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ABSTRACT—The Nebraska Sandhills have been an important resource for better understanding dune activation and the nature of prehistoric Great Plains drought events. However, until recently, few studies have focused on documenting the activation histories of smaller dune fields found along the Great Plains' eastern margin. This study focuses on the Stanton dune field, which lies about 145 km east of the Nebraska Sandhills on an alluvial terrace of the Elkhorn River in northeastern Nebraska. Sediments in the Stanton Dunes were dated with optically stimulated luminescence (OSL) to determine when these dunes were active. The ages indicate three activation periods that cluster into the following time periods: ~5,800–3,800, 960–630, and 510–410 years ago. The ages that fall into our two older clusters closely agree with dune activation records from the Nebraska Sandhills and other major central Great Plains dune fields, suggesting that these large-scale droughts also impacted eastern Nebraska. However, our youngest cluster of ages occurs at a time when the Nebraska Sandhills were thought to be largely inactive, suggesting that the Stanton Dunes may have been activated by a locally important drought event that had a more limited impact on dunes found to the west.

Key Words: dunes, drought, OSL dating, eolian activity, Elkhorn River, Nebraska

INTRODUCTION

Recent work on the chronology of activation records in Great Plains dune fields has allowed assessment of when and how dunes were activated. In large dune fields such as the Nebraska Sandhills, dune activation has been directly linked to increased aridity and hydrologic drought (Mason et al. 2004; Sridhar et al. 2006; Miao et al. 2007). The development of optically stimulated luminescence (OSL) dating, a method that estimates the last time sand grains were exposed to sunlight, has greatly improved our understanding of when dunes were active in the Great Plains. Notably, Miao et al. (2007) used OSL dating to show that the Nebraska Sandhills were activated between 9,600 and 6,500 years ago and during events centered on 3,800, 2,500, and 700 years ago.

Numerous other studies have used OSL and radiocarbon dating on dune fields throughout the central Great Plains, including dunes in Colorado (Clarke and Rendell 2003), Kansas (Arbogast 1996; Arbogast and Johnson 1998; Forman et al. 2008), Oklahoma (Lepper and Scott 2005; Werner et al. 2011), and Wyoming (Stokes and Gaylord 1993) (Fig. 1). These studies have resulted in a wealth of information about Great Plains dune activations and prehistoric climate; however, most of these studies historically were conducted west of the 98th meridian while several smaller dune fields lie to the east along the eastern margin of the Great Plains (Fig. 1).

However, studies of the impacts that prehistoric drought events have had on the smaller dune fields along the eastern margins of the Great Plains have only been conducted in the last few years. Recently, three small dune fields east of the 98th meridian have been studied using OSL dating: the Duncan dune field in Nebraska and the Abilene and Hutchinson dune fields in Kansas (Fig. 1). OSL ages from the Duncan Dunes, located near the confluence of the Loup and Platte Rivers in the east-central portion of Nebraska, show that eolian activity corresponds well with dune activation events in the Sandhills, in which activity occurred around 4,300 to 3,500 years ago and around 900 to 500 years ago (Hanson et al. 2009). The Abilene Dunes, roughly 120 km northeast of the Great Bend Sand Prairie in Kansas, were found to be active 1,100 to 500 years ago (Hanson et al. 2010). The Hutchinson Dunes, located about 50 km northeast of the

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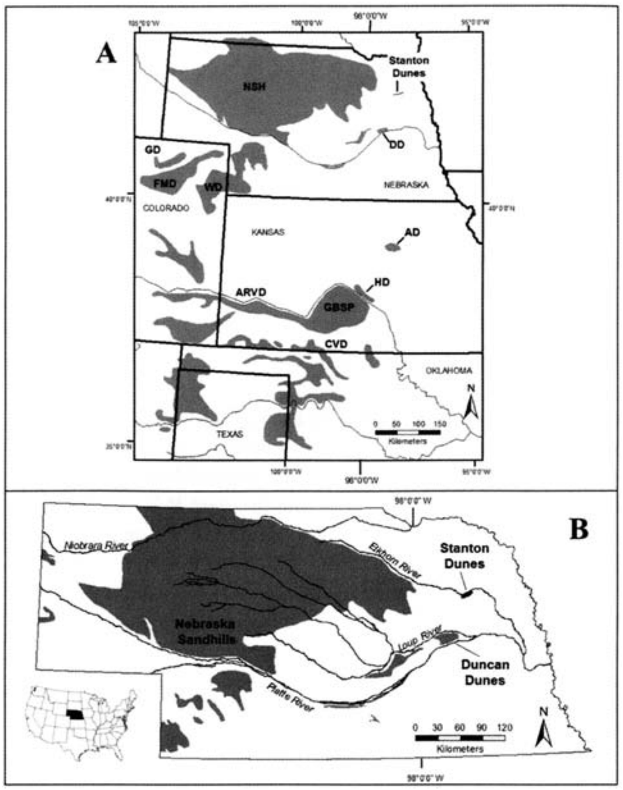

Figure 1. (A) Stanton Dunes and other previously studied dune fields in the Great Plains: AD = Abilene Dunes; ARVD = Arkansas River Valley Dunes; CVD = Cimarron River Valley Dunes; DD = Duncan Dunes; FMD = Fort Morgan Dunes; GBSP = Great Bend Sand Prairie; GD = Greeley Dunes; HD = Hutchinson Dunes; NSH = Nebraska Sandhills; WD = Wray Dunes. (B) Stanton Dunes and the other previously studied dune fields in Nebraska: Nebraska Sandhills and Duncan Dunes.

