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# Geochemical Evidence for an Eolian Sand Dam across the North and South Platte Rivers in Nebraska

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**Geochemical and geomorphic data from dune fields in southwestern Nebraska provide new evidence that the Nebraska Sand Hills once migrated across the North and South Platte rivers and dammed the largest tributary system to the Missouri River. The Lincoln County and Imperial dune fields, which lie downwind of the South Platte River, have compositions intermediate between the Nebraska Sand Hills (quartz-rich) and northeastern Colorado dunes (K-feldspar-rich). The most likely explanation for the intermediate composition is that the Lincoln County and Imperial dunes are derived in part from the Nebraska Sand Hills and in part from the South Platte River. The only mechanism by which the Nebraska Sand Hills could have migrated this far south is by complete infilling of what were probably perennially dry North Platte and South Platte river valleys. Such a series of events would have required an extended drought, both for activation of eolian sand and decreased discharges in the Platte River system. A nearby major tributary of the North Platte River is postulated to have been blocked by eolian sand about 12,000 $^{14}$C yr B.P. We propose that an eolian sand dam across the Plattes was constructed at about this same time.** © 2000 University of Washington.

*Key Words:* **Great Plains; Nebraska Sand Hills; Colorado sand dunes; geochemistry.**

## INTRODUCTION

Extensive tracts of unconsolidated, stabilized sand dunes and eolian sand sheets are found on the semiarid Great Plains of North America. The area covered by these sands is enormous; the 50,000-km$^2$ Nebraska Sand Hills region is the largest dune field (active or stabilized) in North America (Fig. 1). Interest in the eolian sands of the Great Plains has increased in recent years because of rapidly accumulating evidence that these sediments have been repeatedly active in the Holocene, including the past millennium (Ahlbrandt *et al.*, 1983; Swinehart and Diffendal, 1990; Madole, 1994, 1995; Loope *et al.*, 1995; Holliday, 1995a, 1995b, 1997; Wolfe *et al.*, 1995; Arbogast, 1996; Muhs *et al.*, 1996, 1997a, 1997b; Stokes and Swinehart, 1997) and even historic time (Muhs and Holliday, 1995).

Although several of these studies have concentrated on the Nebraska Sand Hills, less attention has been paid to smaller but still-sizable ($\geq$1000 km$^2$) satellite dune fields south of the Sand Hills. Dune fields that are in proximity to one another need not have similar origins, and dune fields relatively far apart from one another can have similar sources. For example, in northeastern Colorado, Muhs *et al.* (1996) showed that dunes north of the South Platte River were derived at least in part from bedrock residuum sources, whereas dunes immediately to the south were derived from South Platte River sediments. In contrast, eolian sands of the Fort Morgan dune field and the Wray dune field are both derived from South Platte River sediments, despite being separated by an extensive bedrock plateau (Fig. 2).

These observations lead to two hypotheses about the origin of satellite dune fields, such as the Lincoln County and Imperial dune fields, found to the south of the Nebraska Sand Hills (Figs. 1–3). The simplest explanation is that because they lie to the south of a major potential sediment source, the South Platte



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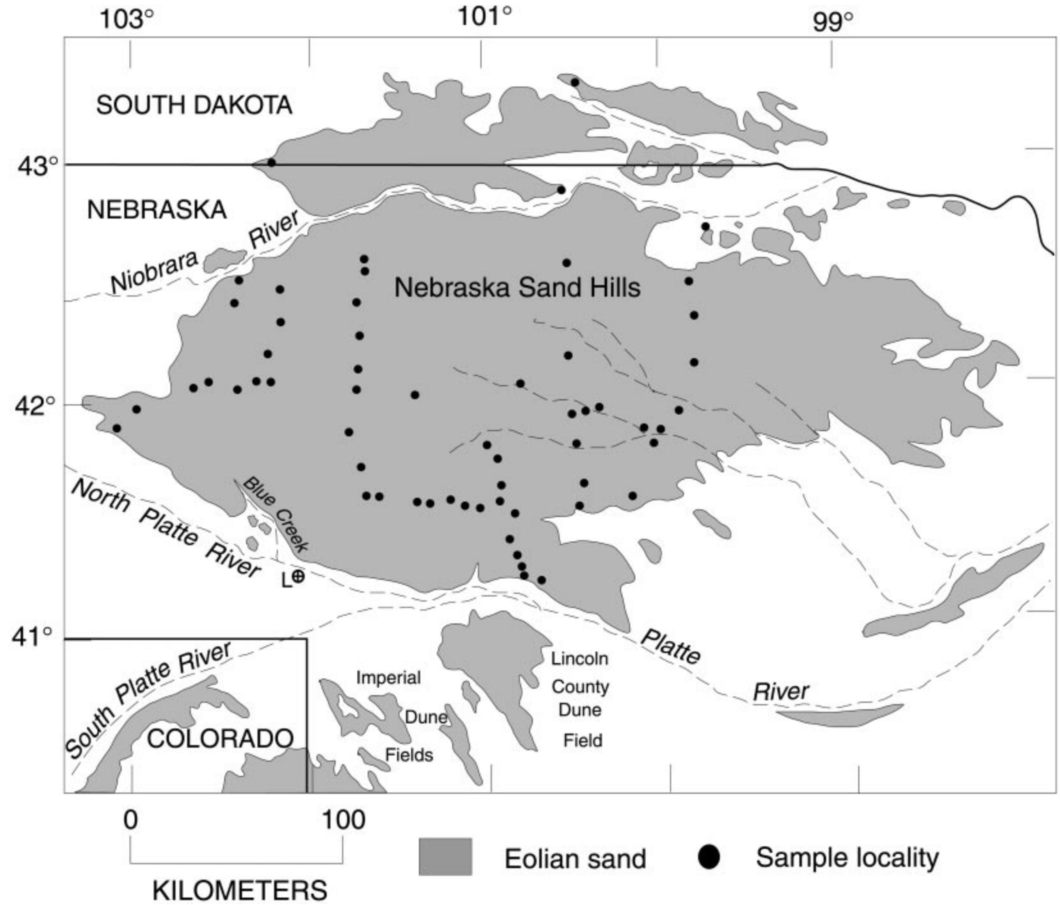


