Spring 2000

Thinking Like a Dune Field: Geologic History in the Nebraska Sand Hills

David B. Loope
University of Nebraska - Lincoln, dloope1@unl.edu

James Swinehart
University of Nebraska - Lincoln, jswinehart1@unl.edu

Follow this and additional works at: http://digitalcommons.unl.edu/greatplainsresearch
Part of the Other International and Area Studies Commons


This Article is brought to you for free and open access by the Great Plains Studies, Center for at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Great Plains Research: A Journal of Natural and Social Sciences by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.
THINKING LIKE A DUNE FIELD: GEOLOGIC HISTORY IN THE NEBRASKA SAND HILLS

David B. Loope

Department of Geosciences
University of Nebraska
Lincoln, NE 68588-0340
dloopel@unl.edu

and

James B. Swinehart

Conservation & Survey Division and Department of Geosciences
University of Nebraska
Lincoln, NE 68588-0517
jswinehart1@unl.edu

ABSTRACT—The Nebraska Sand Hills region is a giant dune field that is presently stabilized by prairie vegetation. During numerous severe droughts within the last 15,000 years, the dunes have lost their plant cover and have migrated freely. Wetlands between dunes are extensive in the central Sand Hills and are connected to the High Plains (Ogallala) aquifer. Lakes and wetlands were formed when dunes blocked and deranged stream systems. Evaporation of water from wetlands may benefit adjacent dune vegetation during extended droughts, by locally increasing humidity and rainfall. Buried bison tracks are abundant within the dunes, suggesting that grass and water remained available in some interdunes, even during episodes of dune migration. Study of the geologic processes operating within this dune field enhances not only our ability to read the paleoclimatic history of the Great Plains, but also our understanding of features found within similar deposits from the rock record.

Introduction

In Sand County Almanac, Aldo Leopold, one of America’s foremost ecologists and conservationists, wrote lyrically of the interplay between Earth and life. In the chapter entitled “Thinking Like a Mountain,” we learn that Escudilla Mountain has “reason to worry.” Due to the extirpation of
New Mexico’s native wolf population, deer are ravaging the vegetation on Escudilla’s slopes, speeding erosion and accelerating the mountain’s ultimate demise. Similarly for the sand dunes in Nebraska, the issue is grass cover. To form and remain active, a dune field needs wind, and sand that is accessible to that wind. These dunes are presently fettered, their migration halted by a thin veneer of prairie grasses. Even as the winds shriek over the landscape, the short thicket of stems renders the underlying sand immobile.

So, the Nebraska Sand Hills (Fig. 1) are a sobering example of climate change. Giant dunes, in form resembling those found in the hyperarid parts of southern California and the Middle East, are now covered with vegetation, which in some years make it more resemble Ireland. Extensive wetlands and numerous lakes lie in the corridors between the dunes. Yet, aptly...
Thinking Like a Dune Field

dubbed a "Desert in Disguise" (Sletto 1997), the Sand Hills lost their grass cover and became fully active several times within the last 15,000 years. Like the Sand Hills, the Gobi of central Asia is situated at high latitude in the core of a large continent. However, it has remained arid for millions of years because mountains prevent the entry of moist air masses from the Indian and Pacific Oceans. The Sand Hills region, under the present climatic and tectonic regime, is bathed by moist air masses that arrive each summer, moving unimpeded all the way from the Gulf of Mexico.

The Great Plains today is one of the major crop-producing areas of the world. Much of the agricultural production west of the 97th meridian is dependent on irrigation from the High Plains (Ogallala) aquifer. The Sand Hills are a major recharge area for the sands and gravels that comprise the aquifer, and about 65% of the total water in storage is in Nebraska (Weeks and Gutentag 1988). The geologic histories of the Sand Hills dunes and of the Ogallala aquifer are intertwined: both have responded dramatically to drought episodes. Blockage of streams by dunes has caused the level of the aquifer to rise 25 m in at least one part of the dune field (Loope et al. 1995). And, water vapor evaporated from interdune wetlands may help to keep the dunes grass-covered and stable.

One motivation for geological research in the Sand Hills region is simply to document the range of climatic fluctuations recorded in the sediments. The record is mainly preserved in buried soils that are exposed in blowouts and in the peat and lake sediments accumulating between the dunes. There is clear evidence of numerous severe droughts that lasted at least several decades and, unlike the Dust Bowl drought, led to full mobilization of the sand sea (Ahlbrandt et al. 1983; Loope et al. 1995). The last such "mega-drought" ended about 1,000 years ago (Ponte 1995). It seems clear that future droughts of similar magnitude would have a devastating effect on non-irrigated, dryland agriculture and would seriously deplete the aquifer.