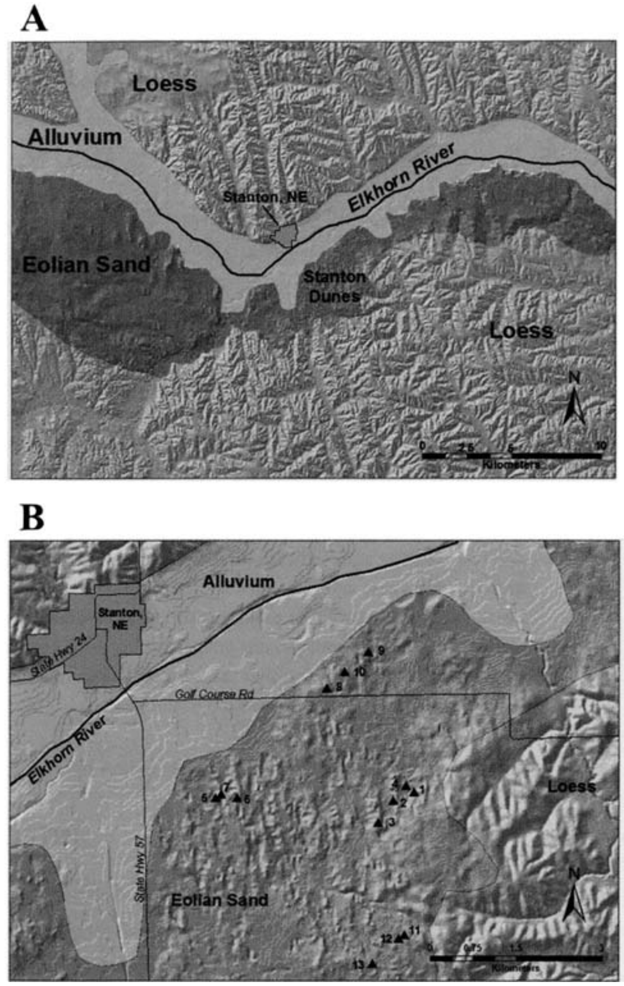

Figure 2. (A) A shaded-relief digital elevation model showing the Stanton Dunes study area and the loess-covered uplands. (B) Digital elevation model of the Stanton Dunes study area showing sediment sampling sites 1–13.

Great Bend Sand Prairie, along the Arkansas River, were found to be active in three major episodes: about 2,100 to 1,800 years ago, 1,000 to 800 years ago, and 600 to 70 years ago (Halfen et al. 2012). The Hutchinson, Abilene, and Duncan Dunes represent the easternmost dune activity of the Great Plains, which, unlike the larger dune fields to the west, do not record all of the multiple drought events of the last 10,000 years.

A small dune field near Stanton, NE, is the easternmost dune field of the central Great Plains (Figs. 1A and 2A) and is thus important for better understanding the geographical extent and impacts of prehistoric droughts on the eastern margin of the Great Plains. However, as noted by Muhs et al. (1996) and Hanson et al. (2009), increased eolian activity in these smaller dune systems, like the Stanton Dunes, may be the result of either a direct or indirect response to drought conditions. A direct response to drought would be a reduction in vegetation cover on the sandy soils of the terrace fill, leading to increased wind erosion and dune mobilization.

Alternatively, dune activation could have been a consequence of changes in sediment availability from the adjacent river system. For instance, drought conditions in the headwaters of the Elkhorn River may have caused an increase in sand moving down the river, and that sand could have been deflated and transported by wind from the valley to the alluvial terrace. This would have been an indirect response to drought and would have significantly different implications for how we interpret past climatic conditions in the Plains. With these scenarios in mind, the purposes of this study were to (1) determine when eolian activity and/or dune formation occurred in the Stanton Dunes, (2) determine the potential causes of dune activation in this area, and (3) compare the dune activity to that

Figure 3. (A) Left: Part of the 1.5–2 m section of the Stanton 8 core, showing typical eolian sand and lamellae-like features found in the area. Right: Part of the 3.6–3.9 m section of the Stanton 8 core, featuring alluvium found in this area. (B) A view of the grassland vegetation currently stabilizing the Stanton Dunes, to the north-northwest from the Stanton 11 study site.

of regional dune fields to identify potential patterns of dune activation histories in the region.

REGIONAL SETTING

The Stanton dune field (~162 km^2) is located on an alluvial terrace along the southern bank of the Elkhorn River in northeastern Nebraska, near the town of Stanton (Fig. 1B). It is the easternmost dune field in Nebraska and the central Great Plains, lying about 145 km east of the Nebraska Sandhills and about 110 km northeast of the Duncan Dunes (Fig. 1B). While high-relief complex megabarchan and barchanoid ridge dunes dominate the Nebraska Sandhills (Goble et al. 2004), low-relief (~5 m) barchan dunes are the most prevalent form in the Stanton dune field (Fig. 3A).

The dunes currently overlie alluvial sediments that are found in a terrace along the Elkhorn River, while being bordered to the south by loess-capped uplands (Fig. 2A). These uplands are comprised of 12–16 m of Peoria loess that was deposited between ~25,000 and 14,000 years ago (Mason 2001; Bettis et al., 2003; Mason et al., 2008). The Carlile Shale Formation forms the uppermost bedrock layer and is buried by Quaternary sediments in the field area, as noted by the geological descriptions in the Nebraska Department of Natural Resources Registered Groundwater Well Logs (NDNR 2011). The groundwater table is located at an elevation of about 1,450 ft, the same elevation of the Elkhorn River, and has fluctuated by about 1–5 ft over the last 10 years (UNL-SNR 2009, 2011).

The primary land uses of the Stanton dune field area are rangeland, pasture, and cropland, and the dune field is currently stabilized by grassland vegetation (Hammond et al. 1982) (Fig. 3B). The 1858 general land office surveys indicated the area was deemed unfit for cultivation, and no bare or unvegetated areas were noted, indicating the dunes were stable over the past ~160 years (Nebraska State Surveyor's Office 1858).