**FIG. 1.** Map showing the distribution of eolian sand in the Nebraska Sand Hills, the Lincoln County and Imperial dune fields, sample localities within the Nebraska Sand Hills, and localities referred to in the text. The crossed circle labeled "L" is a stratigraphic section containing lacustrine sediments shown in Figure 5. Distribution of eolian sand is taken from Swinehart (1990) and Swinehart *et al.* (1994b).

River, these dune fields are derived mainly from this fluvial source, as is the case with other dune fields to the west in Colorado (Muhs *et al.*, 1996). Swinehart and Loope (1992), however, suggested that the Lincoln County dune field is a remnant of a former, larger Nebraska Sand Hills. They hypothesized that eolian sand from the Nebraska Sand Hills may have filled the North and South Platte river valleys when they were dry during the last glacial period (Fig. 4). A giant dune dam would have been created by this eolian sand movement, which in turn would have generated a large lake or series of lakes. Diffendal and Leite (1989) reported widely distributed, diatomaceous lake sediments in tributaries of the North Platte River, and a radiocarbon age of 10,540 $^{14}$C yr B.P. was obtained for a paleosol at the top of a 3-m-thick lacustrine sequence, 45 m above the present floodplain (Fig. 5).

Geomorphologists outside North America have documented infilling of dry washes with eolian sand and building of dune dams across major drainages in Senegal, Mauritania, and Mali (Grove and Warren, 1968), Namibia (Teller and Lancaster, 1986), Botswana, South Africa, and Saudi Arabia (Breed *et al.*, 1979), and Egypt (Haynes, 1980). A spectacular example of this process is the complete infilling and burial of an ancient drainage system by the Selima sand sheet in Egypt and Sudan (McCauley *et al.*, 1982). The presence of the fluvially carved paleolandscape was never suspected until it was imaged by space shuttle astronauts using radar methods.

Despite many examples of dune dams in African and Saudi Arabian sand seas, few geomorphologists have reported evidence of eolian dams or eolian infilling of drainages in North America. It could be argued that the presently perennial rivers of the Great Plains are really not comparable to the mostly ephemeral rivers in Africa cited above, and therefore eolian sand dams ought not to be expected in most of North America. However, prior to human regulation of fluvial systems in the past century, there is good historic evidence that Great Plains rivers were also probably ephemeral (Williams, 1978; Muhs and Holliday, 1995). In addition, there are isolated examples of eolian sand deposition in dry river valleys, such as that which occurred during the mid-Holocene in the Southern High Plains of Texas and New Mexico (Holliday, 1995b). Finally, Loope *et al.* (1995) and Mason *et al.* (1997) documented two periods (latest