The Atlas of the Sand Hills (Bleed and Flowerday 1990) provides excellent summaries of many aspects of the Sand Hills region. The purpose of this paper is to review some of the recent research carried out in the Sand Hills, and to show how such studies can aid in the geologic interpretation of ancient strata.

Dating the Dunes and the Dune Field

The Sand Hills were long viewed as a Pleistocene (Ice Age) feature (Smith 1965). A paper by Ahlbrandt et al. (1983) that presented abundant
evidence of Holocene dune migration (within the last 10,000 years) stirred much interest within the geosciences community. If the dunes were active in recent times, then the implication is that they could well become active in the near future (Muhs and Holliday 1995). The early evidence was based on radiocarbon dates on organic-rich soils and peat deposits that underlie dune sand. The dated material was produced during wet periods, and the dune sand was clearly younger, but how much younger? Now, there are considerably more radiocarbon dates to support the idea of widespread dune mobility in the Holocene, and an exciting new technique called optically stimulated luminescence (OSL) allows the timing of sand deposition to be dated directly. Optically stimulated luminescence dates from outcrops reported by Stokes and Swinehart (1997) support widespread middle- and late-Holocene activity.

Demonstration that much of the material in the dunes is of Holocene origin is not, however, necessarily an indication that the dune field formed that recently. A sand dune moves like a tank tread. As a dune migrates downwind, older material exposed on the upwind side is eroded, moved forward, and "recycled" onto the leading edge. Many earlier workers assumed that the dunes of the Sand Hills were the same age as the late Pleistocene “Peoria” loess (dust deposit) that lies south and east of the dunes. They reasoned that finer-grained material moved by the wind in suspension would leave behind the coarser material that was driven by saltation. Although Ahlbrandt et al. (1983) showed that the present generation of dunes overlies the loess, and thus is younger, it does seem likely that a dune field (or fields) was present as the older (Pleistocene) loess was being deposited. Stokes et al. (1999) recently published a series of optically stimulated luminescence dates from core hole samples taken through the back side of two large dunes in the northern Sand Hills. Their dates suggest that, although a remnant of 10-15,000 year-old dune sand exists, as much as 75% of the material in the dunes was deposited more recently during the Holocene. Smaller dunes are likely to have been completely reworked during the last 10,000 years.

Dunes that Block Streams and Make Wetlands

Since the Great Plains occupy the core of the North American continent, rainfall is sparse and highly variable. Air masses moving north from the Gulf of Mexico are today’s main source of moisture; most rainfall events take place from May through July, and are triggered by eastward moving storms (see Bleed and Flowerday 1990). Forman et al. (1995) noted that
long-term droughts on the Plains could result from the weakening or eastward migration of the Bermuda High, the large-scale gyre that currently brings the moist air northward from the Gulf.

Satellite views of Earth show that the surfaces of the continents are dominated by the action of streams. The area occupied by the dunes, wetlands, and lakes of the Sand Hills region is an exception to this generalization. But, before the dune field organized into its present form, it was probably occupied by integrated fluvial drainages. Our work in the western Sand Hills, concentrated near the southern edge of the dune field near the head of Blue Creek in Garden County, has revealed some of the details of how dunes and streams interact during severe droughts (Loope et al. 1995; Mason et al. 1997). Dunes blocked a large stream system, the present Snake Creek and Blue Creek drainages, that flowed southeastward from the vicinity of the Wyoming-Nebraska border to join the North Platte near present-day Lewellen, Nebraska. Blue Creek now flows in a valley cut into Ogallala Group bedrock and, at its head, emerges at the base of a sand dune that fills that valley (Fig. 2). One thousand lakes lie to the north. Crescent Lake, the one nearest the head of Blue Creek, is only 2.5 km away from the springs at the head of Blue Creek, but it is 25 m higher in elevation. Our drilling, coring, and sampling activity have been especially concentrated near the springs at the head of Blue Creek and in the area just east of Alliance, where Snake Creek disappears at the western edge of the Sand Hills. The evidence from this work indicates there were two episodes of stream blockage by dunes, one just prior to 12,000 years and another just prior to 6,000 years ago (Loope et al. 1995; Mason et al. 1997).