The climate in the Stanton area is humid continental, with hot, wet summers and cold, dry winters, compared to the semiarid climate of the Nebraska Sandhills (Wilhite and Hubbard 1998). The Stanton dune field area and the eastern portion of Nebraska receive an annual average of 25 to 35 inches of precipitation (High Plains Regional Climate Center 2011) while the drier Sandhills region

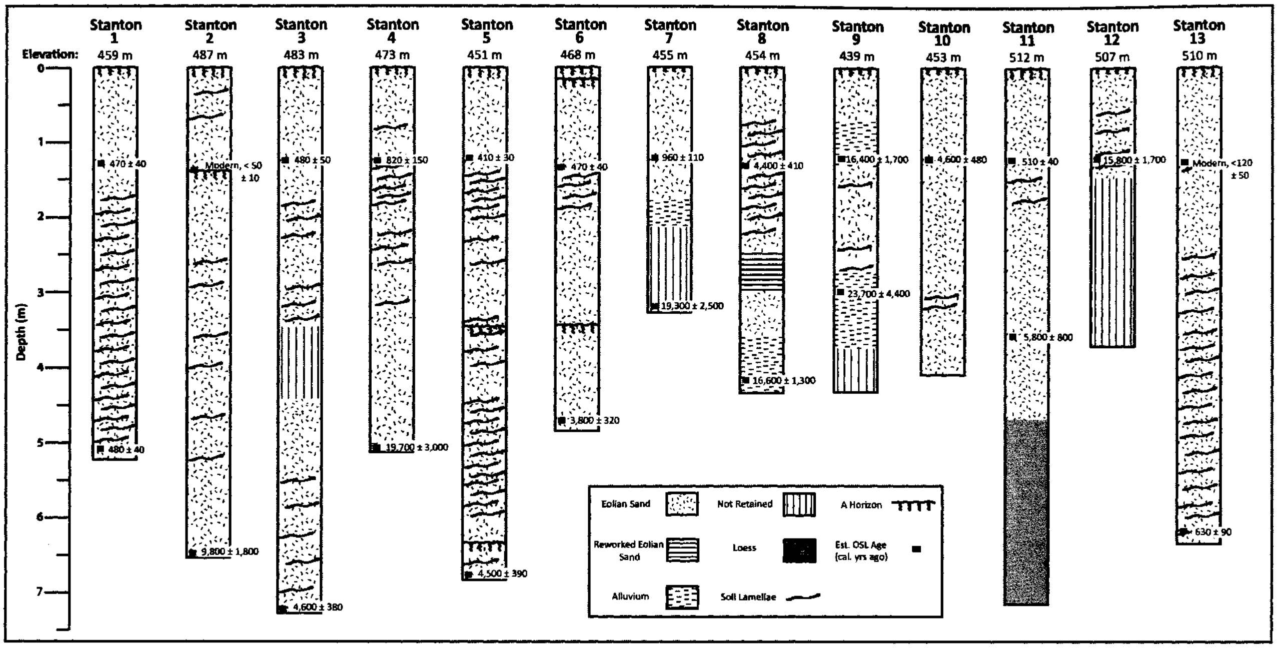

Figure 4. Sediment core stratigraphy and age chronology of the Stanton Dunes in Nebraska. Age is determined using optically stimulated luminescence (OSL). Sediment core locations are noted in Figure 2B.

receives an average of only 17 to 23 inches of precipitation each year (Wilhite and Hubbard 1998). The present wind regime of the Nebraska Sandhills and the central Great Plains can be associated with midlatitude cyclones in the cool winter months, and with anticyclonic flow of warm moist air from the Gulf of Mexico during the spring and summer seasons (Sridhar et al. 2006). Data on modern wind patterns for Norfolk, NE, the nearest long-term weather station, indicate that the Stanton dune field receives north—northwest winds from midfall through winter and southerly winds in spring through summer, with an average annual southerly wind (NCDC-NOAA 1998). Modern winds in the Sandhills are primarily controlled by passing frontal systems (Wilhite and Hubbard 1998) and generally flow from the north or northwest in the winter, and from the south or southeast in spring and summer (Sridhar et al. 2006), with an average annual northwest wind (NCDC-NOAA 1998).

MATERIALS AND METHODS

To characterize the stratigraphy and to subsample sediments for particle size analysis and OSL dating at each site, a truck-mounted Giddings probe was used to collect sediment core samples in plastic liners 7.6 cm in diameter and 1.25 m long. This coring method results in the occasional loss of sediment from the bottom of the core barrel, and those portions that were not recovered intact are labeled as "not retained" in the core stratigraphy shown in Figure 4. Thirteen sites, located in four distinct dune areas, were sampled (Fig. 2B). At least two high (5–10 m) dune crests were chosen for sampling in each of the four areas, as well as one interdune location in each area (Stanton 4, 7, 9, and 12) to develop a better overall chronology and to determine the magnitude of activation in the area. We avoided sampling exposures in blowouts, as they would likely contribute only data on localized erosion. Sediments from the cores were described following standard pedologic and geologic nomenclature (Schoeneberger et al. 2002; USDA-NRCS 2003).

For particle size analysis, 160 samples were taken at 30 cm intervals in each core, and samples were taken from soil lamellae-like formations that were present in several cores. The results of particle size analysis were primarily used to identify any significant changes within stratigraphic units and to determine whether significant changes in clay content existed between the lamellae-like features and their surrounding sediment. Samples were pretreated with sodium hexametaphosphate (NaHMP), a dispersant, then subjected to 1 minute of sonication and analyzed on a Malvern Mastersizer 2000E.

For OSL dating, 36 samples were collected in the field from the sediment cores; 24 samples were processed and analyzed and the remaining samples were archived.

