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Activation history of the Hutchinson dunes in east-central Kansas, USA during the past 2200 years

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ABSTRACT

This paper presents data for the Hutchinson dunes, the third and southernmost of three dunefields that collectively span a 400 km north–south transect of the eastern Great Plains. Optically stimulated luminescence dating was used to create a new, high temporal- and spatial-resolution chronology of dunefield activity, which spans the last 2200 years. Ages indicate that three major episodes of dune activity occurred ~2100–1800, ~1000–900, and after ~600 years ago, especially within the past 420–70 years. Dune activity ~1000–900 years ago correlates to the height of the Medieval Climatic Anomaly. Widespread dune activity during the past 600 years, which peaked ~320 and ~200 years ago, correlates with the coolest periods of the Little Ice Age. Dune activity in the Hutchinson dunes during the Medieval Climatic Anomaly correlates well with available proxy data and dune records from the region, including other eastern-margin dunefields, and suggests that one or more severe droughts were occurring throughout most of the Great Plains at this time. Dune activity during the Little Ice Age, unlike that of the Medieval Climatic Anomaly, does not correlate with other eastern margin dunefields, but does with those in western Kansas, Colorado, Oklahoma, and Texas and with other regional proxies. This pattern suggests that Little Ice Age droughts, unlike those associated with the Medieval Climatic Anomaly, were less intense and/orgeographically limited. Little Ice Age droughts, though, were still significant as evidenced by the migration of large dune forms in the Hutchinson dunes at this time.

1. Introduction

Dunefields of the North American Great Plains are important indicators of past drought because, during extended times of reduced moisture, vegetation cover is diminished and aeolian sedimentation ensues (Muhs and Holliday, 1995). By assigning chronologies to aeolian sedimentation events, evaluations can be made regarding the timing and extent of these droughts. This data collection is particularly important in regions like the North American Great Plains because traditional drought proxies, such as tree rings and fossil pollen, are less common in the paleoclimate record (cf., Stahle et al., 2007). Research using dunefields as indicators of drought has identified region-wide, long-term droughts from large dunefields of the Great Plains (e.g., Mason et al., 2004; Forman et al., 2005; Sridhar et al., 2006; Miao et al., 2007). Recent emphasis, however, has focused on drought records from smaller and more peripheral dunefields of the eastern Great Plains (Hanson et al., 2009, 2010). In keeping with this approach, this study presents a new, high-resolution chronology from a small dunefield along the eastern margin of the east-central Great Plains. The aim of this study, like those prior, is to determine the spatial extent of well-documented Holocene droughts. The first of these studies investigated the Duncan dunes in Nebraska (Hanson et al., 2009), and the second, the Abilene dunes in Kansas (Hanson et al., 2010) (Fig. 1). As with these previous studies, dating dune activity in the Hutchinson dunes will provide important spatial and temporal data on the eastward propagation of Holocene droughts previously recognized in major dunefields of the Great Plains (e.g., the Nebraska Sand Hills; Miao et al., 2007). This study also presents the first numerical ages of dune activity in the Hutchinson dunes and places that record within the broader context of Great Plains aeolian activity and past climate change.

2. Previous studies

Although dunefields cover vast areas of the Great Plains, much of the aeolian-derived, regional drought record has been based on chronologies from a combination of optically stimulated

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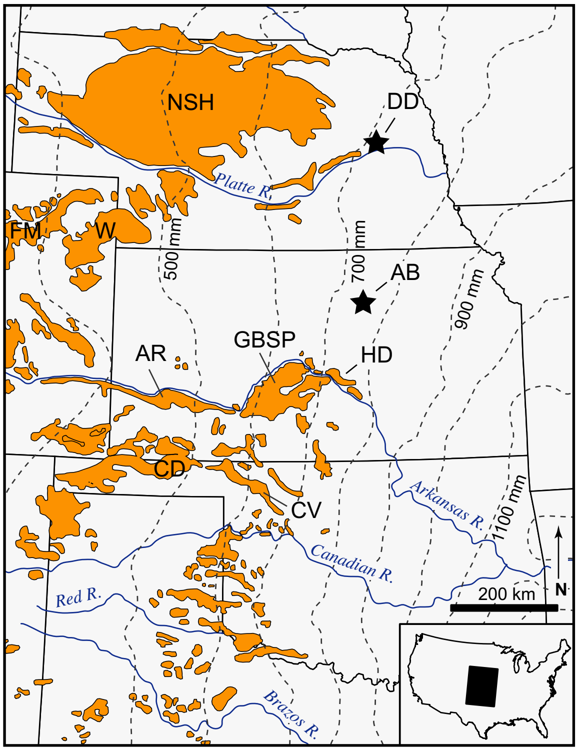

Fig. 1. Dunefields and major river systems of th Central Great Plains (modified from Wolfe et al., 2009). NSH, Nebraska Sand Hills; DD, Duncan dunes; FM, Fort Morgan dunes; W, Wray dunes (Forman et al., 2005); AB, Abilene dunes; AR, Arkansas River dunes; GBSP, Great Bend Sand Prairie; HD, Hutchinson dunes; CD, Cimarron Bend dunes; CV, Cimarron Valley dunes. Isopleths indicate mean annual precipitation (mm) based on 1961–1990 data; modified from Daly and Taylor (2009).

luminescence (OSL) and radiocarbon dating, which for the most part have been generated from the Nebraska Sand Hills, and the Wray and Fort Morgan dunes of Colorado (e.g., Madole, 1995; Forman et al., 2001, 2005; Clarke and Rendell, 2003; Goble et al., 2004; Mason et al., 2004, 2011; Miao et al., 2007) (Fig. 1). Drought-induced dune activity occurred in the Nebraska Sand Hills between ~9600 and ~6500 years ago and during events centered ~3800, ~2500, and ~700 years ago (Goble et al., 2004; Mason et al., 2004; Miao et al., 2007). Forman et al. (2005) also documented aeolian activity in the far western Nebraska Sand Hills ~3700, ~670, ~470, ~240, ~140, and ~70 years ago. Additionally, the Wray and Fort Morgan dunes of eastern Colorado (Fig. 1) were active ~540, ~420, and ~70 years ago, and ~4900, ~2400, ~1100, ~800, ~600–530, and ~370 years ago, respectively (Forman et al., 2005; Clarke and Rendell, 2003).

Less attention has been given to dunes south and east of the Nebraska Sand Hills, for example, the Arkansas River valley and the Great Bend Sand Prairie of Kansas (e.g., Arbogast, 1996; Arbogast and Johnson, 1998; Forman et al., 2008), dunefields adjacent to the Cimarron River in Oklahoma (e.g., Lepper and Scott, 2005; Werner et al., 2011), and those of the Southern High Plains (Holliday, 1997, 2001) (Fig. 1). Radiocarbon dating of buried soils in the Great Bend Sand Prairie, Kansas (Fig. 1) indicated periods of dune stability ~6700, ~3700, ~2300, ~1400, ~1100, ~700, and ~300 years ago (Arbogast, 1996; Arbogast and Johnson, 1998)—each of these periods of stability was followed by aeolian activity. Forman et al. (2008) recognized dune activity within the Arkansas River dunes ~1500, ~430, ~380–320, ~180, and ~70 years ago, and, in the Cimarron River valley of west-central Oklahoma and west-central Kansas, dunes were activated ~900–700 years ago (Lepper and Scott, 2005) and ~800–400 years ago (Werner et al., 2011) (Fig. 1). Aeolian activity on the Southern High Plains occurred in the Muleshoe dunes after ~1300, ~700, ~500 years ago, in the Lea-Yoakum dunes following ~3400 years ago, in the Andrews dunes after ~2300 years ago, and in the Seminole sand sheet between ~400 and ~300 years ago (Holliday, 2001). Additionally, all dunefields studied by Holliday (2001) were active within the last 200 years.

Several smaller dunefields lie on the eastern margin of the Great Plains (Fig. 1). The Duncan dunes in the eastern Platte River valley, Nebraska were active ~4300–3500 years ago and ~900–500 years ago (Hanson et al., 2009), and a companion study of the Abilene dunes (Hanson et al., 2010) documented activation at ~1100–500 years ago. The latter periods of activity from both the Duncan and Abilene dunes correspond very well with regional dunefield records, including those from the Nebraska Sand Hills (Miao et al., 2007) and from other dunefields in Kansas and Oklahoma (Arbogast, 1996; Arbogast and Johnson, 1998; Lepper and Scott, 2005; Werner et al., 2011).

In addition to paleoclimatic records derived from dunefield activity, some data exist from other Great Plains drought proxies, though these data at times are limited in spatial coverage and in some instances, such as lake sediments, are of coarser resolution with less accurate temporal control (Woodhouse and Overpeck, 1998). Nevertheless, drought identified in available records generally correlates well with Great Plains aeolian activation records. Schmieder et al. (2011), for example, provided a 4000-year record of drought from the Nebraska Sand Hills. These investigators contended that drought activity prior to 2000 years ago was more prevalent, but, they also documented both the MCA megadrought and many smaller "minidroughts" within the last 2000 years. Further, they attempted to correlate dune activity in the Nebraska Sand Hills with their drought record and concluded that many Holocene minidroughts recorded in the lake records are not present in the aeolian record.

Laird et al. (1996) documented four Holocene hydrological periods in Moon Lake, North Dakota: (1) a transitional period from glacial conditions to the earliest Holocene; (2) dry conditions during the mid Holocene ~7300–4700 years ago; (3) another transitional period between 4700 and 2200 years ago; and (4) a period of increased, but variable, aridity during the past 2200 years. While recognizing variability during the past 2200 years, Laird et al. (1996) also documented specific increases in aridity during the Medieval Climatic Anomaly (MCA). Similarly, Fritz et al. (1994) reported aridity in North Dakota during the Little Ice Age (LIA).

Using lake-water salinity records from North Dakota, Fritz et al. (2000) documented highly variable climate during the past 2000 years and argued specifically that the MCA and LIA were hydrologically complex, though they also argued that the changes in moisture documented during the MCA and LIA differed little from those recorded in the longer-term hydrological patterns of the Great Plains. Most recently, Hobbs et al. (2011), using diatoms to reconstruct lake salinity records from Kettle Lake, North Dakota, reported several episodes of aridity following ~8400, ~4400, and ~870 years ago in the northern Great Plains.

