MORPHOLOGY OF FIXED SAND DUNES FOR PALEOWIND RECONSTRUCTION IN NORTHWESTERN OKLAHOMA

By

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MORPHOLOGY OF FIXED SAND DUNES FOR PALEOWIND

RECONSTRUCTION IN NORTHWESTERN OKLAHOMA

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CHAPTER I

INTRODUCTION

Background

Sources of paleoclimatic records such as tree rings and lacustrine deposits are scarce in the southern Great Plains. There are, however, alternative sources for paleoclimatic reconstruction in environments typical of this region, such as loess and sand dune deposits, and the paleosols developed in them. Sand dune morphology is a source that has rarely been used for reconstructing periods of droughts and paleowind direction in historic and recent prehistoric times (Sridhar et al. 2006). For the purpose of this study the term paleowind, paleodune and paleoclimate will be used to denote a time before instrument records.

Sand dune fields across the North American Great Plains are located primarily along the rivers that flow out of the Rocky Mountains. Throughout the Holocene there were alternating periods of high precipitation and sustained droughts, which led to the deposition of alluvium that would become available for dune formation (Forman et al. 2001). These dunes could become active under conditions with high evapotranspiration, a lack of precipitation and enough wind power to move the sand grains (Lancaster 1988). The active dunes could then evolve into a shape indicative of the direction of the dominant wind pattern. The dune morphology might then be an indicator of wind conditions in that region at the time of dune formation.

Research Problem

The temporal and spatial patterns of the dunes across the Great Plains have been studied and chronicled using morphology and stratigraphy (Forman et. al. 2001).

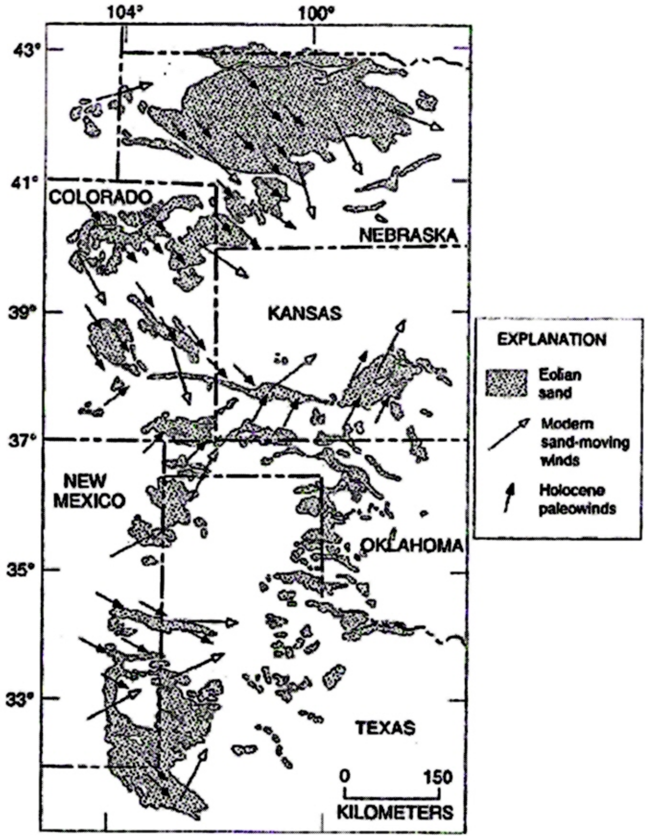

Fig. 1 Distribution of eolian sand deposits across the central and southern Great Plains with modern dominant wind and Holocene paleowinds (Muhs and Zarate 2001).

Muhs and Zarate (2001) compiled studies of paleowind direction and mapped the dominant paleowind patterns as inferred from dune orientations (Fig. 1). Other studies have been conducted that use sand dune activity to determine the existence of mega-droughts across the Great Plains of North America (Forman, Oglesby and Webb 2001; Muhs and Holiday 1995; Cordova et al. 2005). The morphology of active dunes has been associated with the development of climatic fluctuations during the 20th century by Melton (1940), Rhinewald (2005) and Cordova et al. (2005). However, in Oklahoma the relationship between dune formation and climatic conditions prior to the 20th century is not well known.