TABLE 1.
EQUIVALENT DOSE, DOSE RATE DATA, AND OSL AGE ESTIMATES FOR STANTON CORES

Field #	UNL Lab #	Depth (m)	U (ppm)	Th (ppm)	K2O (wt %)	In Situ H20 (%)a	Dose Rate (Gy/ka)	De (Gy) ± 1 Std. Err.	Aliquots (n)b	Sediment Type	OSL Age ± 1 σ
Stanton 1-1	UNL-2729	1.3	0.9	5.2	1.9	4.8	2.15 ± 0.14	1.0 ± 0.1	27/48	Eolian Sand	470 ± 40
Stanton 1-3	UNL-2731	5.1	0.8	4.1	1.9	4.0	1.99 ± 0.13	1.0 ± 0.1	30/48	Eolian Sand	480 ± 40
Stanton 2-1	UNL-2732	6.6	0.8	3.8	1.9	21.2	1.63 ± 0.29	16.1 ± 1.9	27/48	Eolian Sand	9,800 ± 1,800
Stanton 2-2	UNL-2733	1.4	1.0	3.1	1.9	4.8	2.03 ± 0.14	0.1 ± 0.1	15/48	Eolian Sand	50 ± 10
Stanton 3-1	UNL-2735	7.2	0.9	4.3	2.0	4.9	2.05 ± 0.14	9.4 ± 0.4	30/48	Eolian Sand	4,600 ± 380
Stanton 3-2	UNL-2736	1.2	0.8	3.1	1.8	3.6	1.94 ± 0.12	0.9 ± 0.2	29/48	Eolian Sand	480 ± 50
Stanton 4-1	UNL-2737	1.3	0.8	3.8	1.9	9.0	1.96 ± 0.17	1.6 ± 0.7	26/48	Eolian Sand	820 ± 150
Stanton 4-3	UNL-2739	4.8	1.1	5.0	1.9	17.4	1.89 ± 0.27	37.3 ± 3.6	23/24	Alluvium	19,700 ± 3,000
Stanton 5-1	UNL-2743	1.3	0.6	3.4	1.8	4.1	1.99 ± 0.12	0.8 ± 0.1	42/54	Eolian Sand	410 ± 30
Stanton 5-3	UNL-2745	6.8	0.8	3.8	1.8	5.4	1.89 ± 0.14	8.6 ± 0.5	22/24	Eolian Sand	4,500 ± 390
Stanton 6-1	UNL-2746	1.4	0.7	3.9	1.8	4.5	1.98 ± 0.13	0.9 ± 0.1	31/48	Eolian Sand	470 ± 40
Stanton 6-3	UNL-2748	4.7	0.7	5.2	1.8	5.6	1.93 ± 0.14	7.3 ± 0.4	40/48	Eolian Sand	3,800 ± 320
Stanton 7-1	UNL-2749	1.3	1.0	4.7	1.9	7.0	2.08 ± 0.16	2.0 ± 0.5	40/48	Eolian Sand	960 ± 110
Stanton 7-2	UNL-2750	3.2	1.1	5.2	2.0	15.9	1.96 ± 0.26	35.9 ± 3.2	37/48	Alluvium	18,300 ± 2,500
Stanton 8-1	UNL-2751	1.4	0.9	4.8	1.8	7.6	2.02 ± 0.16	9.0 ± 0.7	23/24	Eolian Sand	4,400 ± 410
Stanton 8-3	UNL-2753	4.2	1.1	3.6	1.9	4.0	2.09 ± 0.14	34.7 ± 2.1	23/24	Alluvium	16,600 ± 1,300
Stanton 9-1	UNL-3048	1.3	1.2	4.7	2.0	9.6	2.16 ± 0.19	35.5 ± 2.3	23/24	Alluvium	16,400 ± 1,700
Stanton 9-2	UNL-3049	3.0	1.2	5.4	1.8	23.6	1.75 ± 0.32	41.6 ± 5.0	22/24	Alluvium	23,700 ± 4,400
Stanton 10-1	UNL-3051	1.3	1.0	4.2	2.0	9.5	2.07 ± 0.19	9.6 ± 0.8	23/24	Eolian Sand	4,600 ± 480
Stanton 11-1	UNL-3054	1.3	0.9	4.6	1.8	2.8	2.10 ± 0.12	1.1 ± 0.1	24/24	Eolian Sand	510 ± 40
Stanton 11-2	UNL-3055	3.6	1.1	4.9	1.9	12.8	1.96 ± 0.22	11.3 ± 2.1	23/24	Eolian Sand	5,800 ± 800
Stanton 12-1	UNL-3057	1.2	0.8	4.5	1.8	10.5	1.91 ± 0.18	30.3 ± 3.1	23/24	Eolian Sand	15,800 ± 1,700
Stanton 13-1	UNL-3059	1.4	0.8	3.5	1.9	3.1	2.06 ± 0.13	0.2 ± 0.2	23/31	Eolian Sand	120 ± 50
Stanton 13-3	UNL-3061	6.3	0.9	3.8	1.9	12.0	1.83 ± 0.20	1.2 ± 0.3	24/31	Eolian Sand	630 ± 90

a Dose rate estimate assumes ± 100% variability in measured moisture values.
b Accepted disks/all disks.

Samples were taken at depths of 1.3 m or greater below the ground surface to avoid potential problems related to mixing and bioturbation of surface materials. Pretreatment and data reduction methods followed those of Hanson et al. (2009, 2010). To determine the equivalent dose (D_e) for each sample, the single aliquot regenerative-dose method (Murray and Wintle 2000) was performed on the 90–150 µm quartz grain fractions. A preheat and cutheat temperature of 220°C was chosen, based on the results of a preheat plateau test (Wintle and Murray 2006), and were used in the analyses of all samples on Risø model DA 15 and DA 20 TL/OSL readers. Concentrations of K, U, and Th for the environmental dose rate estimations were determined by inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma atomic emission spectroscopy (ICP-AES) (Table 1). Equations from Prescott and