Rapid channel incision, which results from greater surface runoff due to less vegetation cover, has provided another drought proxy for the Great Plains. Incision events corresponding to the MCA were reported for multiple basins of the southern Great Plains by Hall (1990) and in the Republican River basin of southern Nebraska by Daniels and Knox (2005). Tree-ring series from the western United States have also provided useful paleoclimate data on the timing of recent drought episodes (e.g., Grissino-Mayer, 1996; Cook et al., 2004, 2007). Specifically, Cook et al. (2004) recognized widespread drought ~1100–700 years ago, an interval that matches the timing of the MCA. Cook et al. (2007) also documented drought in the Mississippi River valley ~1000, ~900–750, and ~650–600 years ago.

3. Study area

The Hutchinson dunes are a small, crescentic-shaped dunefield-northeast of the "Big Bend" in the Arkansas River Valley (Figs. 1 and 2). Collectively, the Hutchinson dunes are comprised of a main dunefield and adjacent isolated dune areas around its periphery (Fig. 2). The main dunefield lies atop a Pleistocene terrace deposits ~16–20 m above the modern Arkansas River, which itself is underlain by Permian bedrock, predominantly the Ninnescah shale and Harper sandstone (Bayne, 1956).

Dunes average ~8 m in relief, have weekly developed surface soils (<20 cm of A horizon development), and consist of fine to medium-coarse sand (250–750 μm). Though specific dune forms are not distinguishable in most cases, some of the larger dunes have complex parabolic morphologies, which indicate that sand was mobilized under a southwesterly wind regime. Presently, the dunes are completely stabilized by mixed, tall-short-grass prairie vegetation (e.g., *Andropogon hallii,Calamovilfa longifolia, Prunus angustifolia*). Interdune areas are commonly filled with water following rain, which remains perched due to the fine-grained terrace deposits located immediately below the dune sediments (Fig. 3). The sediment source for the Hutchinson dunes is likely deflated alluvium from the Arkansas River since the sediment size of other possible alluvial sources are too fine to produce the sediment found in the dunefield (Bayne, 1956). Based on this source location, initial dunefield formation occurred when winds were from the south-southwest. In contrast, the Great Bend Sand Prairie and the Arkansas River dunes formed south of the Arkansas River when dominant winds were from the north and northwest (Simonett, 1960; Arbogast and Muhs, 2000) (Fig. 1).

The location of the Hutchinson dunes is important in testing the spatial patterns of regional drought activity because they lay on the eastern edge of a steep east–west precipitation gradient. Precipitation records indicate that the Hutchinson dunes receive ~770 mm precipitation annually, whereas the western edge of the Arkansas River dunes, only 360 km west, receive ~450 mm annually (HPRCC, 2011). The Hutchinson dunes also occur in proximity to several other studied dunefields, e.g., the Great Bend Sand Prairie is ~50 km southwest, the Abilene and Duncan dunes are ~90 km and ~365 km north, respectively, and the Cimarron Valley dunes are ~250 km south (Fig. 1).

4. Methods

Sixty-six samples collected from 35 sites in the Hutchinson dunes were analyzed using OSL dating (Fig. 2) (see Supplemental file 1 for sample site coordinates). The majority of samples were collected from the crests and side slopes of completely stabilized sand dunes by vertical hand auguring with additional samples collected from profiles created in sand and gravel quarries, road cuts, and natural exposures. Dated sediment was collected in 20-cm-long sections of 5-cm-diameter steel conduit inserted into a full auger bucket or profile face. Sediment was packed tightly in the tubes, and then capped and sealed to prevent shifting of sediment during transport. Samples were not taken within 1 m of the surface in order to avoid potentially young ages due to soil-related bioturbation. In addition to the 66 sampled for OSL dating, one bulk organic sample from a buried A horizon was collected for AMS ^{14}C dating, and the age was calibrated using Calib 6.1.0 (Stuiver and Reimer, 1993).

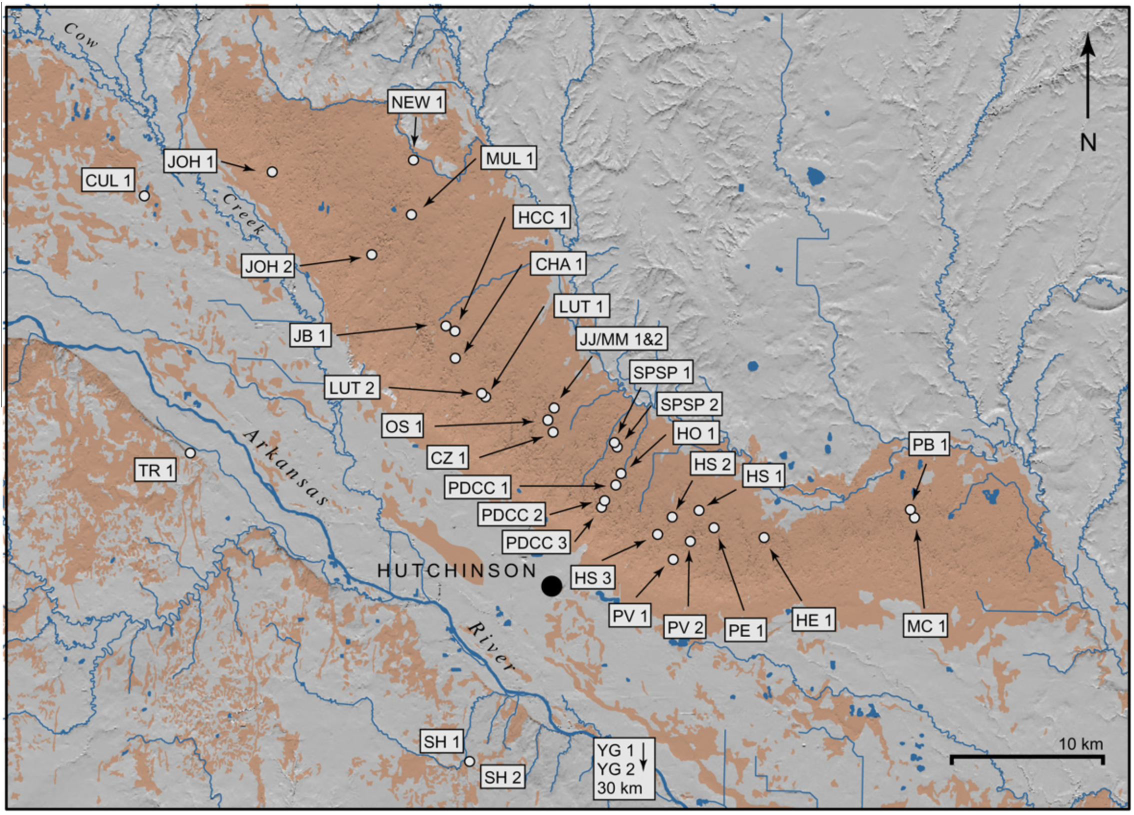

Fig. 2. The Hutchinson dunes and OSL sample sites.

Fig. 3. Aerial view of the Hutchinson dunes illustrating the stability and hummocky dune morphology found throughout the dunefield (Sites SPSP 1, 2: Fig. 2). Interdune areas have high water tables and often standing water where the dunefield overlies the fine-grained terrace fill.

OSL dating was conducted at the University of Nebraska Luminescence and Geochronology Laboratory, using procedures similar to those of Hanson et al. (2010). Samples were removed from the collection tubes in the laboratory, and the outer ~5 cm of each end was discarded. Samples were sieved to isolate 90–150 μm grains and then treated with 1 N HCl to remove carbonates and then floated in a 2.7 g cm^{-3} sodium polytungstate solution to remove heavy minerals. The floated grains were subsequently treated with 48% HF for ~75 min to remove feldspars and to etch quartz grains, followed by a treatment in 47% HCl for 30 min. Finally, samples were re-sieved to remove grains finer than 90 μm.

Equivalent dose (D_e) values were determined using the single aliquot regenerative (SAR) method (Murray and Wintle, 2000) on aliquots containing ~1200–800 quartz grains. Five regenerative doses were used including a zero dose and a repeated initial dose. Individual aliquots were rejected if their recycling ratios were >±10%, or if they had measureable signals during exposure to infrared diodes. Aliquots were also rejected if their equivalent dose (D_e) values were >4σ from the mean D_e value. Final age estimates were calculated using the mean D_e values from at least 18 accepted aliquots. Dose rate estimates were based on elemental concentrations of bulk sediment taken immediately adjacent to the OSL sample. These samples were analyzed for concentrations of K, U, Th, and Rb using high-resolution gamma spectrometry, inductively coupled plasma mass spectrometry (ICP-MS), oratomic emission spectroscopy (ICP-AES). The cosmogenic component of the dose rate was calculated using equations from Prescott and Hutton (1994), and final dose rate values were calculated using equations from Aitken (1998). All OSL ages (Table 1) are presented in calendar years before 2010 (see Supplemental file 2 for representative D_e distributions, OSL growth curves, and natural shine-down curves).

5. Results

In general, dune stratigraphies were consistent throughout the dunefield and were characterized by weakly developed surface soils (<20 cm), an absence of buried soils, and lack of other discernable changes except for various changes in moisture content—at some localities, the underlying alluvial sediment was reached (see Figs. 4–6). Exceptions were documented at the Cullop site (see: Section 5.2.1), Trostle site (see: Section 5.2.2), and alluvial sites (see: Section 5.2.3). OSL dating yielded good results except for one sample, and ages cluster into three groups: (1) underlying alluvial sediments deposited prior to ~90,000–60,000 years ago, (2) loess mantling alluvium, which was deposited prior to ~77,000 years ago, and (3) three periods of aeolian activity at ~2100–1800 years ago, ~1000–900 years ago, and that after ~600 years ago (Table 1). Core profiles, including OSL sample depths for individual dune sites, are presented in Figs. 4–6.

5.1. Dune ages from the Hutchinson dunes

To facilitate discussion of the age results, we have divided the Hutchinson dunes into three sections: northwest (Fig. 4), central (Fig. 5), and southeast (Fig. 6). In the northwest, the majority of dune ages fall into the period of most recent activity (~600–70 years ago). One exception is the Johnson 1 site (JOH 1, Fig. 4), where dune ages of 2070 ± 200 years ago (JOH 1–2) and 1880 ± 190 years ago (JOH 1–1) were obtained. While most ages from shallow samples (<3 m) reflect dune activity during late 19th or early 20th century droughts (possibly 1910s and 1930s droughts), deeper samples are older, ranging in age between 810 ± 10 years ago (CHA 1–2) and 160 ± 20 years ago (LUT 1–2).