We started our work near the head of Blue Creek because the idea that Sand Hills dunes had been actively migrating within the last 10,000 years (Ahlbrandt et al. 1983) had been challenged by Herbert Wright of the University of Minnesota (Wright et al. 1985). Based on their analysis of a 14 meter-long sediment core that they retrieved from the center of Swan Lake, just northwest of Crescent Lake (Fig. 2), Wright et al. (1985) argued that the dunes surrounding the lake had been immobile for the last 10,000 years. Their core contained only peat and lake mud; it was devoid of sand. They interpreted the sediments as a record of a steadily rising regional water table, an indication that the climate had become increasingly wet since 10,000 years ago. They reasoned that if the dunes surrounding the lake had been mobile, sand would have been abundant in the core.

Our data support their view that the water table at Swan Lake has risen more than 14 meters, but we interpret this rise to be the result of local, not regional, changes. Blockage of the through-flowing ancestor of Blue Creek
Figure 2. An aerial view looking northward of the springs flowing from the terminal dune dam at the head of Blue Creek, and Crescent, Blue and Swan Lakes. Photo by Jon Mason.

by dunes would have caused the water table to rise and peat to start accumulating. Our cores (Fig. 3) show that some of the dunes that surround Swan Lake overlie peat and that these dunes were actively migrating during much of the last 10,000 years (Loope et al. 1995; Mason et al. 1997). The wind carries sand by the process of saltation, the grains seldom reach heights more than a meter above the land surface. Sand isn’t present in the center of
the lake basin because vegetation at the lake margin would have trapped the saltating grains.

Near Crescent Lake, it is clear that the area occupied by wetlands has been steadily increasing for the last 12,000 years, and therefore that the elevation of the upper surface of the High Plains aquifer has risen by 25 meters in the same amount of time. We interpret this rise to be the result of
the drastic changes brought to this watershed by dune blockage (Loope et al. 1995). As long as streams were through-flowing, the water table remained low and few lakes or wetlands existed. The dunes that blocked the streams greatly retarded the movement of water toward the Platte River. As the water table rose and wetlands expanded, and as the water table gradient increased within the terminal dune dam, the flow of the springs at the head of Blue Creek was augmented. The elevation of the wetlands behind the dune dam (and, therefore, their area) cannot increase further because spillover to Blue Creek now takes place at the eastern margin of Crescent Lake (Fig. 2).

One of the most obvious examples of wind-blown sand interfering with a stream outside the main body of the Sand Hills is found 5 km north of Henry, adjacent to the Nebraska-Wyoming state line (Fig. 4). A large compound parabolic dune has migrated across, and completely filled, a 2.5 km-long stretch of the 1.5 km wide by 20 m deep Sheep Creek Valley. The Patrick topographic map of 1896 shows Sheep Creek north of the blockage as an ephemeral stream disappearing into the dune sand, while only a dry valley is shown south of the dune dam. The Interstate Canal, built in 1911, crosses Sheep Creek about 10 km to the north. Local residents say that a major canal break in the 1930s diverted a significant amount of water into Sheep Creek for a few weeks. This flow cut a narrow, 7-meter-deep, channel through the dune dam and greatly reduced the area of wetlands, both up-stream and downstream from the dam. We have no dates on the emplacement of this dam, but hypothesize that it occurred within the last few thousand years.

**Peat Accumulation and Wetland-Atmosphere Feedbacks**

Wetlands are also widespread in the northern Sand Hills, especially in Cherry County (see Bleed and Flowerday 1990). The interdune valleys yield abundant hay that ranchers use to feed their cattle over the winter months. As every rancher knows, many portions of these interdune areas are accumulating peat so rapidly that the surface will not support the weight of a tractor. At Jumbo Valley in south-central Cherry County (Fig. 5), peat has reached a thickness of about 7 m (Fig. 6). The oldest peat we have sampled yields radiocarbon dates of about 12,500 years, and it contains abundant spruce pollen and spruce needles (Barbara Nicholson, personal communication). We surmise that the water table rise that allowed the preservation of peat was triggered by dune blockage, but we do not yet know whether the spruce trees were restricted to the interdune valleys or if they grew on the dunes as well. Because of the early experimental work of
Figure 4. Topographic map of the Sheep Creek dune dam in the southwestern corner of Sioux County. The heavy dashed lines indicate the approximate boundaries of the buried valley. The circled A points to where Sheep Creek is shown disappearing into dune sand on the 1896 Patrick topographic map. Base map modified from the Torrington SE, WYO-NEBR 1:24,000 scale USGS topographic map.
Charles Bessey that led to the planting and growth of pine forests on dunes near Halsey and southwest of Valentine, we know that the dunes can support trees (Miller 1990). Fire appears to be the environmental factor that currently maintains grassland vegetation (Bragg 1995). Spruce pollen disappears from the peat at about 10,500 years ago, and the wetlands flora has been dominated by sedges since that time (Margaret Bolick, personal communication; Fig. 6). A number of glacial relict species, however, are still found in the wetlands, including cotton grass and marsh marigold (Steinauer et al. 1996) and fish like the northern redbelly dace (Hrabik 1990).