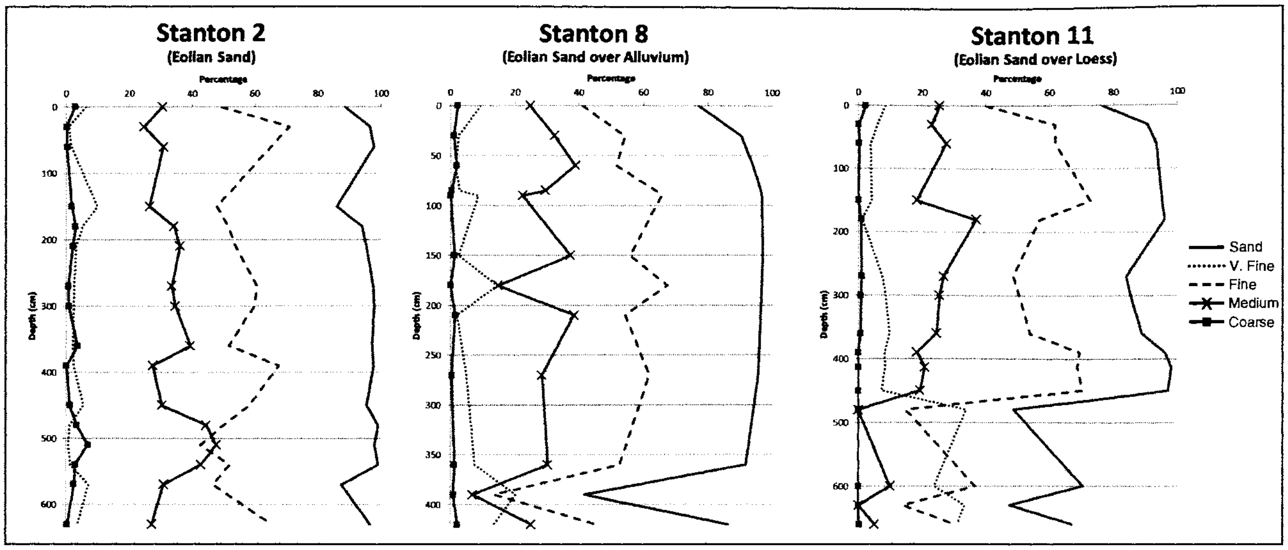

Figure 5. Particle size distribution plots depicting changes in sand-size particles and overall sand content in the three different types of sediment cores from the Stanton Dunes study area.

Hutton (1994) were used to estimate cosmogenic dose rate contribution. Final D_e values were calculated using the central age model of Galbraith et al. (1999), a commonly used calculation method in OSL dating. All OSL ages are presented in calendar years before 2010.

RESULTS

Dune Stratigraphy

Alluvial sediments, loess, and eolian sands were distinguished from one another by sediment texture and, where present, sedimentary structures (see core stratigraphy in Fig. 4). The alluvial sediments were distinguishable from the eolian sands primarily from the dramatic increases in silt and clay content (Figs. 3A, 5).

Loess, which was present only in the lower 2 m of the Stanton 11 core, had an overall very fine sandy loam texture (Fig. 5) with massive to moderate subangular blocky structure. The loess contained soil redoximorphic features that were found throughout the loess portion of the core. Eolian sands were composed of fine to medium sand (Fig. 5), exhibited single grain structure, and often contained soil lamellae-like features (Fig. 3A). Soil lamellae commonly occur in Quaternary sands and are thin bands characterized by an increase of silicate clay and iron (Rawling 2000). Lamellae-like features were present in eolian sand from 11 of the 13 cores taken from the Stanton dune area, occurring at depths ranging from 0.4 m to 7.0 m below the ground surface (Fig. 4).

Particle size analysis showed that clay contents were ~1% greater in the lamellae relative to the surrounding eolian sand. Lamellae thickness varied from 0.1 cm to 2 cm, and often had colors that were lighter or redder than the surrounding eolian sand, ranging from faint light yellow (2.5Y 7/3) to dark grayish brown (2.5Y 4/2) (Fig. 3A).

Geochemical Analysis

A comparison of rubidium (ppm Rb) and potassium (% K_2O) levels (Fig. 6) from the OSL samples showed no meaningful difference between eolian dune sand and the underlying alluvial sands in the Stanton Dunes based on these two elements. When compared to similar geochemical data published in previous studies (Muhs et al. 1997; Hanson et al. 2009), the geochemical properties of the Stanton Dunes are very similar to sediments from streams that drain the Nebraska Sandhills and are similar to the eolian sand in the Nebraska Sandhills.

OSL Age Chronology

For the dune sands and underlying alluvial sediments from the Stanton Dunes, a total of 24 OSL ages were generated (Table 1). For samples taken from the alluvium underlying the dunes, a total of five age estimates ranged from 23,700 ± 4,400 to 16,400 ± 1,700 years ago. Nineteen OSL age estimates taken from eolian sand ranged from ~15,800 years ago to the historical era. The majority of the OSL ages from the eolian sands (15 of 19) fall into three groups: 5,800–3,800, 960–630, and 510–410 years

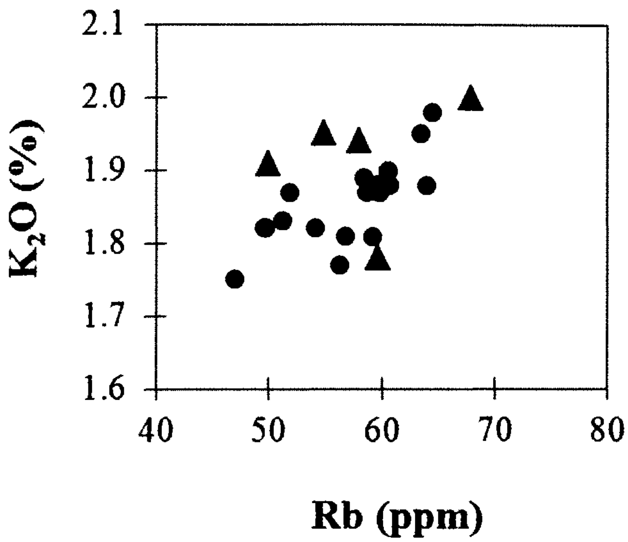

Figure 6. K_2O (%) versus Rb (ppm) values for eolian (circles) and alluvial (triangles) sediments from the Stanton Dunes in Nebraska.

ago. Two OSL ages were older than these age estimates, with one suggesting eolian deposition at 15,800 ± 1,700 years ago and the other indicating deposition at 9,800 ± 1,800 years ago. Both of the two remaining eolian OSL ages were taken from depths of 1.4 m below the present ground surface and indicated that deposition occurred at 120 ± 50 and 50 ± 10 years ago.

DISCUSSION

Lamellae Formation and Development

The lamellae-like features identified in most of the sediment cores from the study area occur in various thicknesses and amounts across the entire range of elevations sampled, in eolian and alluvial parent materials, and in sediments that were deposited from ~16,000 years ago to historical-age sediments based on our OSL ages. The colors and thicknesses of these features make them visually distinct in these sediments (see Fig. 3A); however, the lack of significant clay accumulation (only 1% maximum increase compared to the surrounding sediment) would not qualify these features as lamellae following *Keys to Soil Taxonomy* (USDA-NRCS 2003).

Previous studies have designated lamellae with horizon designations such as E/Bt (Schaetzl 1992) or as Bt&C or C&Bt (Holliday and Rawling 2006). In both of these cases there were significant increases in the clay contents relative to the surrounding sand, which adequately justified these horizon designations. The minor change in clay contents between the lamellae-like features and the sediment in which they were identified in the Stanton Dunes led us to describe soil horizons containing lamellae with more basic horizon designations (i.e., A, Ab, AC, CA, C) and simply noting the lamellae in the description.