Dune ages in the central dunefield are consistent with those of the northwestern section (Fig. 5). Less historic dune activity was detected in the area, and the majority of activity occurred after ~600 years ago, with only two ages occurring outside this period of activity (e.g., PDCC 2–1, 1150 ± 140 years ago; SPSP 1–2, 920 ± 80 years ago). Lastly, dune ages from the southeastern dunefield are in good agreement with ages from the central and northwestern dunefield, once again showing dominance of dune activity after ~600 years ago (Fig. 6). Like those ages from the central dunefield, only three dune ages from the southeastern dunefield fall outside this period of activity (PV 1–2, 920 ± 20 years ago; HS 2–1, 960 ± 80 years ago; HS 2–2, 960 ± 80 years ago).

5.2. Marginal dunefield sites

5.2.1. Cullop site

The Cullop Site (CUL) is located within the western arm of a large (~2 km^2), southward-oriented parabolic dune located on an alluvial surface about 5 km west of the main dunefield (Figs. 2, 7A). The site was selected because it and two accompanying parabolic dunes have a surface morphology unlike any other in the study area. Specifically, these are the only dunes with a distinct morphology indicating formation under a northerly wind regime. A profile, created in a 2 m exposure (Fig. 7B), consisted of aeolian sediments that were fine, dark, and reactive (10% HCl), in contrast tothose in the main dunefield. Visible stratigraphy noted in the profile dipped between 13° and 16° to the west, and a krotovina crosscut the profile at a dip of 26° to the east. Based on the morphology of the dune sampled, we interpret this stratigraphy as the sideslope of a parabolic-dune wing. Visible lamellae and thin packages of coarse sediment in the profile followed the dipping stratigraphy. An OSL sample from the base of the profile (1.8 m) yielded an age of 2050 ± 190 years ago (CUL 1–1). Bucket auguring used to extend the profile to ~5.5 m revealed no detectable

Table 1
Equivalent dose, dose rate data, and optical age estimate for the Hutchinson dunes.

Field site	OSL sample[a]	UNL Lab #	Depth (m)	U (ppm)	Th (ppm)	K_2O (wt.%)	H_2O (%)[b]	Dose rate[c]	Dose rate (Gy/ka)	D_e (Gy) ± 1 Std. Err.	Aliquots (n)[d]	Optical age ± 1σ
Highlands Country Club												
	HCC 1–1 (s)	1874	3.15	0.8	3.6	2.4	3.1	M	2.45 ± 0.16	0.67 ± 0.04	20/20	270 ± 30
	HCC 1–2 (s)	1875	2.70	0.7	2.9	2.6	2.3	M	2.54 ± 0.17	0.82 ± 0.12	22/23	320 ± 50
	HCC 1–3 (s)	1876	9.75	0.6	2.6	2.4	3.4	M	2.22 ± 0.16	0.72 ± 0.07	21/26	330 ± 40
Prairie Dunes Country Club site 1												
	PDCC 1–1 (s)	1877	1.32	0.6	2.6	2.7	1.4	M	2.61 ± 0.17	1.16 ± 0.09	21/24	450 ± 50
	PDCC 1–2 (s)	1878	4.04	0.6	2.7	2.5	2.7	M	2.35 ± 0.16	0.74 ± 0.03	22/24	320 ± 30
	PDCC 1–3 (s)	1879	6.69	0.7	3.1	2.3	5.0	M	2.21 ± 0.17	0.71 ± 0.03	21/23	320 ± 30
Prairie Dunes Country Club site 2												
	PDCC 2–1 (s)	1880	2.77	0.9	3.7	2.4	12.6	M	2.25 ± 0.26	2.59 ± 0.05	24/24	1150 ± 140
Prairie Dunes Country Club site 3												
	PDCC 3–1 (s)	2091	1.80	0.7	2.7	2.6	4.6	M	2.46 ± 0.18	0.30 ± 0.01	24/24	120 ± 10
	PDCC 3–2 (s)	2092	7.70	0.8	3.4	2.8	1.6	M	2.67 ± 0.17	1.03 ± 0.10	21/24	390 ± 50
Prairie Dunes Country Club site 4												
	PDCC 4–1 (a)	2093	4.20	1.1	4.7	2.5	9.8	M	2.47 ± 0.17	>150	–	>61,000[e]
Sand Hills State Park site 1												
	SPSP 1–1 (s)	1881	1.40	0.9	3.7	2.6	1.6	M	2.66 ± 0.16	0.77 ± 0.01	23/23	290 ± 20
	SPSP 1–2 (s)	1882	7.10	0.8	3.2	2.6	4.0	M	2.43 ± 0.17	2.24 ± 0.07	22/24	920 ± 80
Sand Hills State Park site 2												
	SPSP 2–1 (s)	1883	2.40	0.7	3.0	2.5	1.2	M	2.49 ± 0.16	0.75 ± 0.02	20/23	300 ± 30
	SPSP 2–2 (s)	2090	7.40	0.6	2.4	2.7	3.8	M	2.40 ± 0.18	0.83 ± 0.02	22/24	350 ± 30
Young site 1												
	YG 1–1 (a)	2180	2.10	0.8	4.1	2.5	6.3	M	2.47 ± 0.14	>220	–	>89,000[e]
Young site 2												
	YG 2–1 (a)	2181	1.65	0.8	3.4	3.0	2.2	M	2.92 ± 0.11	>220	–	>75,000[e]
Showalter site 1												
	SH 1–1 (a)	2182	1.00	2.0	10.4	2.4	13.4	M	2.89 ± 0.29	>190	–	>66,000[e]
Showalter site 2												
	SH 2–1 (a)	2183	1.00	1.5	7.1	2.4	11.2	M	2.63 ± 0.23	>160	–	>60,000[e]
Trostle site												
	TR 1–1 (l)	2184	2.13	2.4	9.8	2.2	9.9	M	2.86 ± 0.21	>220	–	>77,000[e]
Jarrott site 1												
	JJ 1–1 (s)	2553	1.60	3.2	3.0	2.9	2.0	G	3.39 ± 0.20	0.59 ± 0.02	20/24	180 ± 10
	JJ 1–2 (s)	2554	6.15	2.5	3.6	2.9	5.1	G	3.08 ± 0.22	0.62 ± 0.02	22/24	200 ± 20
Jarrott site 2												
	JJ 2–1 (s)	2555	1.60	2.6	3.4	2.8	2.5	G	3.20 ± 0.19	0.55 ± 0.04	24/24	170 ± 20
Holland site												
	HO 1–1 (s)	2562	1.60	3.5	5.1	2.7	2.8	G	3.43 ± 0.20	0.33 ± 0.01	23/24	100 ± 10
	HO 1–2 (s)	2563	6.33	3.8	3.3	2.9	4.4	G	3.40 ± 0.22	1.78 ± 1.20	24/24	520 ± 50
McCury site												
	MC 1–1 (s)	2560	1.63	4.6	4.7	2.7	4.4	G	3.61 ± 0.22	0.29 ± 0.03	23/24	80 ± 10
	MC 1–2 (s)	2561	5.85	2.6	2.7	2.8	17.7	G	2.63 ± 0.40	0.38 ± 0.03	23/24	140 ± 30
Prairie Bell Angus site												
	PB 1–1 (s)	2558	1.80	2.4	2.7	2.8	3.9	G	3.06 ± 0.20	0.33 ± 0.01	23/24	110 ± 10
	PB 1–2 (s)	2559	6.26	1.2	2.9	2.9	2.0	G	2.79 ± 0.18	0.62 ± 0.04	23/25	220 ± 20
Oswald site												
	OS 1–1 (s)	2556	1.73	2.4	2.8	2.8	1.4	G	3.15 ± 0.18	0.25 ± 0.02	20/24	80 ± 80
	OS 1–2 (s)	2557	6.23	2.6	3.2	2.6	3.3	G	2.92 ± 0.18	0.47 ± 0.03	23/24	160 ± 20
Pease site												
	PE 1–1 (s)	2551	1.63	4.8	3.5	2.8	4.7	G	3.64 ± 0.23	0.64 ± 0.03	23/24	180 ± 20
	PE 1–2 (s)	2552	6.23	4.7	3.8	2.8	4.4	G	3.54 ± 0.22	0.66 ± 0.05	22/24	190 ± 20
Czarnek site 1												
	CZ 1–1 (s)	2686	1.72	0.8	3.6	2.9	6.7	G	2.71 ± 0.22	0.55 ± 0.02	24/24	200 ± 20
	CZ 1–2 (s)	2687	7.42	1.1	2.2	2.9	4.4	G	2.67 ± 0.20	0.63 ± 0.02	22/24	240 ± 20
Czarnek site 2												
	CZ 2–1 (s)	2688	6.65	1.3	4.7	2.8	5.8	G	2.78 ± 0.20	0.73 ± 0.02	22/24	260 ± 30
Czarnek site 3												
	CZ 3–1 (s)	2689	5.43	0.9	2.6	2.9	4.0	G	2.72 ± 0.19	0.55 ± 0.03	24/24	200 ± 20
Swanson site 1												
	HS 1–1 (s)	2692	1.91	0.8	3.5	3.0	3.1	G	2.85 ± 0.19	0.62 ± 0.02	24/24	220 ± 20
	HS 1–2 (s)	2693	5.71	1.1	4.8	2.9	11.0	G	2.65 ± 0.03	0.62 ± 0.03	24/24	240 ± 30
Swanson site 2												
	HS 2–1 (s)	2694	1.74	1.5	4.6	2.9	5.4	G	2.98 ± 0.22	2.86 ± 0.03	23/24	960 ± 80

(*continued on next page*)

Table 1 (*continued*)