Wind direction, wind speed, and ground surface vegetation determine dune shape and mobility (Lancaster 1988). Although paleodune shape has also been used as a proxy for determining wind direction in the Great Plains (Muhs and Zarate 2001; Sridhar et al. 2006), a study of this type has not been conducted in Oklahoma (Fig. 1). Therefore, this study focuses on determining paleowind direction from the shapes of stabilized dune crests in Cimarron County, Woods County (Little Sahara State Park) and Beaver County (Beaver Dunes State Park) in western Oklahoma (Fig. 2). The five localities of this study were selected on the basis of visible dune topography and a lack of plowing or construction to simplify mapping. The information produced is available for cross reference in future geomorphological studies particularly for preliminary chronological framework for the dating of dune generations using Optically Stimulated Luminescence (OSL).

Study Area

Physical Description

The five sites selected for this study are located along the Beaver/North Canadian River and Cimarron River (Fig. 2). The study areas are located between longitudes 103˚ W and 99˚ W and latitudes 36˚ N and 37˚ N. Site A is located in the southwest part of

Cimarron county, located north and south of the Seneca Creek immediately north of the Beaver River. Site B is located in the NE corner of Cimarron County, south of the Cimarron River near the Oklahoma-Colorado border.

Site C is located in the Beaver Dunes State Park in Beaver County. Site D is also located in Beaver county about six miles east of site C, on both sides of Timber Creek. Sites C and D are both located on the northern side of the Beaver River. Site E is located in the northern part of Little Sahara State Park and privately owned fields located north of Dog Creek, in Woods County. The Little Sahara dune field encompasses an extensive area north and east of the Cimarron River.

The dunes of both sites A and B are found on the Vona soil series. The Vona series are comprised of aridisols developed on deep fine sandy loam eolian deposits originating from Pleistocene age alluvium (United State Department of Agriculture USDA 2007a). Some dune overlap occurs on the Conlen series, a coarse loam to clay loam, formed in Pleistocene eolian sediments (USDA 2007a). The dunes of site A and B overlie a Pleistocene carbonate gravel layer (Ogallala Formation). In Site A, Cretaceous Dakota Sandstone Formations outcrop in eroded areas (Rothrock 1925, Schloff 1943). The weathered sands from this formation provide material for dune development.

Dunes in Site A are mostly eroded ridge dunes hairpin parabolic dunes and crescent dunes modified with blowouts and eroded land. The older dunes are located in the eastern and northern sections of Site A.

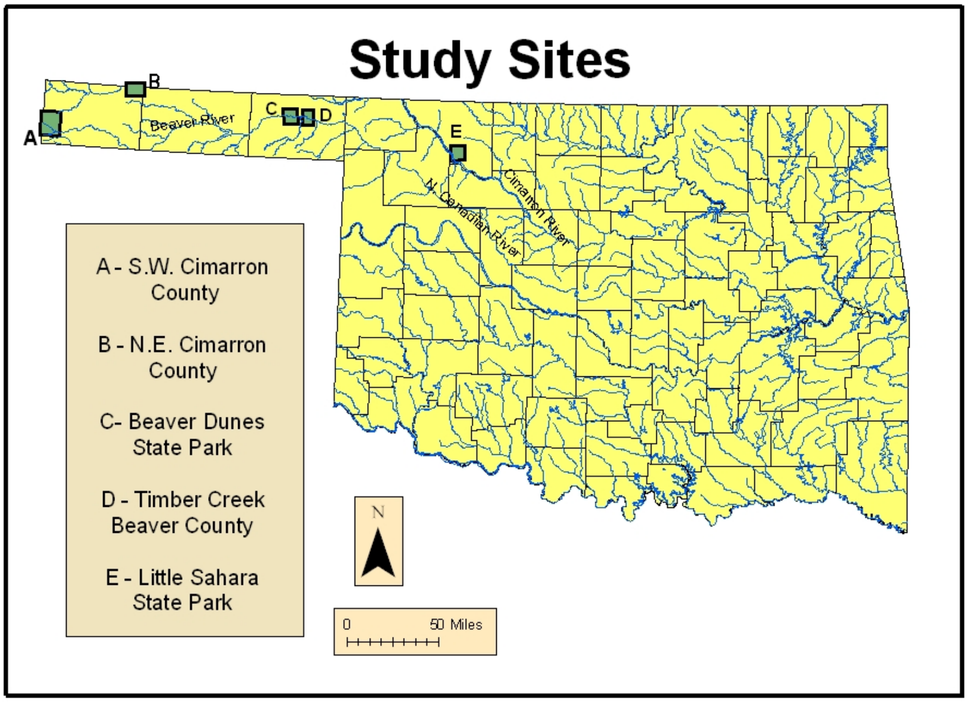

Figure 2 Location of the five study sites: (A) SW Cimarron County, (B) NE Cimarron County, (C) Beaver Dunes State Park, (D) Timber Creek Beaver Co. and (E) Little Sahara State Park