Soil lamellae, or thin subsoil layers containing more clay than the layers above and below them, are common in some sandy soils and sediment of humid temperate regions. These features are particularly common in eolian sand, and are of interest because they are thought to have formed from several methods. Most workers attribute their formation to one of the following: (1) pedogenic processes where clay is mobilized from the upper portions of the soil and accumulates in the subsoil due to clay illuviation; (2) petrogenic processes where the higher clay content results from the deposition of the sediments and has not been mobilized by soil processes; and (3) pedo-petrogenic where clay accumulates from illuviation along bedding or sedimentary structures (Dijkerman et al. 1967; Rawling 2000). Holliday and Rawling (2006) note that in areas with abundant sources of aerosolic dust, such as loess and floodplain alluvium, the dust is deposited on the land surface and then translocated through the soil via water, thus making that dust the likely source of the clay comprising the lamellae.

The loess-capped uplands and alluvial sediments from the Elkhorn River could provide the Stanton dune field with two sources of aerosolic dust that would move through the sandy eolian soils via water to produce these features. However, without further investigation of these lamellae-like features, we cannot determine precisely how they formed.

Alluvial Sediments

Alluvial sediments were present in the lower portions of four of the 13 sediment cores taken from the Stanton Dunes, and OSL ages were collected from alluvium both near the ground surface and at depth (Fig. 4; Table 1). OSL dating is ideally suited to eolian sediments, as sand grains are adequately exposed to sunlight when transported by the wind, and in most cases the OSL signals are reset prior to burial. However, in many alluvial environments, sunlight exposure can be inadequate, leaving remnant OSL signals in deposited grains (Olley et al. 1998). This phenomena is called "partial bleaching" and can result in age estimates that are too old for some alluvial sediments. While this can be problematic in some areas, OSL dating of alluvial sediments was successful in the study of Platte

River sediments underlying the Duncan Dunes (Hanson et al. 2009) and near the town of Grand Island, NE (Horn et al. unpublished data).

With dating procedures and protocols similar between this study and those previously mentioned, and with minimal evidence for partial bleaching of the sediments, confidence in the validity of the alluvial ages from the Stanton Dunes is high. The OSL age estimates from these five alluvial samples range from 23,700 ± 4,400 to 16,400 ± 1,700 years ago. Overall, these ages suggest the alluvial fill within the terrace mantled by dunes was deposited during the last ice age, and during the deposition of Peoria loess in Nebraska (Mason 2001).

Dune Chronology

Of the OSL age estimates from eolian sediments, most (17 of 19) indicate dune movement in the last ~6,000 years (Fig. 4). With the exception of three relatively low-lying sites (Stanton 8, 9, and 10) and Stanton 12, each of the surface sediment samples indicates that the Stanton Dunes were active within the past 1,000 years. Cores from the interdune areas (Stanton 4, 7, 9, and 12) contained several alluvial OSL ages at maximum depth, and a few eolian OSL ages near the surface that were all older than 820 ± 150 years old. The remaining seven OSL age estimates from the eolian sediments indicate much older activation periods. Seven of these ages range from 5,800 to 3,800 years ago, and two age estimates indicate eolian activity occurred around 9,800 and 15,800 years ago. We attribute the two historic age eolian deposits to local blowout activity that is commonly found in dune areas of the Great Plains.

Regional Dune Comparisons and Climatic Implications

A comparison between the Stanton Dunes and the Nebraska Sandhills and other regional dune field records in the Great Plains shows important similarities, as well as some distinct differences (Figs. 7 and 8). The oldest eolian age from the Stanton Dunes, at 15,800 years ago, was deposited during the Late Pleistocene, also during the deposition of Peoria loess in Nebraska, and corresponds to many eolian sand ages from this period recently found deep in large dune structures in the Nebraska Sandhills (Mason et al. 2011).

Dune studies conducted in the Nebraska Sandhills indicate that there were four significant and distinct periods of dune activation in the past 10,000 years, including a period of continuous drought and eolian activity from 9,600 to 6,500 years ago, as well as later, shorter-lived events centered around 3,800, 2,500, and 700 years ago (Goble et al. 2004; Mason et al. 2004; Miao et al. 2007). Two early to middle Holocene dune ages from the Stanton Dunes, at 9,800 and 5,800 years ago, fall within 1σ error of the earliest Holocene activation period in the Nebraska Sandhills, from 9,600 to 6,500 years ago, though similar ages were not found in the nearby Duncan or Abilene Dunes (Fig. 7).

Three dune ages from the Stanton Dunes that range from 4,600 to 4,500 years ago overlap with a single 4,980-year age for eolian sand from the Duncan Dunes (Hanson et al. 2009). These ages fall within a notable gap in dune activation between 6,500 and 4,000 years ago in the Nebraska Sandhills (Miao et al. 2007). While localized blowouts could explain these ages of eolian activity in the Stanton Dunes during a known period of dune stability in the Sandhills, it is possible that these ages reflect the limited preservation of a larger-scale dune activation event present in the Stanton Dunes. This interpretation is based on the fact that these ages occur within five of the 13 sediment cores found throughout the Stanton Dunes. Because this hypothesis is based on a limited number of ages, additional data are needed to further explore its validity.

Two dune ages, from 4,400 to 3,400 years ago, correlate to several similar ages from the Duncan Dunes at approximately 4,400 to 3,400 years ago (Hanson et al. 2009) and fall within 1σ error of the Nebraska Sandhills activation period centered around 3,800 years ago (Miao et al. 2007) (Fig. 7). These ages further support the significance of a drought event dating to this time period as indicated from records of the Nebraska Sandhills. The next major drought event recorded in the Nebraska Sandhills occurred around 2,500 years ago (Miao et al., 2007), but the only dune record that contains evidence for this drought in the eastern Plains dunes is from the Hutchinson Dunes in Kansas (Halfen et al. 2012). This could be the result of an extensive and widespread drought and dune activation event that is not well preserved in the other three eastern dune fields of the Great Plains, or is merely due to sampling biases in these dune fields.