Field site	OSL sample[a]	UNL Lab #	Depth (m)	U (ppm)	Th (ppm)	K_2O (wt.%)	H_2O (%)[b]	Dose rate[c]	Dose rate (Gy/ka)	D_e (Gy) ± 1 Std. Err.	Aliquots (n)[d]	Optical age ± 1σ
	HS 2–2 (s)	2695	6.98	1.3	4.2	2.9	4.6	G	2.86 ± 0.21	2.75 ± 0.03	21/24	960 ± 80
Swanson site 3												
	HS 3–1 (s)	2696	1.83	0.6	3.1	2.8	5.2	G	2.61 ± 0.20	0.25 ± 0.01	22/24	100 ± 10
	HS 3–2 (s)	2697	7.02	0.8	2.9	3.0	3.1	G	2.77 ± 0.19	1.67 ± 0.02	24/24	600 ± 50
Voth site 1												
	PV 1–1 (s)	2700	1.78	1.7	3.7	3.1	7.0	G	3.03 ± 0.25	0.73 ± 0.02	23/24	240 ± 20
	PV 1–2 (s)	2701	6.90	0.9	2.7	2.9	5.3	G	2.65 ± 0.21	2.45 ± 0.08	24/24	920 ± 90
Voth site 2												
	PV 2–1 (s)	2702	1.74	0.9	3.8	2.9	2.5	G	2.90 ± 0.19	0.56 ± 0.02	23/24	190 ± 20
	PV 2–2 (s)	2703	6.45	1.0	4.7	2.9	8.5	G	2.70 ± 0.25	1.13 ± 0.07	22/24	420 ± 50
Epps site												
	HE 1–1 (s)	2690	1.98	0.6	2.6	2.6	7.4	G	2.36 ± 0.20	0.51 ± 0.03	21/24	220 ± 20
	HE 1–2 (s)	2691	6.90	0.9	2.7	2.9	3.6	G	2.71 ± 0.19	0.53 ± 0.02	23/24	200 ± 20
Buttler site												
	JB 1–1 (s)	2698	1.75	0.6	2.9	2.9	5.4	G	2.65 ± 0.21	0.21 ± 0.01	21/24	80 ± 10
	JB 2–1 (s)	2699	7.00	1.5	2.8	2.9	5.0	G	2.77 ± 0.21	0.52 ± 0.02	23/24	190 ± 20
Mull site												
	MUL 1–1 (s)	2984	2.09	0.6	2.5	2.7	2.4	M	2.53 ± 0.17	0.34 ± 0.02	21/27	140 ± 10
	MUL 1–2 (s)	2985	6.38	0.6	2.6	2.7	4.0	M	2.43 ± 0.18	0.34 ± 0.02	21/33	140 ± 20
	MUL 1–3 (s)	2986	6.58	0.7	2.6	2.7	15.9	M	2.16 ± 0.32	0.47 ± 0.01	21/26	220 ± 30
Cullop site												
	CUL 1–1 (s)	2971	1.80	1.2	5.3	2.9	6.9	M	2.91 ± 0.23	5.96 ± 0.09	20/28	2050 ± 190
	CUL 1–2 (s)	2972	5.34	1.2	5.3	2.9	7.9	M	2.84 ± 0.25	5.92 ± 0.09	21/23	2080 ± 200
Johnson site 1												
	JOH 1–1 (s)	2974	1.87	0.7	2.9	2.7	7.0	M	2.49 ± 0.21	4.69 ± 0.16	23/23	1880 ± 190
	JOH 1–2 (s)	2975	4.25	0.7	3.0	2.7	7.2	M	2.42 ± 0.21	5.00 ± 0.10	19/28	2070 ± 200
Johnson site 2												
	JOH 2–1 (s)	2976	1.69	0.7	2.6	2.8	4.7	M	2.58 ± 0.19	0.54 ± 0.01	20/25	210 ± 20
	JOH 2–2 (s)	2977	5.08	0.7	3.1	2.7	19.9	M	2.15 ± 0.37	0.57 ± 0.02	20/22	270 ± 50
Luttgen site 1												
	LUT 1–1 (s)	2981	1.86	0.7	3.1	2.7	6.4	M	2.50 ± 0.20	0.19 ± 0.01	19/20	80 ± 10
	LUT 1–2 (s)	2982	6.55	0.8	3.3	2.6	5.7	M	2.44 ± 0.19	0.38 ± 0.02	19/28	160 ± 20
Luttgen site 2												
	LUT 2–1 (s)	2983	2.12	0.7	2.6	2.7	7.1	M	2.48 ± 0.21	0.22 ± 0.02	20/32	90 ± 10
Newfield site												
	NEW 1–1 (s)	2987	2.07	0.6	2.3	2.7	4.0	M	2.52 ± 0.18	0.26 ± 0.01	18/23	100 ± 10
	NEW 1–2 (s)	2988	6.80	0.5	2.1	2.7	5.8	M	2.33 ± 0.19	0.46 ± 0.02	21/23	200 ± 20
Chalfant site												
	CHA 1–1 (s)	2969	1.85	0.6	2.7	2.7	4.5	M	2.51 ± 0.19	0.27 ± 0.01	20/33	110 ± 10
	CHA 1–2 (s)	2970	7.05	0.6	2.5	2.7	3.3	M	2.56 ± 0.17	2.08 ± 0.06	22/23	810 ± 70

[a] Sediment type: (s) = Sand; (a) = Alluvium; (l) = Loess.

[b] Assumes 100% error in measurement.

[c] Dose rate measurement technique: G = Gamma ray spectrometry; M = ICP-MS/AES.

[d] Accepted disks/all disks.

[e] Sample was too old to produce a meaningful age; this should be considered a minimum age estimate for the sample.

sedimentary changes. An additional OSL sample collected using the bucket auger at 5.3 m yielded an age of 2080 ± 200 years ago (CUL 1–2).

5.2.2. Alluvial sites (Young, Showalter, and Prairie Dunes Country Club 3)

The Young site (YG) is a 6 m-deep sand quarry ~40 km south of the Hutchinson dunes (Fig. 2) (see Supplemental file 3 for stratigraphic column). Although this site is the most distal from the dunefield, it does expose alluvial stratigraphy similar to that in the main dunefield. Coarse sand and gravel dominate the quarry sediment and are capped by a dark, fine-grain, organic- and carbonate-rich zone. Two OSL samples were collected from the alluvium below this zone, one on the northern quarry face at 2.1 m and another on the western quarry face at 1.7 m. Ages of these samples exceeded the limits of OSL dating, but we did calculate minimum ages for them: sample YG 1–1 was deposited prior to ~89,000 years ago, and YG 1–2 was deposited prior to ~75,000 years ago.

The Showalter site (SH) is located on southern edge of the Arkansas River valley ~10 km south of the dunefield (Fig. 2) (see Supplemental file 3 for stratigraphic column). Stratigraphy of this site is similar to that of the Young Site in that it consists of coarse alluvium overlain by a dark, fine-grained, organic-rich deposit interpreted as a thin, pedogenically influenced loess deposit. In general, however, the alluvium at the Showalter site was not as coarse as that at the Young site. Two OSL samples were taken within the alluvium at 1.0 m and 2.5 m. Like those of the Young site, these samples were too old to date with OSL, but minimum age estimates were calculated for them, which indicated that the alluvium at the Showalter site was deposited prior to ~66,000–60,000 years ago (SH 1–1, SH 2–1). In addition to the two OSL ages, a radiocarbon sample collected at 0.5 min the loess yielded an age of 2762 ± 27 calibrated years before present (2640 ± 45 ^{14}C yrs BP).

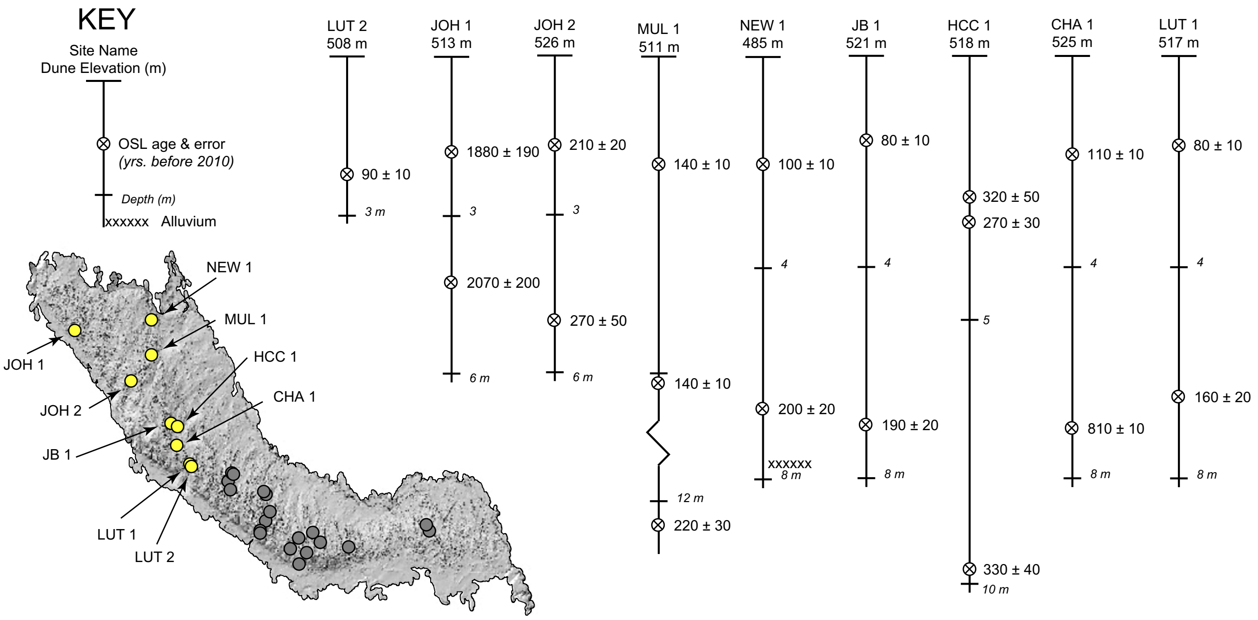

Fig. 4. Depth relationships of OSL samples collected from the northwest section of the Hutchinson dunes. OSL ages are reported in years before 2010 and shown with 1σ errors. Elevations of auger sites are given in meters above sea level.