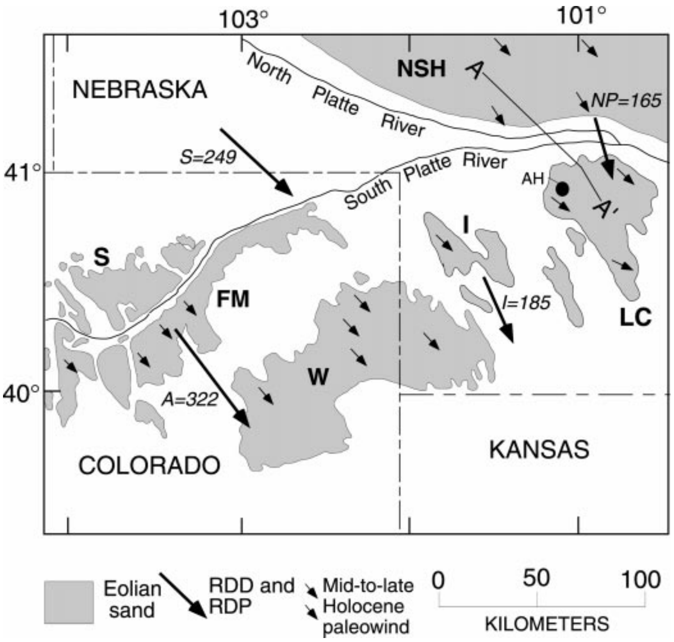


**FIG. 2.** Map showing distribution of eolian sand in southwestern Nebraska and northeastern Colorado, and paleowinds (small arrows). Annual resultant sand drift directions (RDD; shown by bold arrows) and resultant drift potentials (RDP) in vector units (terminology from Fryberger and Dean, 1979) are also shown for the following localities: A, Akron, Colorado; S, Sterling, Colorado; I, Imperial, Nebraska; NP, North Platte, Nebraska. Eolian sand distribution is from Swinehart *et al.* (1994b) and Muhs *et al.* (1996). Dune field abbreviations: LC, Lincoln County dune field; I, Imperial dune field; NSH, Nebraska Sand Hills; W, Wray dune field; FM, Fort Morgan dune field; S, Sterling dune field; AH, auger hole locality. Cross section A-A′ shown in Figure 4.

Pleistocene and mid-Holocene) of eolian sand activity that dammed drainages within the Nebraska Sand Hills.

In this paper, we test the competing hypotheses of a South Platte River origin versus a Nebraska Sand Hills origin for the Lincoln County and Imperial dune fields. Both mechanisms require that late Quaternary paleowinds were dominantly from the northwest. In addition, if the first hypothesis is correct, the Lincoln and Imperial dunes should have compositions that are indistinguishable from those in Colorado. The second hypothesis requires that the Lincoln and Imperial dunes have a composition similar to dunes in the Nebraska Sand Hills. These two hypotheses are not mutually exclusive; it is possible that the Lincoln and Imperial dunes have been derived from both sources at different times in their histories, and they may have a composition that is intermediate between Nebraska and Colorado dunes. Testing of these hypotheses is possible because the Nebraska Sand Hills and northeastern Colorado dunes have mineralogical and geochemical compositions that are significantly different (Muhs *et al.*, 1996, 1997a).

## FIELD AND GEOCHEMICAL METHODS

Eolian sand in the Lincoln County and Imperial dune fields was mapped using aerial photographs and soil surveys, and field-checked in detail (Fig. 3). The relative age of the dunes in the Lincoln County and Imperial dune fields was assessed using soils. Recent studies in Colorado and Nebraska at localities with radiocarbon-dated sections (Madole, 1994, 1995; Muhs *et al.*, 1996; Muhs *et al.*, 1997a) indicate that dunes with A/Bw or [Bt]/C soil profiles probably date to the mid-Holocene or before, whereas dunes with A/AC/C soil profiles are likely of late Holocene age. Relative ages based on soil profiles were assigned to all localities.

The two largest dune fields in northeastern Colorado, the Wray and Fort Morgan dune fields (Fig. 2), are derived from the South Platte River and are relatively rich in K-feldspar compared to most eolian sands that have been reported for dune fields in North America and elsewhere. In contrast, dunes of the Nebraska Sand Hills were probably derived from multiple sources (Aleinikoff *et al.*, 1995), but they are mineralogically mature and are characterized by relatively high quartz contents and low K-feldspar contents (Ahlbrandt and Fryberger, 1980; Muhs *et al.*, 1997a). Thus, the Colorado dune fields are relatively enriched in K and Rb (both found in K-feldspar) compared to the Nebraska Sand Hills.

Eolian sands were collected just below the depth of pedogenic alteration at 54 localities distributed over the entire extent of the Lincoln County and Imperial dune fields (Fig. 3). We also collected samples of eolian sand that occurs on the interfluve between the North and South Platte rivers (Figs. 1–3) and samples of North Platte River alluvium, which were sieved to remove gravel, coarse sand, silt, and clay. All samples were ground and analyzed as bulk powders by energy-dispersive X-ray fluorescence. Geochemical analyses were supplemented with semiquantitative mineralogical analyses obtained by X-ray diffraction, with relative mineral abundance estimated by diffraction peak heights, following the method of Muhs *et al.* (1995). Both geochemical and mineralogical data for the Lincoln and Imperial dunes were compared to the composition of 62 samples from the Nebraska Sand Hills (Fig. 1) reported by Muhs *et al.* (1997a) and 50 samples from Colorado dune fields reported by Muhs *et al.* (1996). Patchy eolian sands from the interfluve between the North and South Platte rivers and from an auger hole through a single parabolic dune in the Lincoln County dune field were also analyzed.