Our two youngest clusters of eolian ages (Fig. 8) include nine age estimates that indicate dune activity occurred between 960-630 and 510-410 years ago. The ages in the older of these two clusters closely overlaps dune activity identified from other dune fields in the Great Plains, including the Nebraska Sandhills, Duncan Dunes, Abilene Dunes, and Hutchinson Dunes (Figs. 7 and 8). These ages overlap the so-called Medieval Warm Period or Medieval Climatic Anomaly, when droughts were like-

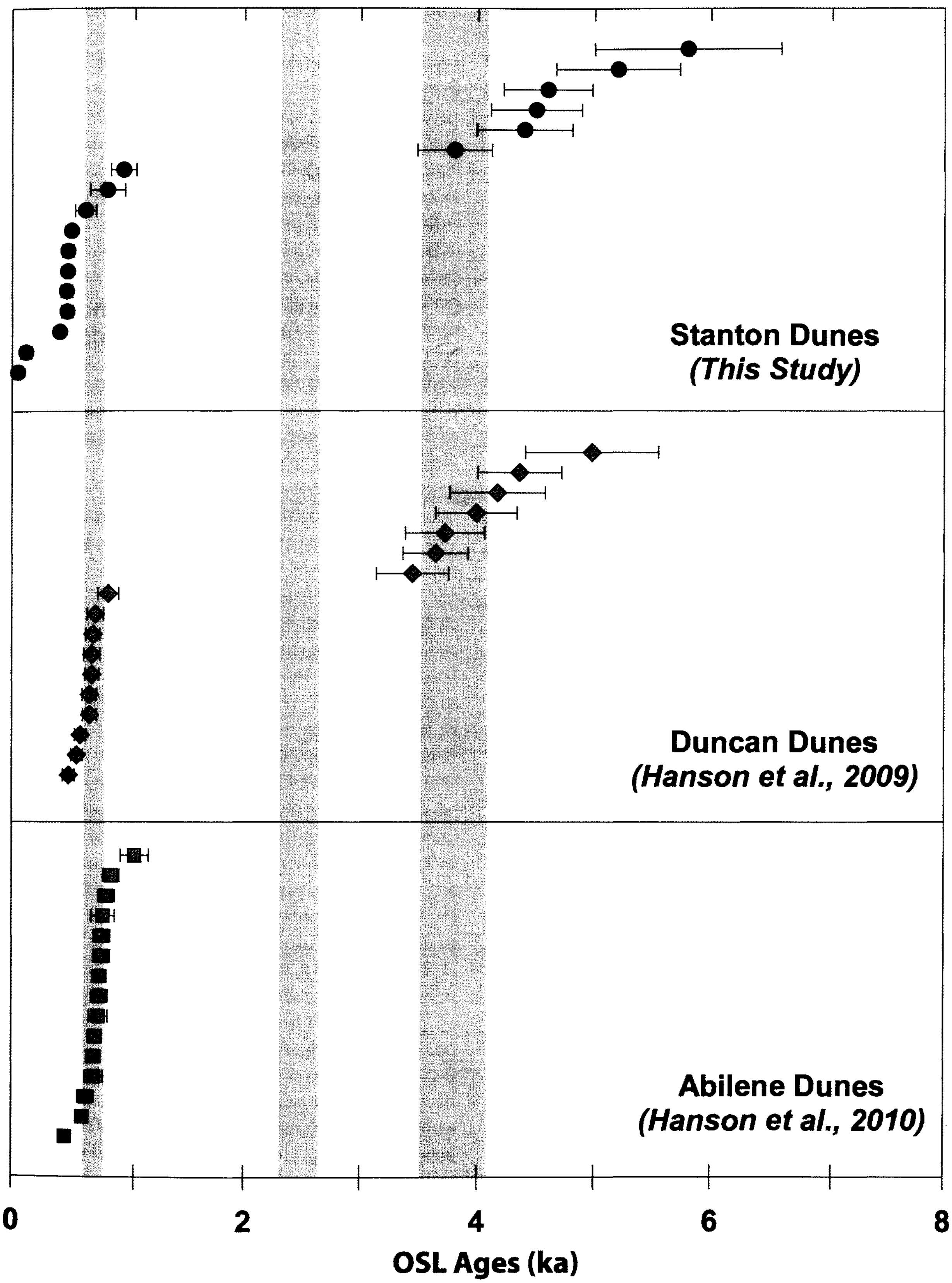

Figure 7. Plots of OSL age estimates with 1σ error from three eastern-lying dune fields in the Great Plains, including data from this study. Gray bars represent megadroughts identified in the Nebraska Sandhills (Miao et al., 2007).