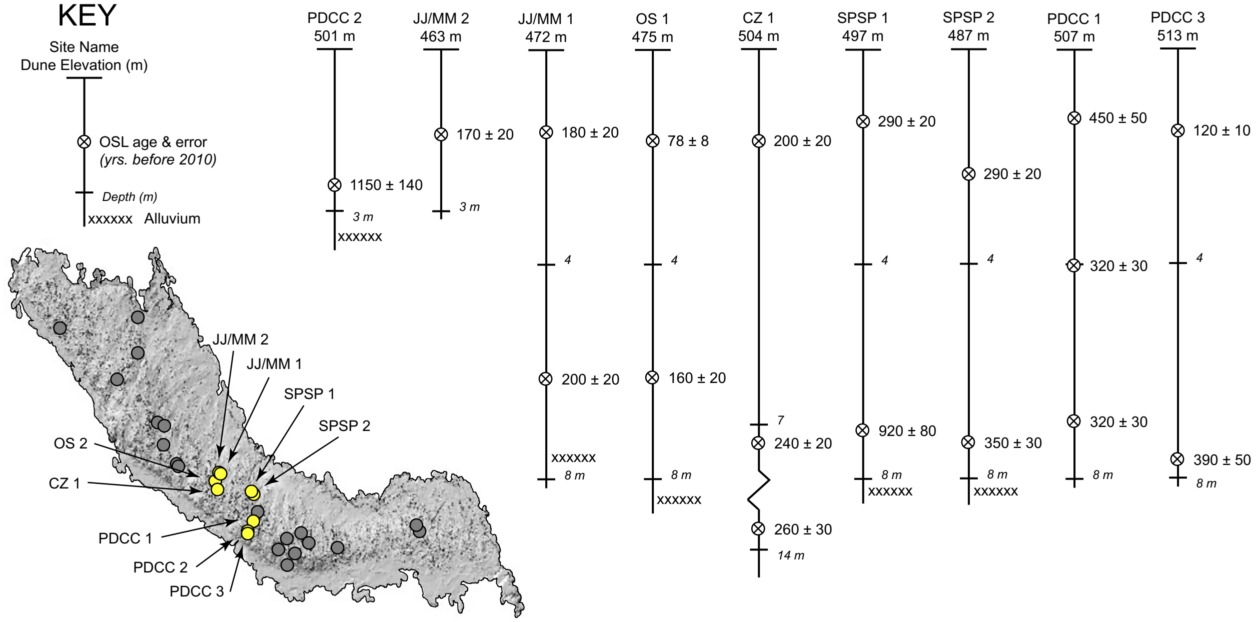

Fig. 5. Depth relationships of OSL samples collected from the central section of the Hutchinson dunes. OSL ages are reported in years before 2010 and shown with 1σ errors. Elevations of auger sites are given in meters above sea level.

Alluvial sediments, similar to those documented at the Young (YG) and Showalter (SH) sites, were also detected with a bucket auger at the Prairie Dunes Country Club 4 Site (PDCC 4), an interdunal site adjacent to the PDCC 3 Site. At the PDCC 4 site, an upper alluvial unit consisting of fine-grained, gleyed sediment occurred at 2.4 m and was underlain by reduced alluvial sand to a depth of ~4.5 m where auguring ceased. We interpret these alluvial sediments as floodplain deposits overlying alluvial sands. A minimum age of >61,000 years ago (PDCC 4–1) was estimated from a sample taken within the alluvium at 4.2 m, demonstrating its deposition prior to ~61,000 years ago. Sediments interpreted elsewhere as alluvium were identified below the Hutchinson dunes while bucket auguring (see Figs. 4–6), however no OSL samples were collected from these sediments.

5.2.3. Trostle Site

The Trostle site (TR) is an exposure of loess in a road cut located southwest of and ~10 m above the modern Arkansas River (Fig. 2) (see Supplemental file 4 for stratigraphic column). The site consists of ~2.8 m of oxidized loess with abundant carbonate concretions. OSL was used to date a zone of concentrated carbonate at

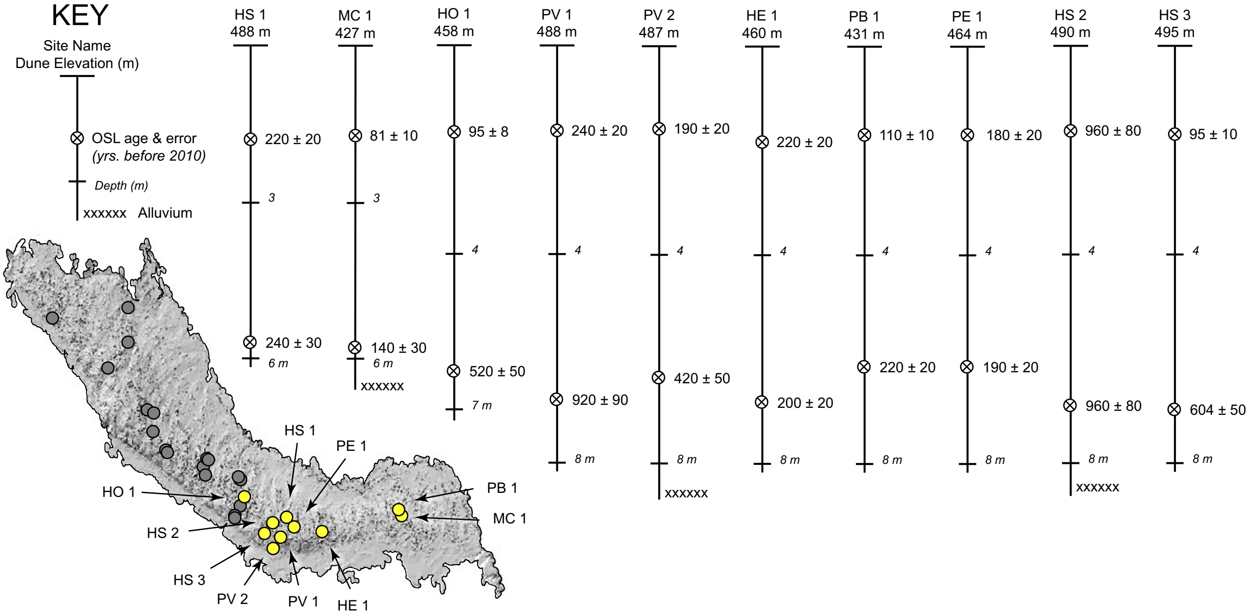

Fig. 6. Depth relationships of OSL samples collected from the southeast section of the Hutchinson dunes. OSL ages are reported in years before 2010 and shown with 1σ errors. Elevations of auger sites are given in meters above sea level.

1.8–2.2 m. A minimum age estimate indicated loess deposition prior to ~77,000 years ago (TR 1–1).

6. Discussion

6.1. OSL age inversions

All OSL ages are in stratigraphic order except for those at three sites: the Highlands Country Club site (HCC 1), Epps site (HE 1), and Prairie Dunes Country Club site 1 (PDCC 1). At HCC 1 (Fig. 4), an age 270 ± 30 years ago (HCC 1–2) obtained from 3.2 m depth is overlain by an older age of 320 ± 50 years ago (HCC 1–1) at 2.7 m. A similar case occurs at the Epps site (Fig. 6), where an age of 220 ± 20 years ago (HE 1–1) at 1.98 m overlies an age of 200 ± 20 years ago (HE 1–2) at 6.9 m. Both sets of ages fall within 1–2σ of each other, and, therefore, no statistical difference exists between the pair of ages from each of the two sites. At the PDCC 1 site (Fig. 5), an age of 450 ± 50 (PDCC 1–1), sampled at a depth of 1.3 m, overlies two ages at 4.0 and 7.0 m; both of these latter samples dated to 320 ± 30 years ago (PDCC 1–2, 1–3). Considering that the ages at 4.0 m and 7.0 m are identical, the near-surface (1.3 m) age is most likely erroneous.

6.2. Hutchinson dunes chronology

The suite of accepted ages ($n = 65$) documents three larger periods of aeolian activity between ~2100–1800 years ago, ~1000–900 years ago, and after ~600 years ago, as well as deposition of Pleistocene alluvium and loess prior to ~90,000–60,000 years ago and ~77,000 years ago, respectively. The high concentration of dune ages within the last 600 years, relative to those in the other age clusters, suggests that recent aeolian activity was intense and widespread. Our chronology also provides an estimate on the size of migrating dunes at this time, which in some cases exceeded heights of 8–10 m (e.g., CZ 1, HCC 1, MUL 1). Considering that present-day dune forms are similar in size to those that migrated within the past 600 years, we speculate that the majority of the dunefield was active during this time, rather than simply isolated blowouts or localized accumulation of aeolian sediment. Additionally, we speculate that aeolian activity in the Hutchinson dunes within the last 600 years, especially the dune activation between ~420–70 years ago may have been sufficiently widespread as to overprint much of the evidence for prior aeolian activity. This may include overprinting of eolian activity between ~1000–900 years ago and ~2100–1800 years ago, and possibly even older periods of dune activation. Despite this potential bias, the Hutchinson dunes still contain evidence of late-Holocene dune activation, which correlate with other regional dunefields and proxies.

Five samples from an alluvial terrace ~16–20 m above the modern Arkansas River produced ages indicating deposition occurred prior to ~90,000–60,000 years ago. These ages are older than those of terraces upstream underlying the Great Bend Sand Prairie and Arkansas River dunes, which were deposited ~16,000 years ago (Arbogast, 1996; Forman et al., 2008). Unlike the terrace underlying the Hutchinson dunes, those underlying the Great Bend Sand Prairie and Arkansas River dunes are only 3–5 m and 4–6 m above the modern Arkansas River, respectively (Arbogast, 1996; Arbogast and Johnson, 1998; Forman et al., 2008). Our OSL age estimates for the alluvial fills that underlie the Hutchinson dunes area are also supported by ages from loess deposition at the Trostle site, which suggests that underlying alluvial surface was abandoned prior to ~77,000 years ago.

The earliest period of dune activity in the Hutchinson dunes is documented with four ages from two sites that cluster between ~2100–1800 years ago. These ages are not documented throughout the dunefield, but are geographically isolated in the northwestern corner. Two of these ages (CUL 1–1, CUL 1–2) were obtained from the Cullop site, the large south-trending parabolic dune located on alluvial sediments of Cow Creek (Fig. 7). Because dune morphology at the CUL 1 site does not match the wind vectors required to form the Hutchinson dunes, we suggest that activity between ~2100–1800 years ago does not represent the first episode of aeolian dune formation in the Hutchinson dunes area. The two additional ages documenting activity between ~2100–1800 years ago (JOH 1–1, JOH 1–2) were derived from a dune ridge at the periphery of the main dunefield. In the Great Bend Sand Prairie, only 50 km southwest of CUL 1, Arbogast (1996) and Arbogast and Johnson (1998), using radiocarbon ages from weakly developed buried soils, constrained dune activity within four parabolic dunes between ~2300 and ~1400 years ago.