## RESULTS

Stratigraphic and soil evidence indicates that at least two episodes of eolian sand movement occurred in the Lincoln/Imperial dunes during the late Quaternary. Based on soil evidence, the most recent episode of eolian sand movement occurred during the late Holocene. Examination of modern soils in dozens of hand-dug pits and roadcuts in the Lincoln/Imperial dunes shows only the development of A/AC/C profiles. However, a few roadcuts and one deep (~6 m) auger hole show that eolian sands with A/AC/C soil profiles are locally underlain, at a depth of 2–5 m, by older eolian sands that have either

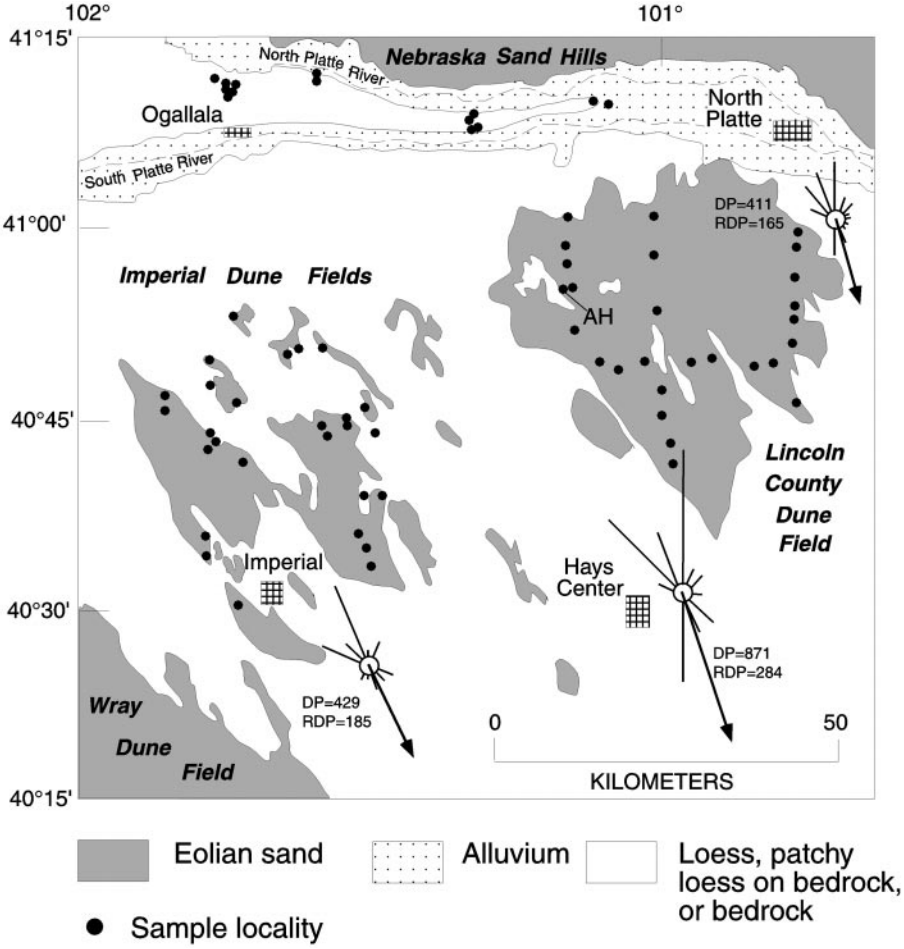


**FIG. 3.** Distribution of eolian sand in the Lincoln County and Imperial dune fields, sample localities (including deep auger hole, AH), and detailed sand roses for the cities of North Platte, Hays Center, and Imperial. Generalized extent of eolian sand taken from Soil Conservation Service–Conservation and Survey Division, University of Nebraska (1978) with field checking by the authors.

A/Bw/C profiles or profiles with weak Bt horizons, both of which indicate an older and longer-lasting period of eolian sand stability and pedogenesis. It is concluded from these observations that deposition of the older eolian sands in the Lincoln/Imperial dune fields could have occurred in or before mid-Holocene time, but the most recent episodes of eolian sand movement probably occurred in the late Holocene and affected almost all of the Lincoln/Imperial dunes.

Critical to tests of either hypothesis is geomorphic evidence of the direction of eolian sand migration. A compilation of modern wind data, using the methods of Fryberger and Dean (1979), shows that sand-moving winds come from the northwest in western Nebraska (Figs. 2 and 3). Measurement of the orientation of several hundred parabolic dunes of probable Holocene age in Colorado, the southern part of the Nebraska Sand Hills, and the Lincoln/Imperial dune fields shows good agreement with modern wind directions (Fig. 2). Furthermore, winds during full-glacial time also likely came from the northwest. Regional patterns of loess thinning and particle-size decrease in the midcontinent, summarized by Muhs and Bettis (1998), show that northwest winds were dominant during the late Wisconsin period. Similar patterns of late Wisconsin (Peoria) loess thinning to the southeast are apparent in Nebraska (Swinehart *et al.,* 1994). Drainage alignments with a northwesterly trend are also evident on the interfluve between the North and South Platte rivers and may be the result of eolian erosion (Diffendal, 1994), similar to that described in Iowa by Hallberg (1979). Northwesterly winds probably were the major synoptic-scale pattern over much of the midcontinent during the past glacial–interglacial cycle. Therefore, it is possible that eolian sand could have moved from either the Nebraska Sand Hills or the South Platte River to the southeast under full-glacial or modern climatic conditions.