Although the ultimate source of most of the water that falls as rain on the Great Plains is the Gulf of Mexico, there is a strong likelihood that much of the water that comes into the Great Plains will fall from clouds more than once before it finally returns to the sea. The total volume of water returned annually by rivers to the sea (35,000 km³) is only about 30% of the annual
Figure 6. Stratigraphy, radiocarbon ages and preliminary pollen data from VC93-16. Refer to Figure 5 for location in Jumbo Valley. Note that between 6.7 and 5.2 m there is a change from a spruce/grass dominated pollen profile to a grass/pigweed profile. The pollen record was analyzed by M. Bolick of the University of Nebraska State Museum. Figure modified from Ponte (1995).

Precipitation on the continents; the remainder is evaporated directly or is transpired by plants (Price 1996: 15). Both the Great Plains and the Sahel region on the southern edge of the Sahara are subject to especially long-term...
droughts. In these regions, evaporation from the land surface is an important source of atmospheric moisture, if the sources of surface moisture can be depleted, the droughts may be self-reinforcing (Nicholson 1988). In the last 50 years, there has been a tremendous increase in irrigation in the parts of the Great Plains that have access to the High Plains (Ogallala) aquifer (see Bleed and Flowerday 1990). Coinciding with this boom in irrigation is a trend of increasing precipitation in the same areas. For example, a recent study by Moore and Rojstaczer (1999) indicates this represents a cause-and-effect relationship — the increases in precipitation are concentrated in the summer months and are irrigation-induced. Apparently, much of the irrigation water that directly evaporates or is transpired from the corn fields condenses and falls nearby.

Although we are not advocating a “Rain Follows the Center Pivot” campaign, we are intrigued by the possibility that an understanding of how irrigation influences regional rainfall could be used to decipher the paleoclimatic record of the Sand Hills. River systems efficiently channel water that has fallen onto the continents back to the sea. In arid regions, wetlands are widespread only in areas where glaciers or dunes have modified river systems. Wetlands are widespread in western and central Sand Hills (see Bleed and Flowerday 1990). We speculate that the evaporation from the wetlands between the Sand Hills dunes “recycles” water stored in the High Plains aquifer in basically the same way that irrigation does. Thus, as long as there are interdune wetlands to supply abundant water vapor to the atmosphere during the critical summer growth season, the grasses on the adjacent dunes will benefit in two ways: 1) they will not need to transpire as much water; and, 2) they will receive more rainfall. Compared to other kinds of soils, the weakly developed soils on the dune, have very low water-storage capacity (Lewis 1990); the dune grasses would thus seem to be quite vulnerable to drought. Were droughts, such as those experienced in the Dust Bowl years of the 1930s, more severe in Oklahoma and Kansas because that region, unlike the central and northern plains, lacks extensive wetlands to provide a “drought cushion?” Since the wetlands and lakes of the Sand Hills are hydrologically connected to a vast aquifer, drawdown during a long-term drought would have taken place much more slowly than in the northern plains where most surface water is underlain by glacial materials with low permeability.

From the sediment record, we know that the Sand Hills have undergone many episodes of active migration in the last 15,000 years, but how much of a drought is needed to cause the dunes to lose their grass cover and become active? Are all parts of the dune field equally susceptible to activa-
Figure 7. North to South vibracore transect in the Jumbo Valley peatland (refer to Fig. 5 for location) showing the distribution of the upper sand sheet. The radiocarbon ages shown are average ages of two to four samples of sedge seeds recovered from 1 to 2 cm below or above the sand sheet. Each age has an error (one standard deviation) of about ±50 years.
types of dune sites within the Sand Hills: those adjacent to interdune wetlands and those distant from wetlands. Our data from the dune field as a whole support this suggestion. Several radiocarbon and optically stimulated luminescence (OSL) dates from buried soils and dune sands are considerably younger than 1,000 years (Fig. 9).