Site B is much less eroded than Site A. This is evident in the deeper soils and a more developed dune field. The dunes of Site B are found on Vona soil series, with some dunes found on the Dalhart series. Dalhart soils are fine sandy loam eolian deposits also formed in the Pleistocene (USDA 2007a). The dune field in this site contains large dune and many crescent dunes and blowouts. Many of the large dune have been modified by crescent and blowout dunes developed on them.

Dunes at Site C are found on dune land soils of the Tivoli soils, Vona-Tivoli complex, and the Mobeetie-Devol complex series. Dunes at Site D occur on Tivoli soils, Vona-Tivoli complex and the Mobeetie-Devol complex series. Tivoli soils are sandy eolian sediments found on the river terraces in this region (USDA 2007a). The Mobeetie soils consist of alluvium and colluvium deposits and the Devol soils are eolian sands found on upland terraces (USDA 2007a). Timber Creek flows through the dune field in Site D and the drainage has caused some erosion. As in Site B, Sites C and D have older large dune with many blowouts and crescents modifying them.

The dunes at Site E consist of active dune Tivoli soils located at the northern extent of the Park, as well as an inactive dunes on the Tivoli complex, Jester, and the Westola series. Jester soils were formed during the Holocene from eolian sandy deposits found on alluvial terraces (USDA 2007b). Westola soils are Holocene age calcareous loamy alluvium found on lowlands (USDA 2007b). The dunes in this site are moderately eroded and stabilized to active. The older dunes in this site are in the northern portions of the site.

Climate

The climate conditions in the study area are influenced by strong westerly air circulation in the winter and a weakened westerly air circulation in the summer (Mitchell 1976). During drought years, the westerly circulations become more dominant during the summer as well as the winter, effectively cutting off the moisture from the Gulf of Mexico in the region (Borchert 1950). The result of this event is a predominant wind either out of the northwest or southwest during severe droughts; conditions that would lead to eolian activity and dune formation and activity (Borchert 1950). It may also indicate that the shift from northerly to southerly wind direction could be an indication of the seasonality of droughts associated with dune formation periods (Barry 2002).

Using data from Mesonet stations, vectors have been charted on wind roses to indicate the percent of time wind (at a height of 2 meters) has been measured above 12 knots from the various compass directions following the methodology by Fryberger (1979) (Fig. 3). Winds above 12 knots are used as standard for sand dune formation (Freyberer1979). Dominant dune-forming winds in Cimarron County (Sites A and B) are from the southwest, south southwest and west southwest, with a strong north component (Fig. 3.1). Beaver County (Sites C and D) has a dominant wind from the south and south

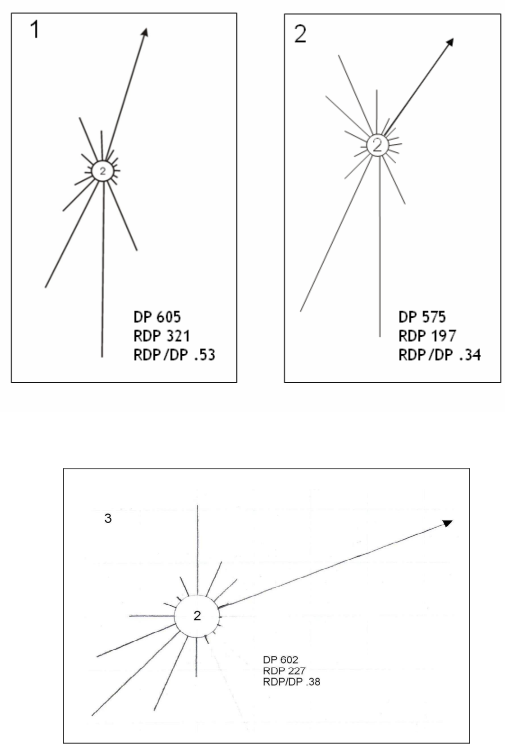

Figure 3 Wind roses constructed using 1994-2003 wind data from the Oklahoma Mesonet for (1) Site C, Beaver Dunes State Park (2) Freedom (proxy for the Little Sahara/Site D), (3) Boise City (proxy for Cimarron Co. Sites A and B).Sources: Cordova et al. (2005) and Rhinewald (2005).

southwest, with less time out of the south southeast and the north (Fig. 3.2). Little Sahara has strong vectors out of the south and south southwest and to a lesser extent northwest and north northwest (Fig. 3.3).