The Lincoln and Imperial dunes have concentrations of K and Rb that are intermediate between eolian sands of the Nebraska Sand Hills and northeastern Colorado (Fig. 6). Because previous studies (Muhs *et al.,* 1996, 1997a) indicate that these elements are found mainly in K-feldspar, a reasonable

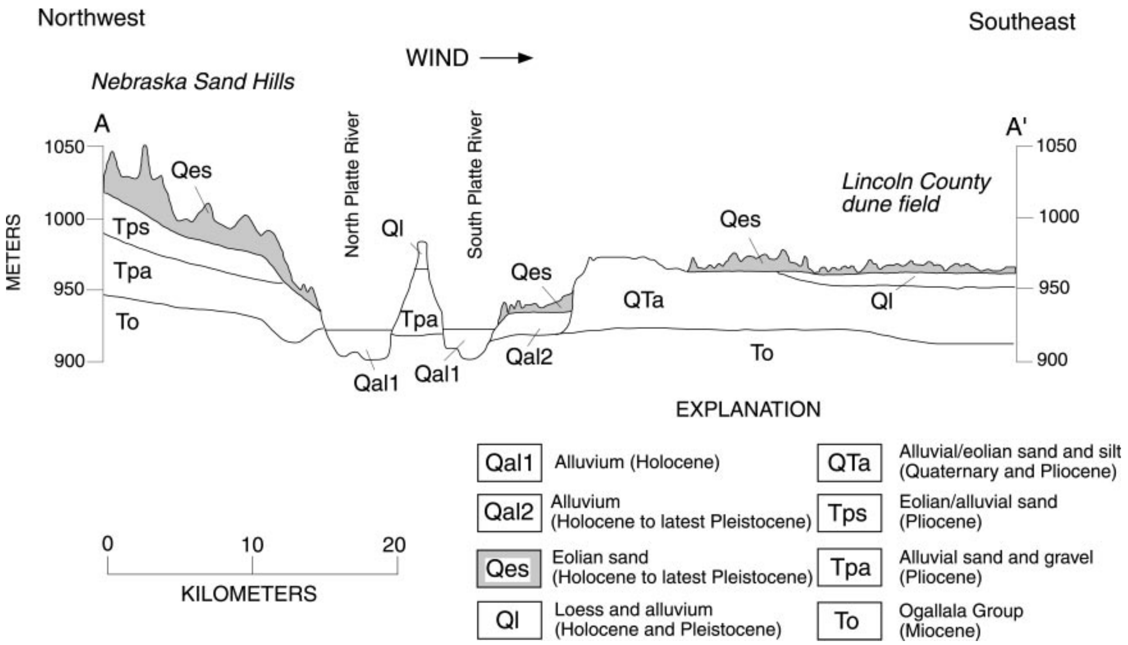


**FIG. 4.** Schematic cross section of surficial and upper bedrock geologic units in southwestern Nebraska (location shown by A-A′ in Fig. 2). Taken partly from Swinehart and Diffendal (1990); geology southeast of the South Platte River is from the present study. Vertical exaggeration is about 100×.

interpretation is that the Lincoln/Imperial dunes have K-feldspar contents that are intermediate between the Nebraska Sand Hills and Colorado dune fields. Semiquantitative mineralogical analysis by X-ray diffraction supports this interpretation.

The samples in the analysis described above were collected just below the modern soil at all localities, and therefore they reflect the composition of the most recent episode of eolian sand movement. However, stratigraphic and geochemical data also indicate that this composition is typical of older eolian sand as well. Analysis of sediments collected from a 6-m-deep auger hole in a parabolic dune from the Lincoln County dune field shows that eolian sand at all depths, including the past two major periods of deposition (mid-Holocene or before, and late Holocene), have both K and Rb concentrations that are intermediate between the ranges of values for the Nebraska Sand Hills and Colorado dune fields (Fig. 7).

Small patches of eolian sand are found on the interfluve between the North and South Platte rivers. These sands have compositions that are intermediate between the Nebraska Sand Hills and fine-grained fluvial sands of the North Platte River (Fig. 8), suggesting that they formed as a mixture of the two sources. The interfluve eolian sands are also depleted in K and Rb relative to the Lincoln County dunes.

## GEOMORPHIC AND PALEOCLIMATIC SIGNIFICANCE

We interpret the geochemical data as showing that the Lincoln/Imperial dunes evolved as a mixture of two compositionally distinct sand sources. Although modern winds above threshold velocity are from the northwest, saltating grains (confined to $<2$ m above the ground surface; Pye and Tsoar, 1990) from the Nebraska Sand Hills obviously cannot move across the North Platte River at present because this valley is not dry. Thus, the North Platte River valley now serves as a sediment sink. In contrast, sand from the south side of the South Platte River valley can be transported southeast to the Lincoln/Imperial dunes, and was a likely late Holocene sand source. These observations suggest, therefore, that the geochemical similarities between the Lincoln/Imperial dunes and northeastern Colorado dunes is the result of a geomorphic setting much like the present, where the South Platte River is the only available source.