**Dune and Interdune Paleoecology**

Two lines of evidence suggest that not all interdune wetlands were lost during the drought episodes. The survival of relict plants, like cotton grass,
Late Holocene Eolian and Soil Chronology
Nebraska Sand Hills

Figure 9. Eolian and paleosol stratigraphy versus time for eight locations scattered across the Sand Hills. The thickness of any given section ranges from 3 to 20 m. Blank spaces are estimated intervals of missing sediment either due to erosion or nondeposition. Radiocarbon ages from the Seneca locality are from Muhs et al (1997) and the optical (OSL) ages are from Stokes and Swinehart (1997).
suggest that suitable wetland habitat has been available within the dune field for at least 12,000 years.

Another clue that some wetlands were maintained comes from disturbed layers of sand within the dunes (Fig. 10). When we first saw these features, we thought they might be produced by snow that melted, long after having become interbedded with sand during winter storms. In the Killpecker dune field north of Rock Springs, Wyoming, we know that considerable thicknesses of snow accumulate on the lee faces of sand dunes during the winter (Steidtmann 1973). If the snow is then buried by sand, the snow can persist for months or years. When such snow eventually melts, the overlying layers of sand are distorted. Earthquake shocks are another possibility. They can liquefy dune sand, allowing layers to be folded and broken. For this mechanism to work, however, the sand must be water saturated. Nearly all of the deformed layers we have observed are high within dunes and have never been below the water table. Upon closer observation, the contorted
sand layers in the Nebraska Sand Hills turn out to be of a quite different origin. When the details of their morphology are clearly seen (Fig. 11), the contortions can be recognized as bison tracks in vertical cross-section. The bison walked on the dunes when their lee slopes were covered with wind ripples, a clear indication that the slopes were nearly bare of vegetation. The tracks are sufficiently common throughout the dune field to indicate that the
animals must have had local supplies of food and water, and interdune wetlands seem to be the most likely sources (Loope 1986).

**Rain and Dustfall on the Dunes**

Seeking shelter from winter winds and exposure to the winter sun, ranchers in the northern and central Sand Hills have commonly chosen to place their homes at the bases of steep, south-facing slopes. These slopes are steep and long because they represent the lee (downwind) side of giant dunes that, when mobile, migrate southward primarily under the influence of northerly and northwesterly winds. Their shape and movement are also influenced by rain and vegetation.

Summer cloudbursts in the Sand Hills can deliver several inches of rain in less than an hour. Although common sense and simple laboratory studies, suggest that dune sand could soak up all rainwater that falls on it, the lee slopes of many of the largest dunes in the Sand Hills are deeply gullied; and, alluvial fans have been built at the break in slope (Sweeney 1999; Fig. 12). Sand entrained by heavy runoff can rapidly bury fences or other property (Fig. 13). Recognizing this and the possibility that sand can be rapidly deposited at the edge of a sand dune allowed us to reinterpret the history of some famous dinosaur fossils in Mongolia (see below).
Thinking Like a Dune Field

Figure 13. Truck buried by sand washed from steep lee face of dune during thunderstorm in July of 1991. Dumbbell Ranch, north of Hyannis, NE. Photo by Linda Brown.

Perhaps more importantly, the plants that grow on the Sand Hills keep these stabilized dunes from starting to migrate again. The plants are sustained by summer rainfall. Any water that runs off the dunes, rather than infiltrating the sand, is unavailable for plant growth. Studies carried out along the coast of Holland have shown that runoff from certain parts of dunes after rain events is caused by water repellency of the sand. Organic coatings on the grains appear to give these Dutch dunes their tendency to repel water (Joe Mason, personal communication). Such organic coatings may likewise be responsible for the runoff from the Sand Hills. Using the scanning electron microscope, thin coatings of clay can be observed on sand grains from Sand Hills dunes (Fig. 14). Although this finer material makes up only about 2% of a typical sand sample (Ehrman 1987), its presence greatly enhances the water-holding capacity of the soil, making life on the dunes significantly easier for plants. Also, the ancient bison tracks (Fig. 11), like their modern counterparts made by Sand Hills cattle, are steep sided. Steep-sided tracks are produced in slightly cohesive sand,
sand of a consistency that allows the shaft of the track to stay open rather than slumping inward. The morphology of the ancient tracks indicates that the consistency of modern dune sand is not anomalous; clay-coated grains have been around for thousands of years.