In general, for the five sites, the north and northwesterly trends are more common during the winter months. South and southwesterly wind directions are more common during spring and summer. This indicates that dune formation may also respond to factors related to seasonality of drought periods in the past.

Thesis statement

Using the vectors obtained from mapped dune crests, and a relative age derived from vegetation and soil development, this study attempts to establish a relative chronology of paleowind directions as a basis for application of numeric age dating. Therefore, this study tested the following hypothesis: The different orientations of inactive dunes are the result of variations in wind direction at the time of formation, which in turn are the result of shifts in wind circulation patterns associated with dry periods.

Objectives

The following outlines the process and goals of this study through four specific objectives.

1. Select areas of visible dune topography along the Beaver River and Cimarron River in Cimarron County, Beaver County and Woods County by using existing maps, digitized aerial photos (NAIP images), and digital soil surveys.
2. Manually map the crest of sand dunes in selected areas using digitized 2003 aerial

photos.

3. Using wind vectors inferred from mapped dunes, establish direction of dune development in order to infer the dominant wind pattern at the time of dune formation.
4. Corroborate relative age using a combination of soil series and vegetation associations as well as visible erosion on dunes, to establish phases for a relative chronology of eolian activity phases.

Thesis Structure

Chapter 1 is an introduction to the research project including general background of the region, description of the study sites, subject and study problem as well as the hypothesis and objectives. Chapter 2 is a comprehensive review of literature associated with the project including dune dynamics and conditions of sand dune formation, dune shapes in Oklahoma, and dune morphology mapping. Chapter 3 outlines the methodology used for mapping sand dunes and spatial analysis of variability in sand dune age. Chapter 4 analyzes the results of the mapping across the five study sites. Chapter 5 contains the conclusions of this research and suggestions for the application of the results of this research to future studies. The appendix includes the completed maps for each of the five sites, including the different dune types as well as the associated paleowind vectors. Also included in the appendix is the process for extracting compass directions from the paleowind vectors (line features) in ArcGIS.

CHAPTER II

REVIEW OF LITERATURE

Dynamics and Conditions of Dune Formation

In order to have sand dunes, certain conditions must be met: a source of sand, wind energy to move the sand and a lack of vegetative cover to stabilize the sand (Muhs and Maat 1993). When these conditions are met, the movement of sand will begin to create shapes that include the backslope or windward surface, the crest and slip face or lee slope. The angle of repose and the shape of the crest are the factors that contribute to differentiate the various types of dunes.

Freyberger (1979) discusses the concepts of drift potential (DP) which is expressed in vector units (VU), resultant drift direction (RDD) and resultant drift potential (RDP), based on the equation:

$$Q = V^2(V-V_t) \cdot t$$

"Where Q is proportionate to the amount of sand drift, V is the average wind velocity at 10 meters, V_t is impact threshold wind velocity and t is the time the wind blew, and expressed as a percentage (W) in a wind summary" (Freyberger 1979). Using W with the wind information, it is possible to predict what type of dune will be formed at a site and which direction it will migrate, or if it will not migrate as with a star dune.

A wind rose is the 360° graph of wind directions and magnitudes (VU), the VUs are then totaled to calculate the RDD and the RDP. The RDD is the direction in which the dunes are expected to move. It is represented by the arrow in the wind rose (see

Fig. 3). A unimodal wind regime, whether narrow or wide, would be an environment that could produce a transverse or crescentic dune. Wind roses have been completed for current conditions at each of the study sites by Cordova et al. (2005) and Rhinewald (2005) and they are consistent with 20th century dune formations (see Fig. 3). It is not possible to infer the wind rose from aerial photos but it will be possible to infer the RDD simply by dune shape.

Dune mobility is an issue not taken into account in the Freyberger (1979) chapter. Dune mobility, as Lancaster (1988) calculated it, factors in a vegetative cover by way of the precipitation and potential evapotranspiration P:PE ratio. The P:PE ratio corresponds to the moisture stress on vegetation and can be an indicator of sand cover. Lancaster (1988) used the W/(P:PE) equation to calculate M (dune mobility). A value less than 50 would be inactive, 50-100 only crests would be active (sporadic blowouts), 100 -200 there would indicate activity in all but interdune areas, and above 200 the dunes are fully active. Lancaster used this equation to describe deserts- he mostly worked in the Kalahari.