In contrast, the geochemical character of the Lincoln/Imperial dunes which resembles that of the Nebraska Sand Hills must have been inherited from a geomorphic setting that was dramatically different. Inputs of sand from the Nebraska Sand Hills to the Lincoln/Imperial dunes could have occurred only if sediment from the former source completely filled both the North and South Platte river valleys. A likely scenario would be filling of a dry North Platte River valley with eolian sand, buildup of this sediment into climbing dunes or eolian sand ramps on the north side of the interfluve between the North and South Platte rivers, and gradual overtopping of this divide by moving sand. Continued migration of sand to the southeast would have created a falling dune on the southeastern side of the interfluve, filling of a dry South Platte River valley, and migration onto the upland south of the river. The small, remnant patches of eolian sand we found on the interfluve between the two rivers (Fig. 3), with their K and Rb concentrations intermediate between the Nebraska Sand Hills and the

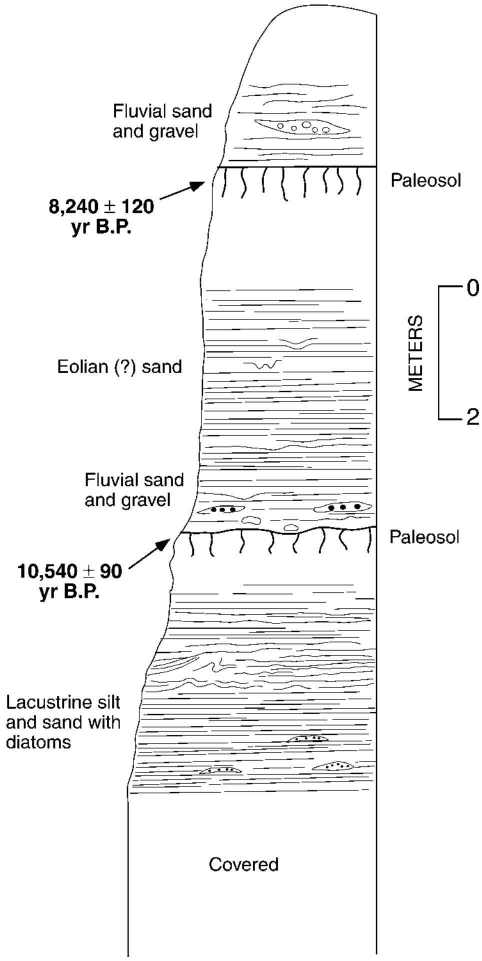


**FIG. 5.** Stratigraphic section exposed in a tributary to the North Platte River in westernmost Keith County, Nebraska (SW 1/4, SW 1/4, sec. 17, T15N R41W) showing diatom-bearing lacustrine sediments overlain by fluvial and eolian (?) sediments, and radiocarbon ages of organic matter from paleosols (upper age is Beta-31684; lower age is Beta-31683). Locality is shown in Figure 1. Stratigraphy and radiocarbon ages are from Leite and Diffendal (1988), Diffendal and Leite (1989), and Swinehart and Loope (1992), and are redrawn from Swinehart *et al.* (1994a).

North Platte River (Fig. 8), support this hypothesis. Subsequent breaching of the dune dams that were likely created by this process by the North and South Platte rivers would have cut off the Nebraska Sand Hills source and allowed only a South Platte River source to the Lincoln/Imperial dunes. Repeated mixing, through reworking of older sediment derived from the Nebraska Sand Hills with sediment derived from the South Platte River, would have resulted in the present intermediate composition. Sand that was originally present between the South Platte River and the present northern extent of the Lincoln County and Imperial dunes must have been eroded and reworked to the south (Fig. 3).

The rather complex series of events outlined above would require a climate considerably drier than at present. The modern stability of the Nebraska Sand Hills is due to an extensive vegetation cover; absence of this cover requires a more-negative moisture balance than at present. A regionally drier climate would also be required for the greatly reduced discharges in both the North and South Platte rivers, such that eolian filling of their valleys could take place.

## DISCUSSION AND CONCLUSIONS

Results of geochemical analyses indicate that the Lincoln/Imperial dune fields in southwestern Nebraska probably formed from two sand sources. The latest influxes of sediment, which probably occurred repeatedly in Holocene time, were dominantly from the South Platte River and are characterized by relatively high amounts of K-feldspar. However, the earlier, K-feldspar-depleted influxes of sediment were from the Nebraska Sand Hills. This could only have occurred if the North and South Platte river valleys were dry long enough to allow eolian sand from the Nebraska Sand Hills to fill the valleys, create climbing and falling dunes, and migrate over interfluves, thus creating one or more dune dams. A radiocarbon age of 10,540 $^{14}$C yr B.P. above lacustrine deposits in a tributary of the North Platte River suggests that this dune dam was in existence prior to 11,000 $^{14}$C yr B.P. (Swinehart and Loope, 1992). More compelling evidence for the timing of the damming comes from Mason *et al.* (1997). They interpreted eolian sand to have blocked the 5800-km$^2$ Blue Creek basin, in the Nebraska Sand Hills, sometime prior to 10,500 $^{14}$C yr B.P. Additional radiocarbon ages from basal lake sediments in the upstream portion of the Blue Creek basin (Sweeney *et al.*, 1998) suggest dune blockage occurred prior to 12,000 $^{14}$C yr B.P. The southernmost dune dam in the Blue Creek basin is ~100 km from the North Platte River. The blockage of a significant tributary would have further reduced the flow in the ancestral North Platte River. A latest Pleistocene age assignment for dune blockage is consistent with stratigraphic and geochemical data which suggest that the Lincoln/Imperial dune sands have been well mixed over the past two (middle and late Holocene) periods of deposition.