The bridges connecting the coatings of adjacent sand grains show that the fine particles of clay are carried by infiltrating water downward through the pore spaces of sand that lies above the water table. Two different explanations have been proposed to account for the source of the clay. According to the "top-down" hypothesis, the fine material originated as atmospheric dust and was washed directly into the dunes by rainwater (Winspear and Pye 1995). Alternately, according to the "inheritance" hypothesis, the fine particles were carried in suspension by a stream that lost its water (and fine sediment load) to the thirsty sands of its dry channel. In this scenario, wind then carried away the already coated sand grains to form dunes (Wilson 1992; Loope and Dingus 1999). According to the inheritance hypothesis, the bridges connecting the clay coats of adjacent sand grains within the dune are produced when infiltrating rainwater redistributes the fine material that
Thinking Like a Dune Field

is already present. Dust has certainly fallen onto the surface of the Sand Hills. And we know that the source of the sand for the dunes was dryland streams. However, so far, it has proven difficult to determine which process has been more important for the Sand Hills dunes.

Evidence of Former Dune Dams

There are only a few ways to form lakes on the unglaciated portion of the Great Plains, and our experience with the dune dams in the western Sand Hills (above) has led us to interpret several ancient lake deposits in western Nebraska as products of these processes. Of course, when sand dams are still in place (as in Garden County), it is much easier to make a case for dune blockage in lake formation. In 1995, Bruce Bailey of the University of Nebraska State Museum (personal communication) found a thick body of lake sediments containing abundant fish and amphibian fossils, lying within the canyon of the Niobrara River west of Valentine. Detailed investigation of the site indicates that two large lakes occupied the floor of the canyon about 40,000 years ago; the eastern one was possibly 20 km long, and the western one was at least 4 km long (Swinehart et al. 1996). The great thickness of the lake deposits (to 55 m) and their presence near the rim of the canyon seem to preclude the explanation that the stream was blocked by landslides from the canyon walls. Also, large dunes are present on the tableland both north and south of the modern canyon, and at least 30 m of dune sand is present immediately down gradient from the thickest portion of the fill in the western lake.

While mapping the geology of the North Platte River valley in 1977, Robert Diffendal of the Conservation and Survey Division at the University of Nebraska (personal communication) encountered lake deposits lying 70 meters above river level and below a 10,500 year-old soil layer. Based on our discovery of the “living dune dam” in Garden County, we proposed that dunes at the southern margin of the Sand Hills had blocked both the North Platte and South Platte Rivers, forming lakes far up the North Platte valley (Swinehart and Loope 1992). We argued that the large, triangular patch of dunes in Lincoln County south of the rivers; (Figs. 1, 15) was an additional result of the blockage. Of course, unlike Blue Creek and the Niobrara River, the Platte River carries snow melt from the continental divide. Blocking such a major river with dunes would seem to require a huge climate change, but not necessarily. To provide some perspective, in the middle 19th century before dams had been built in its upper watershed, the South Platte was
Figure 15. Landsat image (MSS band 7) of the south-central Nebraska Sand Hills, North and South Platte rivers and the western half of the Lincoln County dune field (see Fig. 1). The landscape is accentuated by snow cover and a low sun angle.

typically dry during July, August, and September from Fort Morgan, Colorado, to its junction with the North Platte River (National Research Council 1992: 140).

Dan Muhs and his colleagues at the U.S. Geological Survey, were originally dune-dam skeptics. However, recently they analyzed the mineralogy and elemental chemistry of the sand from dunes south of the Platte River to see if any of it had come from the Sand Hills. The results indicate that the Sand Hills along with the South Platte River were a major source of that sand (Muhs et al. 2000). These results are consistent with our dune-dam hypothesis. Additional work is needed to further test this hypothesis.
The Sand Hills: a Modern Analog for Ancient Eolian Sandstones

Eolian (wind-blown) sandstones are well-represented in the stratigraphic record. On the Colorado Plateau of the western United States, eolian sandstones comprise a Late Paleozoic through middle Mesozoic (about 300-150 million year old) sequence that is 3500 m-thick (Kocurek 1988). On the upper Great Plains, dune deposits of the Arikaree Formation are 25-30 million years old (Miocene). They can be seen along the summit-to-museum trail at Scotts Bluff National Monument (Swinehart and Loope 1987) and in Bear Creek and Lone Tree canyon, in Goshen County, Wyoming (Bart 1977). Studies of these dunes has led to insights on global climate change and paleogeography.