Muhs and Maat (1993) noticed when the Lancaster method was used in the North American Great Plains that they had very similar results when comparing the calculated M and reviewing aerial photos of the corresponding areas. Other than a few areas in the Nebraska Sand Hills that are attributed to management practices (overgrazing), the mobility index was very close to the visual examination. Thus, the degree of vegetative cover in the Great Plains sand dunes is due to the delicate balance between precipitation and evapotranspiration (Muhs and Maat 1993). With a strong wind and a low P:PE there is a much higher chance of having dune activity in the study area. If there are dunes present, this implies that all of these conditions would have been met at the time of activity and provides some clues to the paleoclimate of the region.

Dune Development and Dune Shapes in Western Oklahoma

The morphology of a dune is dependent on the type of sand and impediments within the source, as well as the amount of wind energy (velocity and time)and the direction of the wind (Ritter 1986). In Oklahoma, the main network of dunes occurs along the Beaver River and the Cimarron River. Although these dunes have developed along these two rivers, the source material in Beaver County and Woods County is associated with Pleistocene and Early to Middle Holocene alluvial deposits left behind by the southward migration of rivers and not material moved out of the river channel directly (Brady 1989; Cordova et. al. 2005; Scott 1999). In Cimarron County, along the Beaver River the material has been associated with alluvium that has eroded from the surrounding Dakota sandstone found in the river valley (Rothrock 1925; Schoff 1943). The dunes here are found on both sides of the river (north and south) (Cordova et. al. 2005; Rothrock 1925; Schoff 1943). Along the Cimarron River in NE Cimarron County, the dunes are thought to have sourced by material from Pleistocene river terraces and are found on the south side of the existing channel (Cordova et. al.2005; Rothrock 1925; Schoff 1943). The most recent dunes occur closest to the current river channel, and the dunes get progressively older to the north on the terraces (Cordova et al. 2005). Under present climatic conditions, the dunes are only active under land management strategies that are either deliberate in keeping dunes active, as is the use of the Little Sahara State

Park and Beaver Dunes State Park (Rhinewald 2005), or utilizing poor management strategies such as over grazing, as is the case in Cimarron County (Cordova et. al. 2005).

Rhinewald (2005) recorded aerial changes in eolian activity at Beaver Dunes State Park and Little Sahara State Park at three intervals in the 20th century based on available aerial photos. These state parks are managed for recreational activity (ATV riding) on the dunes, so no attempt is made to encourage stability. The activity level at each site was measured using a grid superimposed over the area and bare sand was considered to be active dunes. This information was then cross referenced with the wind rose and M index for each site. Rhinewald (2005) found that in spite of numerous dry years in the 1950's and 1960s, the P:PE ratio had actually increased for the period 1937-2003. Precipitation in the periods 1940-1947 and 1970-2000 were generally above average. This trend of predominantly high moisture led to the stabilization of large tracts of dunes in the Little Sahara and Beaver Dunes State Parks (Cordova et al. 2005). The only areas with active dunes correspond to those used for all-terrain vehicle driving (Rhinewald 2005).

In the southern Great Plains, Melton (1940) established a classification regime that is still being used. Essentially Melton (1940) classified dunes into two groups, simple and complex. Simple dunes require the assumption that the wind direction is dominant from one direction. Complex dunes are just that, a more complex version of simple dunes. In order to understand complex dunes it is first necessary to have an understanding of the simple dunes.

Simple dunes were divided into two larger groups: the bare surface or loose sand group (Group 1) and the wind in conflict with vegetation group (Group 2) (Melton 1940).

Group 1 dunes in this study are the transverse dunes. Group 2 contains the blowout dunes which are visible throughout the study area. The complex dunes include forms that given an unlimited area and shallow sand and equally opposing winds, form a transverse ridge. The transverse dunes become elongated with the crest pushing forward and the legs trailing behind the direction of migration (Melton 1940).

More recent shape forms have been identified by Scott (1999) and Cordova et al. (2005) (Fig. 4). The predominant types are parabolic and blowout parabolic. However, among modern active dunes in the ATV-driven grounds of the Little Sahara and Beaver Dunes State Parks, the most common type of dune is the transverse dune. Hairpin parabolic dunes are rare, but they tend to be more common in fixed dune fields in Cimarron County and the states neighboring Oklahoma. Scott (1999) also identified recent formation of linear dunes (also known as linear ridge dunes) on floodplains. Some of these dunes have formed very recently, particularly during the drought years of the 20th century. Based on observations on sequences of aerial photographs, Cordova (personal communication) suggests that these dunes are a precursor of parabolic dunes (Fig. 4, E).