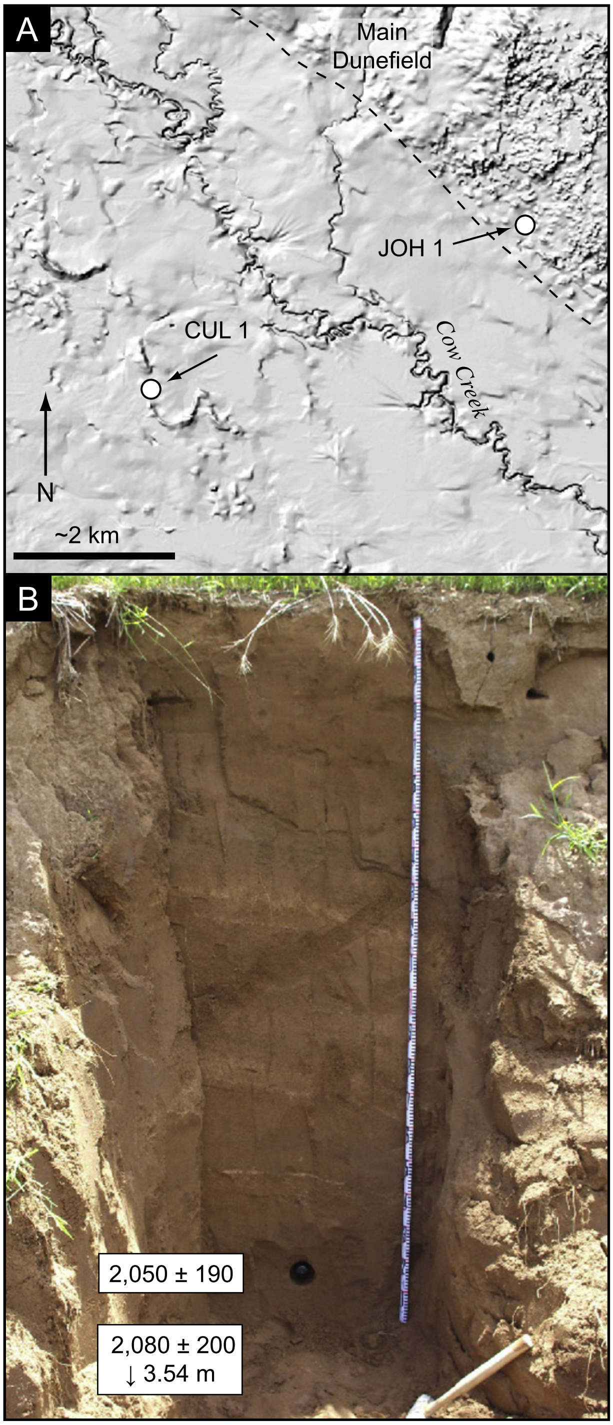

Fig. 7. Location and stratigraphy of the Cullop 1 site (CUL 1). (A) Hillshade DEM showing three south-trending parabolic dunes, the location of the Cullop 1 and Johnson 1sites. (B): Cullop 1 site profile showing dune stratigraphy and optical sample still within the profile face. A small-mammal burrow can be seen crosscutting the dune stratigraphy. Zones of light-colored sediment are small lenses of coarse-grain sand.

While only a limited number of ages from the Great Bend Sand Prairie and the Hutchinson dunes support activity ~2100–1800 years ago, they may indicate a period of drier floodplain conditions during which alluvial or previously deposited aeolian sediments were reworked. Dune activity ~2100–1800 years ago may have occurred throughout the entire dunefield; however, the younger episodes of aeolian activity may have erased most of this record except in specific localities (e.g., CUL 1, JOH 1). We speculate that these sites were spared during younger episodes of dune activity due to their proximity to Cow Creek (Fig. 7), which may have provided a higher water table sufficient to stabilize the adjacent landscape when the rest of the dunefield was active ~1000–900 years ago. This increased stability led to greater soil development, which in turn aided in keeping these dunes stable during the most recent episodes of aeolian activity within the last ~600 years. A similar scenario was documented by Werner et al. (2011) where older dunes with better-developed soils (i.e., a greater abundance of fine particles) could retain moisture and remain stable during drought conditions, whereas younger dune forms with less developed soils could not.

A single age of ~1100 years ago was obtained from the Hutchinson dunes but does not cluster with any of the other ages. If correct, this age may represent a period during which isolated dune activity occurred, similar to the manner in which isolated blowouts form in other Great Plains dunefields today. We do acknowledge that activation could have occurred in the Hutchinson dunes after ~1800 years ago and ended before ~1000 years ago, because similar timing of aeolian activity was recognized in the Great Bend Sand Prairie at this time (Arbogast, 1996; Arbogast and Johnson, 1998). Our current age data are too limited, however, to document this distinctive period of activity.

The second period of aeolian activity (~1000–900 years ago) is indicated by four ages scattered throughout the dunefield. With the exception of one age (HS 2–1), all were obtained from samples at depth, directly above the underlying alluvial surface, although they may not represent initial formation of the dunes. We argue that these ages may represent a reactivation event that overprinted most of the earlier dune activity ~2100–1800 years ago, or earlier. Widespread aeolian activity is documented ~960 years ago at HS 2, where two identical ages (HS 2–1, HS 2–2) are separated by ~5 m of aeolian sand, suggesting the rapid accumulation of sand or migration of an entire dune form at this time.

Activity ~1000–900 years ago correlates with a period of aeolian activity in the Great Bend Sand Prairie, which was bracketed by weakly developed soils dating to ~1000 and 700 years ago (Arbogast, 1996; Arbogast and Johnson, 1998). A lone age of 810 ± 70 years ago (CHA 1–2) was collected from the CHA 1 site, but, we do not consider this age to cluster with those between ~1000–900 years ago because no other ages of ~810 years ago were obtained from the dunefield. We speculate that this age is erroneous, though, it is still plausible that dunes were active in the Hutchinson dunes ~810 years ago given that activity was noted in the Great Bend Sand Prairie ~800 years ago (Arbogast, 1996; Arbogast and Johnson, 1998).

The most recent period of aeolian activity in the Hutchinson dunes began~600 years ago and became more widespread by ~420 years ago, eventually peaking ~320 and ~200 years ago. These peaks appear to correspond with the movement of significant quantities of sand in the Hutchinson dunes. For example, ~9 m of sand accumulated at ~330 years ago at the HCC 1 site, ~13 m of sand between ~260–200 years ago at the CZ 1 site, and ~12 m of sand at ~220–140 years ago at the MUL 1 site (Figs. 4 and 5).

Dune activity continued into historic times, perhaps in response to 19th century droughts, such as the 1910s and 1930s. Evidence of historic dune activity was found in documents dating to the early settlement of Hutchinson, Kansas. These documents indicate that the Hutchinson dunes were fully activated in the 1870s but had stabilized at some locations by the early 1900s (e.g., Cole, 1918; Bradshaw, 1957). Dune activity during the 1930's Dust Bowl is also well documented by historical accounts and photography.

Dune activation in the past 700 years correlates well with records from the Great Bend Sand Prairie by Arbogast (1996) and Arbogast and Johnson (1998), where they reported dune activity occurring after brief periods of stability dating to ~700, ~500, and ~300 years ago. The brief periods of stability in the Great Bend Sand Prairie were indicated by thin (~10–20 cm) buried soils (Ab Horizons). Unlike the Great Bend Sand Prairie, however, no such buried soils were found in the Hutchinson dunes. While our sampling strategy included only a fraction of the dunes in the dunefield, it is unlikely that any soils formed as the result of widespread stability were missed. Rather, we propose that any stability during the last 600 years was too short-lived to foster visible accumulations of organic matter, or at least none that survived ensuing episodes of aeolian activity.

We suggest that the identified periods of dune activity were the result of extended reductions in moisture (i.e., drought), which resulted in the desiccation of vegetation and subsequent activation of dunefield. While other factors such as a rapid influx of sediment could potentially cause dune activity (e.g., Muhs et al., 1996; Hanson et al., 2009), all evidence in the Hutchinson dunes suggest this is not the case. For example, no well-developed dunes are found on the floodplain between the Hutchinson dunes and the modern Arkansas River, a distance of ~10 km. Additionally, there is no correlation between ages of dune activation and distance from the Arkansas River. If dune activity were driven by changes in sediment supply, one would expect to see younger dunes closer to the river.

6.3. Regional comparisons of late-Holocene dune activation

The activation chronology of the Hutchinson dunes presents a new, high-resolution chronology of dune activity in the Great Plains and defines periods of aeolian activity that have been observed in other Great Plains dunefields. One period of activity that appears in both the Hutchinson dunes and neighboring Great Bend Sand Prairie is that documented between ~2100 and 1800 years ago, though, this activity is absent from many other Great Plains dunefields. For example, dune activity occurred prior to ~2300 years ago in the Nebraska Sand Hills with a peak in activity ~2500 years ago (Goble et al., 2004; Miao et al., 2007), and the Fort Morgan dunes of Colorado were active ~2300 years ago (Clarke and Rendell, 2003). Dune activity between ~2100 and 1800 years ago is also absent from dunefields in Oklahoma (Lepper and Scott, 2005; Werner et al., 2011). Limited activity was noted in dunefields of Wyoming between ~2100 and 1800 years ago (e.g., Mayer and Mahan, 2004; Halfen et al., 2010), but this activity may not have been climatically linked to a drought covering the entire Great Plains, because the Nebraska Sand Hills and numerous other dunefields separating Kansas and Wyoming did not record the same activity. Nevertheless, formation of well-developed, south-trending parabolic dunes at this time (e.g., CUL 1 site) clearly indicates that activity was present in at least the Hutchinson dunes and neighboring Great Bend Sand Prairie.

Albeit somewhat earlier than many dunefields, the second period of dune activity in the Hutchinson dunes (~1000–900 years ago) is coincident with widespread activity recognized within the Great Plains, including the Nebraska Sand Hills, active ~1000–700 years ago (Goble et al., 2004; Mason et al., 2004; Miao et al., 2007) (Fig. 8), the Fort Morgan dunes, active ~1,000 and ~800 years ago (Clarke and Rendell, 2003); and the Muleshoe dunes of the Southern High Plains, active after ~1300 years ago up until ~800 years ago (Holliday, 2001). The Cimarron Valley dunes show activity ~900–760 years ago (Lepper and Scott, 2005) and the Cimarron Bend dunes ~800–500 years ago (Werner et al., 2011) (Fig. 8). In addition, dune activity was identified in the Duncan dunes between ~800 and 500 years ago and in the Abilene dunes between ~900 and 500 years ago (Hanson et al., 2009, 2010) (Fig. 8). Both these latter dunefields are eastern Great Plains dunefields, and their activity, together with that documented in the Hutchinson dunes, suggest that dunefields across the Great Plains were active at this time.