Tracks. The tracks we have found in the central Sand Hills are no larger than those made by modern bison. However, tracks in the eolian strata exposed near the southern margin of the dunes, and within the Pliocene Broadwater Formation, are considerably larger (Myers 1993; Fig. 16).
These 2-3 million-year-old strata also contain skeletons of proboscideans (elephants and their relatives) (Myers 1993), and we surmise that these animals made the bigger tracks. These older wind-blown sands are un cemented, and they are interbedded with river-deposited sands. So, these deposits may have been an important, immediate source of sand for the present-day Sand Hills. This would be especially likely if, after their deposition, downcutting by streams lowered the water table, leaving these deposits high, dry, and available to the wind.

Dune deposits are also widespread in the Late Cretaceous (75 million year old) Djadokhta Formation of the Gobi Desert in east-central Asia. These sandstones were made famous in the 1920s by field parties from the American Museum of Natural History, led by Roy Chapman Andrews. At Flaming Cliffs in southern Mongolia, they found abundant skeletons and egg-filled nests of a diverse group of dinosaurs and mammals, but no evidence of dinosaur tracks. Most dinosaur tracks are discovered when sedimentary rocks split along bedding planes, revealing a plan view of the features. However, the soft sandstones of the Djadokhta rarely split this way; so, despite the abundance of bones, the tracks of dinosaurs were unknown from the Djadokhta Formation until we observed them in vertical cross-section in cliff exposures of the dune deposits (Loope et al. 1998). The tracks were preserved exactly like the bison tracks within the Sand Hills, with steep sides and individual toeprints. The belated discovery of these tracks proves once again that, like everyone else, scientists see what they are prepared to see.

**Dinosaur Fossils Adjacent to Dunes.** The fabulous fossils in the Gobi Desert were preserved as unscavenged skeletons, suggesting that they were buried rapidly and perhaps buried alive. Since the fossils were found in a formation with abundant dune deposits, the animals were thought to have been overwhelmed and buried by dune sand during violent desert wind-storms. A recent study, however, points out that none of the skeletons at an especially fossiliferous site west of Flaming Cliffs, Ukhaa Tolgod, lie within well-bedded dune sand, as would be expected if the animals had been quickly buried in a wind storm (Loope et al. 1998). Instead, they lie within structureless (unbedded) sandstone laterally adjacent to the slopes of the ancient dunes.

Observations of sand movement on modern dunes indicate that the material accumulates in distinctly layered deposits. Being buried alive by blowing sand means you are unable to outrun a migrating dune. Sandslides, triggered by heavy rainfall events, provide a more likely burial agent
for the Gobi dinosaurs (Loope et al. 1999). In general, a dune field is not a dangerous place to be in a rainstorm. Most of the water infiltrates the permeable sand and, weeks later, it may eventually reach the groundwater table. Devastating mudslides and debris flows, like those that have claimed many human lives recently in Central and South America, are triggered by elevated pore water pressure that develops when the downward infiltration of water through slope material is stopped by underlying bedrock (Campbell 1975). The Gobi Desert dunes of Mongolia developed calcite-cemented soil layers, about 1 m below their steep leeward slopes (Loope et al. 1999). These layers would impede the downward infiltration of rainwater. When the sand above the soil layer became saturated during heavy rainstorms, elevated pore-water pressure could have caused the 1 m-thick deposit of sand to move rapidly downslope, burying anything in its path. Luckily for the ranchers living at the bases of Sand Hills dunes, the Nebraska slopes do not have impermeable soil layers underneath and, apparently, seldom generate lethal landslides.

**Carbon-rich Interdune deposits.** Some of the geologists who have studied the Sand Hills are interested in the origin and location of oil and gas in ancient sedimentary rocks. For example, a large volume of petroleum (hydrocarbons) is trapped within the Tensleep and Jurassic Nugget Sandstones, dune sands deposited in western and central Wyoming, about 300 and 175 million years ago, respectively (e.g., Ahlbrandt and Fryberger 1981). Ahlbrandt and Fryberger point out that the hydrocarbons now trapped in the dune sandstones may have had organic-rich interdune deposits as their source, similar to those now accumulating in the peat-developing valleys of the Nebraska Sand Hills.