Eolian activity in the Nebraska Sand Hills during late-glacial time is consistent with regional evidence for dune sand movement at this time over much of the Great Plains. In addition to the dune blockage of Blue Creek prior to 12,000 $^{14}$C yr B.P., discussed above, 50-m-high barchanoid dune ridges elsewhere in the Nebraska Sand Hills have a maximum-limiting radiocarbon age of 13,160 ± 450 $^{14}$C yr B.P., and therefore could date to late-glacial time (Swinehart and Diffendal, 1990). Eolian sands in northeastern Colorado have minimum-limiting radiocarbon ages of 9580 ± 90 $^{14}$C yr B.P. (Muhs *et al.*, 1996). Stratigraphic and pedologic evidence suggests that eolian sheet sands of about this age are extensive over northeastern Colorado (Madole, 1995; Muhs *et al.*, 1996). Near Clovis, New Mexico, Clovis (~11,500–11,000 $^{14}$C yr B.P.) artifacts underlie eolian sands that contain Hell Gap (~10,500–9500 $^{14}$C yr B.P.) artifacts, which tightly constrains the age of eolian sand

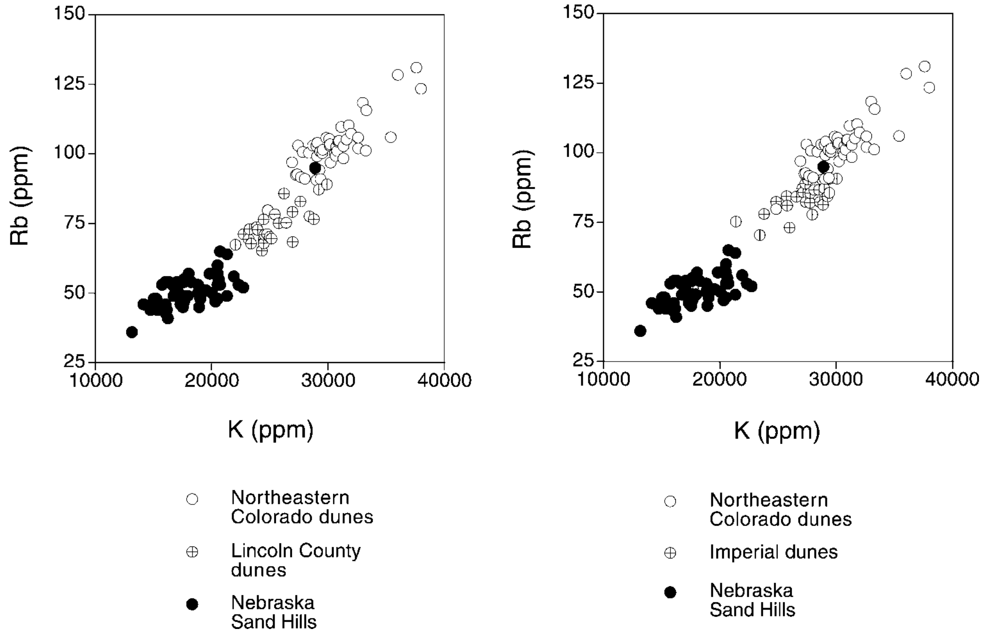


**FIG. 6.** Concentrations of K and Rb in the Lincoln County and Imperial dune fields, the Nebraska Sand Hills, and northeastern Colorado dune fields. Colorado data are from Muhs *et al.* (1996); Nebraska Sand Hills data are from Muhs *et al.* (1997a).

deposition there to the late-glacial interval; archaeological evidence suggests a similar age for eolian sands in the Southern High Plains of Texas (Holliday, 1997).

The results presented here suggest that eolian processes may have a much greater influence on fluvial systems in North America than previously supposed: the Platte River system is the largest tributary system to the Missouri River. If this system were blocked by dune dams in the latest Pleistocene in southwestern Nebraska, then possibly such dams were created during arid periods in other dune fields of North America. Evidence for dune blockage should be sought in localities where dune fields lie on both sides of major drainages, such as the South Saskatchewan River in Alberta and Saskatchewan, the Souris River in North Dakota, the South Platte River in