Regional dune activation ~1000–900 years ago is probably related to climate conditions associated with the MCA, as was suggested to be the case in the Nebraska Sand Hills (Miao et al., 2007), Duncan dunes (Hanson et al., 2009), and Abilene dunes (Hanson et al., 2010). Several continental-scale drought reconstructions indicate megadroughts occurred in the Great Plains and surrounding areas during the MCA (Booth et al., 2006; Feng et al., 2008; Cook et al., 2009). Though the exact climatic cause of these droughts is still not fully understood, they have been attributed to increased La Niña conditions in the tropical Pacific Ocean (e.g., Feng et al., 2008; Cook et al., 2009) and possibly even warm sea-surface temperatures in the North Atlantic Ocean (Feng et al., 2008).

Unlike many Great Plains dunefields, the Hutchinson dunes show little evidence for activation between ~800 and 600 years ago. Whether the lack of ages at this time represents stability or a sampling/preservation bias is unknown. Given the timing of dune movement identified in the Hutchinson dunes, a preservation bias against older activation events clearly exits, including the period of activity between 800 and 600 years ago. A bias could also exist because we did not sample every dune within the dunefield, or a potentially unrecognized problem with the OSL dating may also account for a lack of ages at this time. It is still reasonable, however, that the Hutchinson dunes may have stabilized by this time considering that weakly developed soils in the proximal Great Bend Sand Prairie formed ~700 years ago (Arbogast, 1996; Arbogast and Johnson, 1998). If the Hutchinson dunes were stable at this time, any evidence of their stability was erased by later episodes of dune activity.

Many Great Plains dunefields also express dune activity throughout the past ~600 years, though the timing of this activity varies somewhat across the region. For example, Forman et al. (2005) documented four periods of aeolian activity during the past 600 years in far western areas of the Nebraska Sand Hills, ~470, ~240, ~140, and 70 years ago, yet only a handful of similar ages have been obtained from the rest of the Sand Hills (e.g., Goble et al., 2004; Miao et al., 2007). Records derived from other dunefields, especially those of the western Great Plains, show activity during the past 600 years as well. Muhs et al. (1997) identified activity during this time in the Wray dunes (Fig. 1), which was further supported by Clarke and Rendell (2003), who reported the last major period of activity in the Fort Morgan dunes beginning at ~600 years ago and lasting until ~370 years ago. Dune activity was also reported in the Arkansas River dunes ~430, 380–320, 180, and 70 years ago (Forman et al., 2008) (Fig. 8), and dune activity occurred after ~600 years ago in the Cimarron Bend dunes (Werner et al., 2011) (Fig. 8) as well, but this activity ceased by ~450 years ago.

Significant aeolian activity also occurred in the Southern High Plains within the last ~700 years. For example, the Muleshoe dunes were active after ~700 and ~500 years ago, and the Seminole sand sheet was active between ~400 and ~300 years ago (Holliday, 2001). The Muleshoe dunes and Seminole sand sheet, as well as the Lea-Yoakum and Andrews dunes of Texas, were all active within the last 200 years (Holliday, 2001).

The geographical distribution of dunefields with activity after ~600 years ago prompted Hanson et al. (2010) to conclude that most dune activity in the Great Plains at this time was restricted to areas west of the 500 mm isohyet (Fig. 1). Data from the Hutchinson dunes, located east of the 700 mm isohyet, indicate that this is not the case for all locations in the Great Plains. We suggest that dune activity during the last 600 years was not restricted to western Great Plains dunefields, but also to dunefields in the southern High Plains. This pattern of drought may be similar to that observed during the extensive droughts of the 1930s and 1950s. During these droughts, the Panhandle of Oklahoma and southwestern

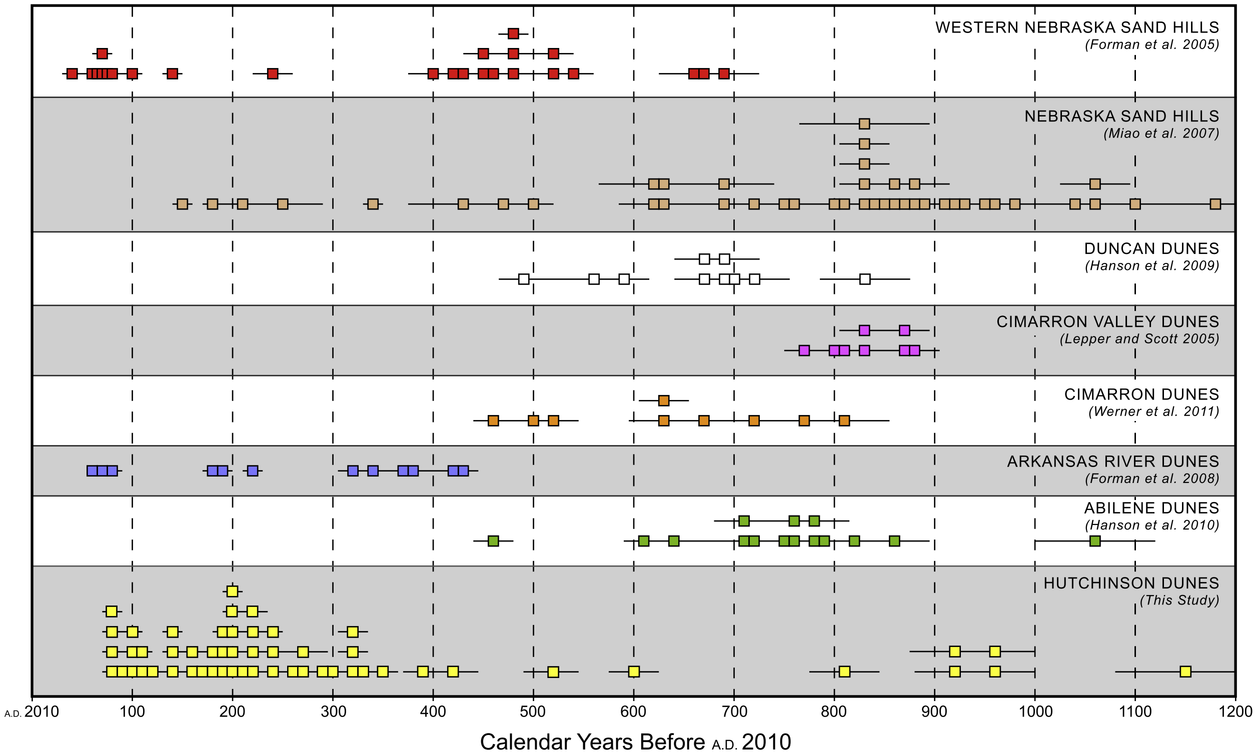

Fig. 8. Asymmetrical point plots of OSL ages from dunes in the central Great Plains, including data from this study.

Kansas experienced widespread drought, whereas areas of the northern and eastern Great Plains did not (e.g., Schubert et al., 2004; Cook et al., 2009; Seager et al., 2008). Further evidence that droughts impacting the Great Plains within the last 600 years were more geographically isolated than those of that occurred during the MCA has been documented in other Great Plains proxies (e.g., Fritz et al., 1994, 2000; Laird et al., 1996).

Hutchinson dune activity during the past 600 years, especially increased activity after ~420 years ago, correlates well with the coolest periods of the LIA (Mann et al., 2009). Widespread, continental megadroughts of the LIA are not as well recognized as those during the MCA. Nevertheless, Cook et al. (2009) concluded that North America remained under drought-prone climates following the MCA well into the LIA, and, despite drought-prone climate, many dunefields of the Great Plains did stabilize at this time. Several tree-ring reconstructions also document drought in the mid-continental North American during the past 600 years (e.g., Stahle et al., 2000; Herweijer et al., 2006). Fritz et al. (1994) documented drought in the Northern Great Plains during the LIA, but this record did not agree with Laird et al. (1996), who reconstructed mesic conditions during the same time. Fritz et al. (2000) later argued that drought occurred during the LIA, but that decreases in precipitation during the LIA were not anomalous compared to the longer-term hydrological patterns of the Great Plains. It is clear from these records that drought, while not as widespread as during the MCA, was present in the Great Plains during the LIA. Dune activation ages from the Hutchinson dunes has allowed us to re-evaluate the geographical patterns of LIA megadrought activity, and, based on these ages, we suggest that LIA droughts were restricted more to the southern and western Great Plains.

7. Conclusions

Numerous OSL ages provide a reliable chronology of dune activation for the Hutchinson dunes, resulting in the identification of three significant periods of dune activity ~2100–1800 years ago, ~1000–900 years ago, and after ~600 years ago, especially within the past 420–70 years. Regional correlation between dune activity in the Hutchinson dunes and that of other Great Plains dunefields is limited between ~2100–1800 years ago, however dune activity ~1000–900 years ago and that within the last 600 years correlates well. As previous investigations have hypothesized, dune activity in the Great Plains ~1000 years ago appears to correlate with significant climate change associated with the MCA, though the Hutchinson dunes appear to stabilize earlier than many other Great Plains dunefields at this time. Nevertheless, the geographical location of dunefields with activity after ~1000 years ago suggests that megadroughts impacting the region during the MCA were widespread and impacted most of the Great Plains. Activity in the Hutchinson dunes during the past 600 years does not correlate well with that of other northern and eastern Great Plains dunefields. It does correlate, however, with activity reported for western Nebraska, Colorado, Oklahoma, the Arkansas River valley of Kansas and the Southern High Plains, suggesting that widespread droughts also impacted the Great Plains throughout the LIA and into historic times. Notably, droughts during the LIA were less extensive and limited more to the southern and western Great Plains. Despite being less extensive, droughts at this time were significant in that the Hutchinson dunes were active with migrating dune forms exceeding 8–10 m in height.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.aeolia.2012.02.001.

References

Aitken, M.J., 1998. An Introduction to Optical Dating: The Dating of Quaternary Sediments by the Use of Photon-Stimulated Luminescence. Oxford University Press, New York.

Arbogast, A.F., 1996. Stratigraphic evidence for late-Holocene aeolian sand mobilization and soil formation in south-central Kansas, USA. Journal of Arid Environments 34, 403–414.

Arbogast, A.F., Johnson, W.C., 1998. Late-quaternary landscape response to environmental change in south-central Kansas. Annals of the Association of American Geographers 88, 126–145.

Arbogast, A.F., Muhs, D.R., 2000. Geochemical and mineralogical evidence from eolian sediments for northwesterly mid-Holocene paleowinds, central Kansas USA. Quaternary International 67, 107–118.

Bayne, C.K., 1956. Geology and ground-water resources of Reno County, Kansas. Kansas Geological Survey Bulletin 120, 130.

Booth, R.K., Notaro, M., Jackson, S.T., Kutzbach, J.E., 2006. Widespread drought episodes in the western Great Lakes region during the past 2000 years: geographic extent and potential mechanisms. Earth and Planetary Science Letters 242, 415–427.