It does seem likely that interdune wetlands, like those of the Sand Hills, have been extensive in the geologic past. What would these deposits look like if they were turned to rock and exposed in a cliff face? Typically, sediments rich in organic matter, like coal and shale, retain their dark color even after generating hydrocarbons. But, the typical interdune deposits in the rock record are light-colored or red, suggesting desert-like conditions during deposition. It is also possible, however, that the organic matter generated in environments like those in the Sand Hills wetlands was decomposed before it was buried by advancing dunes leading to lighter-colored rock. Furthermore, along with the organic matter, the peat that accumulates in Sand Hills interdunes contains abundant silt that was transported to the site as dust. What would happen to the interdune deposits if the water table dropped and did not come back up for hundreds of years? It would either
catch fire and burn, like the peat lands in southeast Asia during the El Niño of 1998, or it would be broken down by the combined action of aerobic microbes and burrowing invertebrates like worms. The silt, however, would remain, providing evidence of the burrows that were produced during the “feeding frenzy.” Abundant burrows typically extend downward from the thin red siltstones that are common within some sandstone formations mainly composed of dune deposits (Loope 1985). This evidence suggests that the long-term fate of the Sand Hills peat is to become worm food, rather than to produce oil and gas.

**Vegetation on Ancient Dunes.** Dunes are today generally restricted to deserts and beaches, areas where loose sand is not held in place by vascular plants. Plants are especially effective in preventing dune formation because they increase the surface roughness, greatly reducing the wind’s velocity at the land surface (Pye and Tsoar 1990). Because grasses did not evolve until about 20 million years ago, and land plants in general have only been on the scene since about 400 million years ago, some geologists have speculated that dunes were more widespread earlier in Earth’s history. Before land plants stabilized river banks, streams would have been much more laterally mobile, allowing them to rework deposits of wind-blown sand before they had accumulated into large dunes (Eriksson and Simpson 1998). Although sandstones representing ancient dunes have been recognized in strata as old as 2.1 billion years, they do not represent an especially large part of early sedimentary records (Eriksson and Simpson 1998).

Plants do not fossilize well in most upland habitats. However, some of the best evidence comes from our studies of the ancient dune fields of Asia. The oldest clear evidence of vegetation that grew on uncemented sand dunes comes from southern Mongolia. We found rhizoliths (calcified plant roots) in great abundance within 75-million year-old dune deposits there (Loope and Dingus 1999). Interestingly, the fossilized roots of the dune-dwelling plants lie parallel to the steeply sloping sand layers that accumulated on lee slopes. This growth pattern would efficiently exploit the soil water that is held longer in the finer grained sands than in the adjacent coarser layers. Similar patterns may occur in the Sand Hills.

**Conclusion**

If, like Aldo Leopold’s New Mexican mountain, our dune field has a long memory, what stories could it tell? We know that there have been many episodes of dune activity in the Sand Hills during the Holocene (geologi-
Figure 17. Estimates of intervals and relative intensities of sand dune activity in the Sand Hills during the last 13,000 years.

cally recent times). However, we do not yet have an accurate chronology of these events, and we do not know if different parts of the dune field have been more active than others. Our best estimate of the most significant periods of dune activity is shown in Figure 17. In the future, more optically stimulated luminescence (OSL) dating, which frees researchers from dependence upon carbon-rich deposits for samples, should be very useful. Although geologists typically study young, uncemented sediments to help them to understand older strata, the reverse perspective can also be informative. We have not had the chance yet to see a deep cross-section through a Sand Hills dune, but observations from sandstone cliff faces in Mongolia and Utah can provide some clues. Future work will take advantage of both perspectives.

Acknowledgments

We thank Jon Mason, Mike Ponte, Mark Sweeney, Chuck Markley, Pat Helland, Bob Diffendal, Mark Schroeder, Bruce Bailey, Jim Goeke, Dan Muhs, and Joe Mason for their ideas and their help in the field. Andy Applegarth and Mick Knott of the Gudmundson Sand Hills Laboratory were genial hosts on numerous occasions. Many landowners graciously provided us with access to their land; special thanks go to The Nature Conservancy and The Sand Hills Task Force, Vic and Martha Eldred, Rob Ravenscroft, the Lawrence Hanson family, and Linda Brown. Funding from the National Science Foundation (EAR91-05948, ESH97-09742) and the National Geographic Society is greatly appreciated, as is the support of the
Department of Geosciences and the Conservation and Survey Division at University of Nebraska-Lincoln.

References


