozygosity within the population, which could also decrease fitness and population viability (Frankham 1995). In light of generally high capture probabilities observed in other studies (Blagen 1967; Merritt 1981), our inability to capture *C. gapperi* suggests that remnant populations of *C. gapperi,* if they exist, are not likely to be large.

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