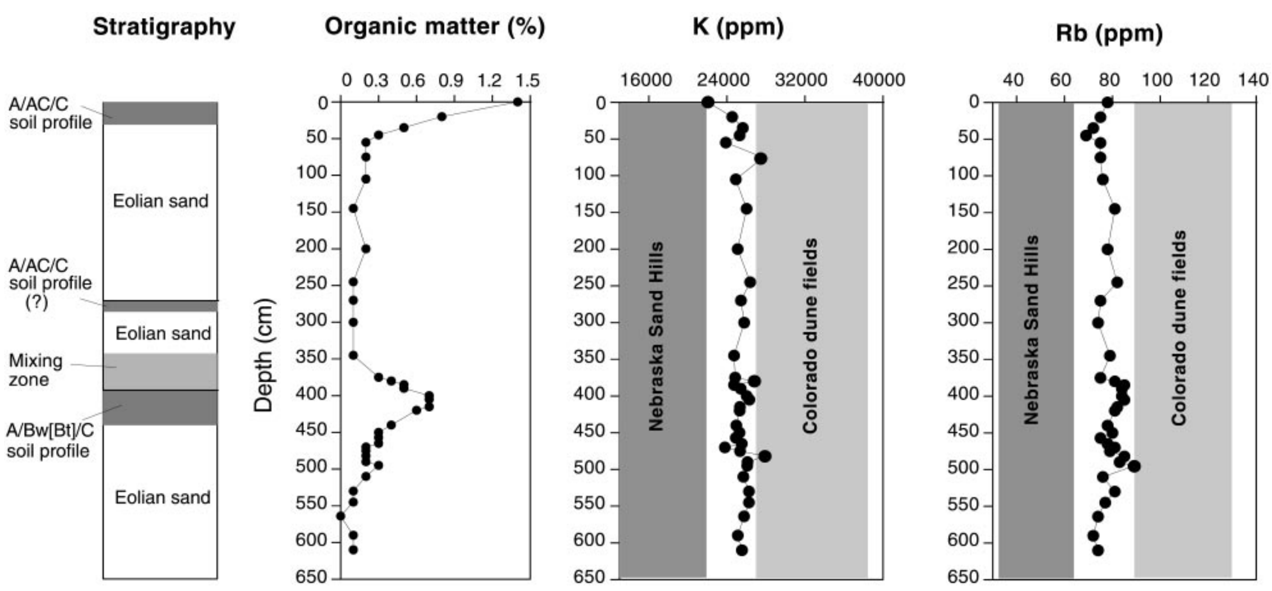


**FIG. 7.** Concentrations of organic matter, K, and Rb shown as a function of depth in auger hole samples taken from a parabolic dune (locality AH in Figs. 2 and 3) in the Lincoln County dune field. Shown for comparison are the ranges of concentrations of these elements for the Nebraska Sand Hills and Colorado dune fields given in Fig. 6.

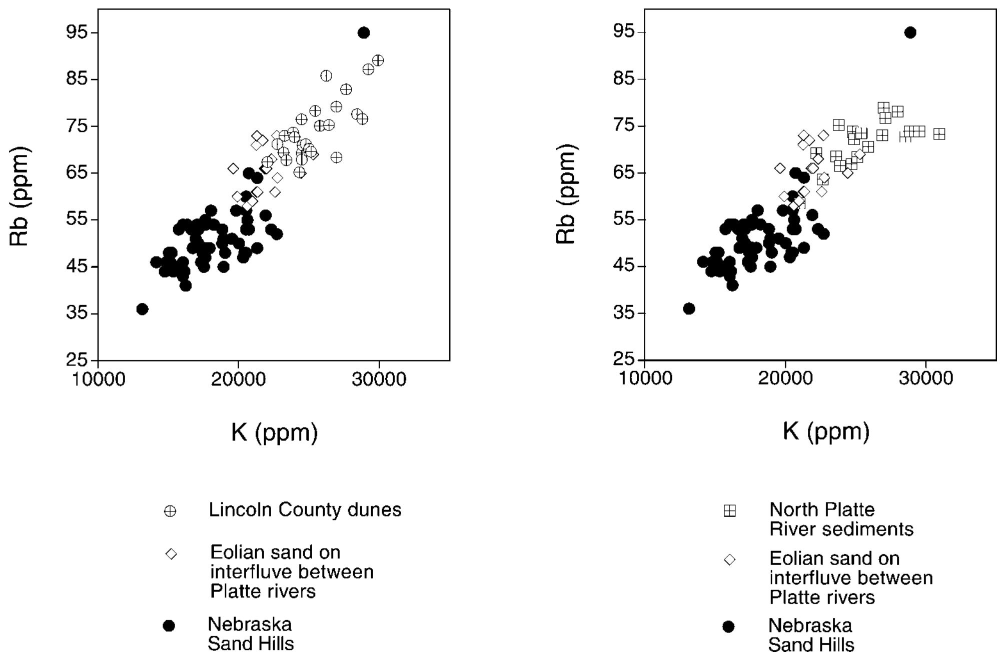


**FIG. 8.** Concentrations of K and Rb in the Lincoln County and Imperial dune fields, the Nebraska Sand Hills, North Platte River sediments, and eolian sands on the interfluve between the North and South Platte rivers.

Colorado, the Arkansas River in Kansas, the North Canadian and Cimarron rivers in Oklahoma, and the Colorado River in Arizona and California.

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