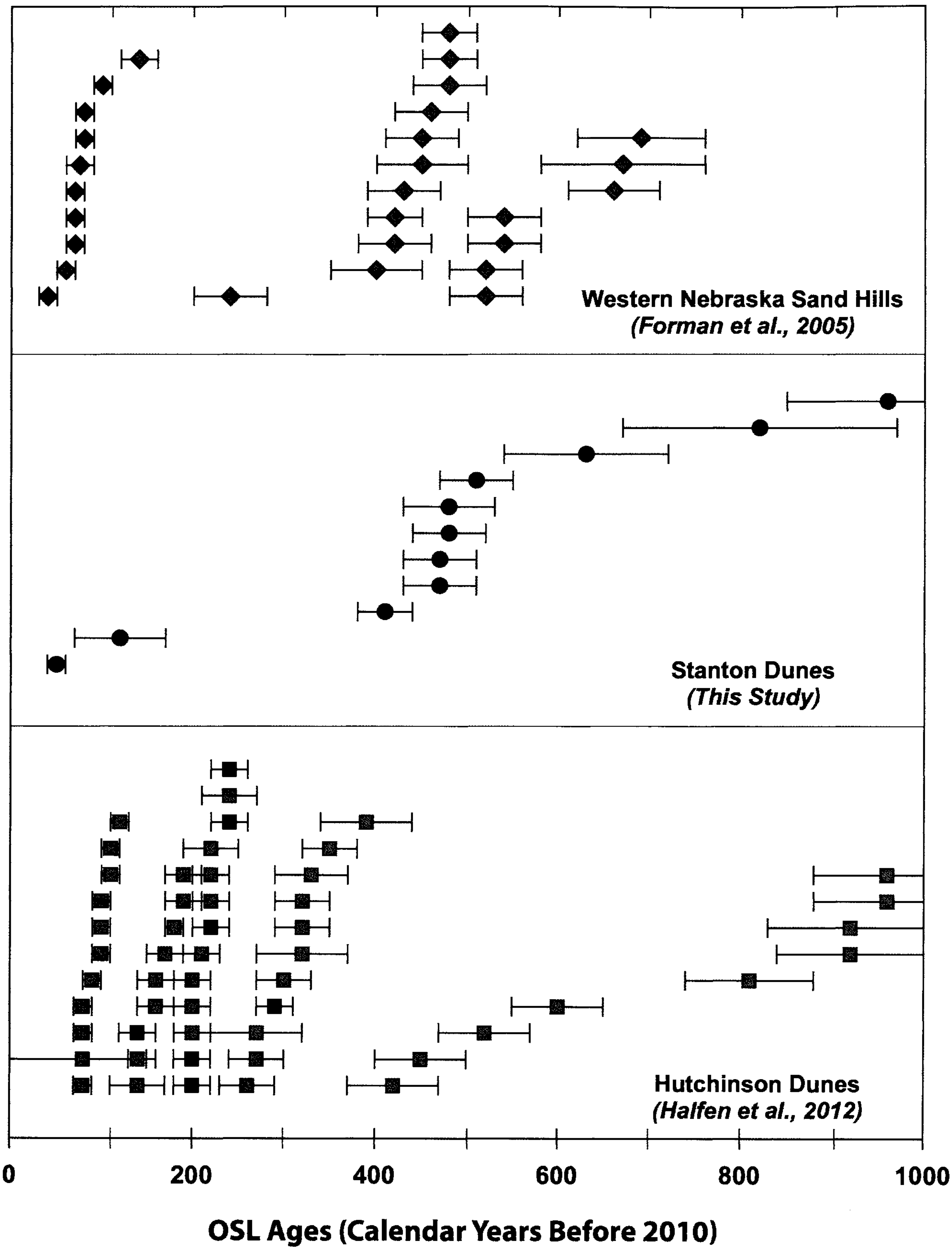

Figure 8. Plots of OSL age estimates with 1σ error during the last 1,000 years from three dune fields in the Great Plains, including data from this study.

ly present throughout much of the western United States (Cook et al. 2004).

Six ages from the Stanton Dunes indicate significant sand movement occurred between ~510 and 410 years ago. The upper portion of five of our 13 core sites contained sand that dated to this time period; at the Stanton 1 core site up to 4 m of eolian sand was deposited during this interval (Fig. 4). Interestingly, these ages do not overlap with Miao et al.'s (2007) drought events recorded in the Nebraska Sandhills, which suggests the last large drought event ended by ~600 years ago. Other studies have also shown that the last activation period for dune movement in the Nebraska Sandhills occurred prior to 650 years ago (Goble et al. 2004; Mason et al., 2004). This apparent discrepancy could be explained by one of three possible causes.

First, these six ages from the Stanton Dunes could be younger than their "true" depositional age due to problems with the OSL dating, such as inaccurately measuring moisture content and/or the concentrations of K, U, and Th for the dose rate estimate. This is probably not likely to be a significant problem, as our dose rate values are very consistent in the Stanton Dunes, yet our OSL age estimates range from ~24,000 to the modern era (Table 1). The second possible explanation suggests that the OSL ages are accurate, and that these young dunes formed from an increase in sediment supply from the Elkhorn River rather than from a drought-related reduction in vegetation cover on the dunes. In this scenario, north—northwest winds may have blown sediment from the Elkhorn River floodplain onto the adjacent land surface to the south of the river between ~510 and 410 years ago. If valid, we would expect that these dunes would be concentrated along the Elkhorn River, in areas near or adjacent to the floodplain. However, dune ages that date to this time period are scattered throughout the dune field (Fig. 2B). In fact, these six young ages were found at Stanton 1, 3, 5, 6, and 11 study sites and not exclusively in the area closest to the Elkhorn River (Stanton 8, 9 and 10; Fig. 2B).

The third explanation for the young set of ages, and the one that we prefer, is that regional droughts impacted areas differentially in the central Great Plains in the past ~500 years. This hypothesis suggests that dune activity identified between ~510 and 410 years ago in the Stanton Dunes resulted from drought conditions that directly impacted sediment availability to wind erosion. This would most likely have been facilitated by a reduction in vegetation cover on the eolian sand that was mobilized during previous drought events. While these ages may not correspond to most dune records from the Nebraska Sandhills, several studies have shown eolian activity and drought conditions existed in Kansas and Nebraska during this time period (see Fig. 8).

Forman et al. (2005) showed sand movement occurred in the western Nebraska Sandhills from ~500 to 400 years ago. Similarly, several ages from the Hutchinson Dunes in central Kansas suggest dune activation at this time period (Halfen et al. 2012). In addition, a recent study of diatoms in the lacustrine records of five shallow interdunal lakes of the Nebraska Sandhills noted a shift in the diatom community structure around this time, which suggests a period of drought conditions and low lake levels (Schmieder et al. 2011). These records show that this may have been a period of smaller scale or locally important drought events that impacted different areas of the central Great Plains to different degrees. The Stanton dune record suggests that this drought period had a significant impact in the Stanton, NE, area at this time.

CONCLUSIONS

Our OSL chronology shows that the sediment found in the alluvial terrace that underlies the dunes was deposited between 23,700 and 16,400 years ago. The dune activation history of the Stanton Dunes was determined based on 19 OSL age estimates, with fifteen of these ages clustered into the following time periods: ~5,800–3,800, 960–630, and 510–410 years ago. Additional ages indicate dune movement at ~15,800 and 9,800 years ago, as well as during the historic period at ~120 and 50 years ago. Ages from our two oldest clusters correspond to dune activation events identified from other dune fields in the central Great Plains including the Nebraska Sandhills. However, the Stanton dune activation event that dates to 510–410 years ago does not correspond to dune records from the Nebraska Sandhills, indicating that drought events at this time may have been locally, rather than regionally, important.

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