Bradshaw, A.B., 1957. When the Prairies Were New. A.J. Allen Press, Turon, Kansas, USA, p. 96.

Clarke, M.L., Rendell, H.M., 2003. Late Holocene dune accretion and episodes of persistent drought in the Great Plains of Northeastern Colorado. Quaternary Science Reviews 22, 1051–1058.

Cole, R., 1918. The Old Trail and the New, 1865–1918. Reno Country Kansas County Superintendent and Teachers of Reno County, Hutchinson, Kansas, USA, p. 400.

Cook, E.R., Seager, R., Cane, M.A., Stahle, D.W., 2007. North American drought: reconstructions, causes and consequences. Earth Science Reviews 81, 93–134.

Cook, E.R., Seager, R., Heim, R.R., Vose, R.S., Herweijer, C., Woodhouse, C., 2009. Megadroughts in North America: placing IPCC projections of hydroclimatic change in a long-term palaeoclimate context. Journal of Quaternary Science 25, 48–61.

Cook, E.R., Woodhouse, C., Eakin, C.M., Meko, D.M., Stahle, D.W., 2004. Long-term aridity changes in the western United States. Science 306, 1015–1018.

Daly, C., Taylor, G., 2009. Map: United State Average Annual Precipitation. Available online: <http://www.ncgc.nrcs.usda.gov/products/datasets/climate/data/index.html>.

Daniels, J.M., Knox, J.C., 2005. Alluvial stratigraphic evidence for channel incision during the Mediaeval Warm Period on the central Great Plains, USA. The Holocene 15, 736–747.

Feng, S., Oglesby, R.J., Rowe, C.M., Loope, D.B., Hu, Q., 2008. Atlantic and Pacific SST influences on Medieval drought in North America simulated by the Community Atmospheric Model. Journal of Geophysical Research 113, D11101.

Forman, S.L., Marin, L., Pierson, J., Gomez, J., Miller, G.H., Webb, R.S., 2005. Aeolian sand depositional records from western Nebraska: landscape response to droughts in the past 1500 years. The Holocene 15, 973–981.

Forman, S.L., Marin, L., Gomez, J., Pierson, J., 2008. Late quaternary sand depositional record for southwestern Kansas: landscape sensitivity to droughts. Palaeogeography, Palaeoclimatology, Palaeoecology 265, 107–120.

Forman, S.L., Oglesby, R., Webb, R.S., 2001. Temporal and spatial patterns of Holocene dune activity on the Great Plains of North America: megadroughts and climatelinks. Global and Planetary Change 29, 1–29.

Fritz, S.C., Engstrom, D.R., Haskell, B.J., 1994. 'Little Ice Age' aridity in the northern American Great Plains: a high-resolution reconstruction of salinity fluctuations from Devils Lake, North Dakota, USA. The Holocene 4, 69–73.

Fritz, S.C., Ito, E., Yu, Z., Laird, K.R., Engstrom, D.R., 2000. Hydrologic variation in the Northern Great Plains during the last two millennia. Quaternary Research 53, 175–184.

Goble, R.J., Mason, J.A., Loope, D.B., Swinehart, J.B., 2004. Optical and radiocarbon ages of stacked paleosols and dune sands in the Nebraska Sand Hills, USA. Quaternary Science Reviews 23, 1173–1182.

Grissino-Mayer, H.D., 1996. A 2129-year reconstruction of precipitation for northwestern New Mexico, U.S.A. In: Dean, J.S., Meko, D.M., Swetnam, T.W. (Eds.), Tree Rings, Environment, and Humanity. Radiocarbon, Tucson, Arizona, pp. 191-204.

Halfen, A.F., Fredlund, G.G., Mahan, S.A., 2010. Holocene stratigraphy and chronology of the Casper Dune Field, Casper, Wyoming, USA. The Holocene 20, 773–783.

Hall, S.A., 1990. Channel trenching and climatic change in the southern US. Great Plains. Geology 18, 342–345.

Hanson, P.R., Joeckel, R.M., Young, A.R., Horn, J., 2009. Late Holocene dune activity in the Eastern Platte River Valley, Nebraska. Geomorphology 103, 555–561.

Hanson, P.R., Arbogast, A.F., Johnson, W.C., Joeckel, R.M., Young, A.R., 2010. Megadroughts and late Holocene dune activation at the eastern margin of the Great Plains, north-central Kansas, USA. Aeolian Research 1, 101–110.

Herweijer, C., Seager, R., Cook, E.R., 2006. North American Droughts of the mid-to-late nineteenth century: a history, simulation and implication for Mediaeval drought. The Holocene 16, 159–171.

High Plains Regional Climate Center (HPRCC), 2011. http://www.hprcc.unl.edu/data/historical/ (last accessed 09.09.2011).

Hobbs, W.O., Fritz, S.C., Stone, J.R., Dovocan, J.J., Grimm, E.C., Almendinger, J.E., 2011. Environmental history of a closed-basin lake in the US Great Plains: diatom response to variations in groundwater flow regimes over the last 8500 cal. yr BP. The Holocene 21, 1–14.

Holliday, V.T., 1997. Origin and evolution of lunettes on the high plains of Texas and New Mexico. Quaternary Research 47, 54–89.

Holliday, V.T., 2001. Stratigraphy and geochronology of upper quaternary eolian sand on the Southern High Plains of Texas and New Mexico, United States. Geological Society of America Bulletin 113, 88–108.

Laird, K.R., Fritz, S.C., Maasch, K.A., Cumming, B.F., 1996. Greater drought intensity and frequency before AD 1200 in the Northern Great Plains, USA. Nature 384: pp. 552–554.

Lepper, K., Scott, G.F., 2005. Late Holocene aeolian activity in the Cimarron River Valley of west-central Oklahoma. Geomorphology 70, 42–52.

Madole, R.F., 1995. Spatial and temporal patterns of Late Quaternary eolian deposition, Eastern Colorado, USA. Quaternary Science Reviews 14, 155–177.

Mann, M.E., Zhang, Z., Rutherford, S., Bradley, R.S., Hughes, M.K., Shindell, D., Ammann, C., Faluvegi, G., Ni, F., 2009. Global signatures and dynamical origins of the Little Ice Age and Medieval Climatic Anomaly. Science 329, 1256–1260.

Mason, J.A., Swinehart, J.B., Goble, R.J., Loope, D.B., 2004. Late Holocene dune activity linked to hydrological drought, Nebraska Sand Hills, USA. The Holocene 14, 209–217.

Mason, J.A., Swinehart, J.B., Hanson, P.R., Loope, D.B., Goble, R.J., Miao, X., Schmeisser, R.L., 2011. Late Pleistocene dune activity in the central Great Plains, USA. Quaternary Science Reviews 30, 3858–3870.

Miao, X., Mason, J.A., Swinehart, J.B., Loope, D.B., Hanson, P.R., Goble, R.J., Liu, X., 2007. A 10,000-year record of dune activity, dust storms, and drought in the central Great Plains. Geology 35, pp. 119–122.

Muhs, D.R., Stafford Jr., T.W., Cowherd, S.D., Mahan, S.A., Kihl, R., Maat, P.B., Bush, C.A., Nehring, J., 1996. Origin of the late Quaternary dune fields of northeastern Colorado. Geomorphology 17, 129–149.

Muhs, D.R., Stafford Jr., T.W., Swinehart, J.B., Cowherd, S.D., Mahan, S.A., Bush, C.A., Madole, R.F., Maat, P.B., 1997. Late Holocene eolian activity in the mineralogically mature Nebraska Sand Hills. Quaternary Research 48, 162–176.

Muhs, D.R., Holliday, V.T., 1995. Evidence of active dune sand on the Great Plains in the19th century from accounts of early explorers. Quaternary Research 43, 198–208.

Murray, A.S., Wintle, A.G., 2000. Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. Radiation Measurements 32, 57–73.

Prescott, J.R., Hutton, J.T., 1994. Cosmic ray contributions to dose rates for luminescence and ESR dating: large depths and long-term time variations. Radiation Measurements 23, 497–500.

Schmieder, J., Fritz, S.C., Swinehart, J.B., Shinneman, A.L.C., Wolfe, A.P., Miller, G., Daniels, N., Jacobs, K.C., Grimm, E.C., 2011. A regional-scale climate reconstruction of the last 4000 years from lakes in the Nebraska Sand Hills, USA. Quaternary Science Reviews 30, 1797–1812.

Schubert, S.D., Suarez, M.J., Pegion, P.J., Koster, R.D., Bacmeister, J.T., 2004. On the cause of the 1930s Dust Bowl. Science 303, 1855–1859.

Seager, R., Kushnir, Y., Ting, M.F., Cane, M., Naik, N., Velez, J., 2008. Would advance knowledge of 1930s SSTs have allowed prediction of the Dust Bowl drought? Journal of Climate 21, 3261–3281.

Simonett, D.S., 1960. Development and grading of dunes in western Kansas. Annals of the Association of American Geographers 50, 216–241.

Sridhar, V., Loope, D.B., Swinehart, J.B., Mason, J.A., Oglesby, R.J., Rowe, C.M., 2006. Large wind shift on the Great Plains during the Medieval Warm Period. Science 313, 345–347.

Stahle, D.W., Cook, E.R., Cleaveland, M.K., Therrell, M.D., Meko, D.M., Grissino-Mayer, H.D., Watson, E., Luckman, B.H., 2000. Tree-ring data document 16th century megadrought over North America. Eos. Transactions of the American Geophysical Union 81, 121–125.

Stahle, D.W., Fye, F.K., Cook, E.R., Griffin, R.D., 2007. Tree-ring reconstructed megadroughts over North American since A.D. 1300. Climate Change 83, 133–149.

Stuiver, M., Reimer, P.J., 1993. Extended 14C data base and revised CALIB 3.0 14C age calibration program. Radiocarbon 35, 215–230.

Werner, C.M., Mason, J.A., Hanson, P.R., 2011. Non-linear connections between dune activity and climate in the High Plains, Kansas and Oklahoma, USA. Quaternary Research 75, 267–277.

Wolfe, S.A., Robertson, L., Gillis, A., 2009. Late Quaternary Aeolian Deposits of Northern North America: Age and Extent. Geological Survey of Canada, Open File 6006, CD-ROM.

Woodhouse, C.A., Overpeck, J.A., 1998. 2000 Years of Drought Variability in the Central United States. Bulletin of the American Meteorological Society 79, 2643–2714.