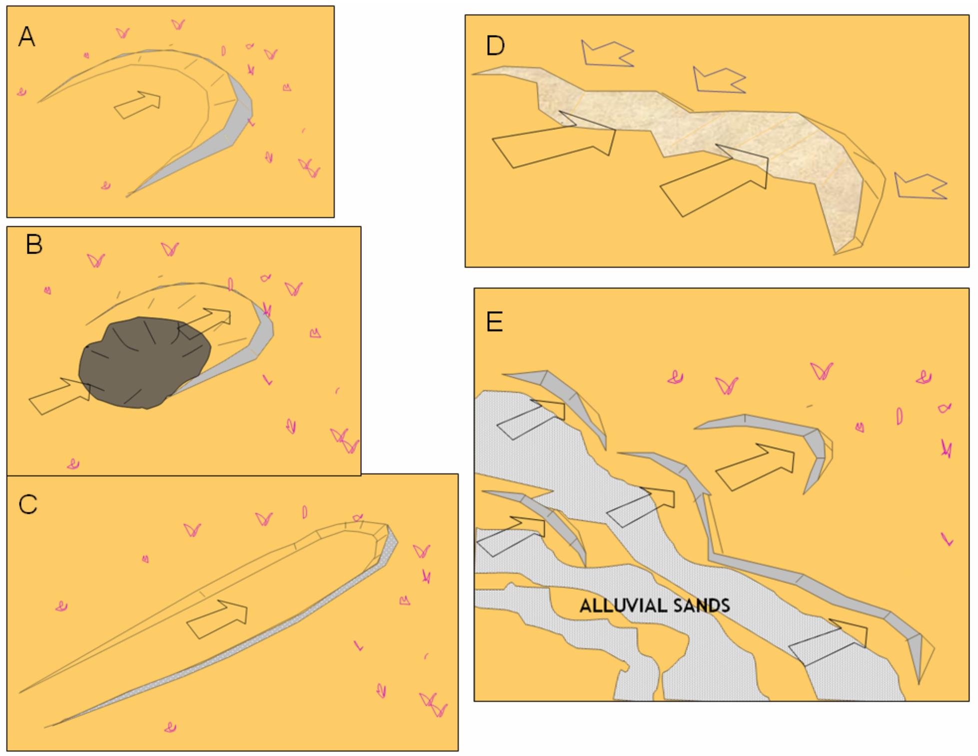

Figure 4 Typical dune types in Oklahoma. A) parabolic; B) blowout parabolic; C) hairpin parabolic, D)Transverse, and E) linear ridge. Arrow represents wind direction. Unpublished diagram provided by Carlos Cordova.

Dune Morphology Mapping

Levin and Ben-Dor (2004) have studied dunes near Ashdod-Nizanim, Israel, using aerial photos. The mapping was performed in order to gain an understanding of why these dunes are active when they do not meet the climatological requirements as proposed by Lancaster (1988). The mapping was done by scanning and orthorectifying a series of aerial photos (23 photos taken over the time 1944-1999). The dunes were mapped by locating the slipface and creating a polygon around the dune to assemble a group of vectors that could be totaled to provide a migration direction (Levin and Ben-Dor 2004). For this project a slightly modified version of their methodology was use; however the concept of creating a polygon around the dune crest (due to erosion the crest may be the only visible feature in this study) and applying vectors to the polygon will be used. This method should provide a good indicator of the direction of the forming wind. Anthonsen et al. (1996) used a similar technique in their study of the evolution of a crescentic dune to a parabolic dune in relation to climate change. This study does not focus on the evolution or migration of dunes; it is concerned with the formation. However, the evolution and migration are part of the process that active dunes will undergo before becoming stabilized. Anthonsen et. al. (1996) used a digital elevation model which this study will not utilize for mapping dune crests. The lee slope of the dune was used as the outline of the dune, and the RDD was related to the perpendicular trend of the slip face or parallel to the axis of the parabolic dune (Anthonsen et. al. 1996). The crest of the dune follows the shape of the slip face of the dune; so this study proposes that a vector perpendicular to the crest will achieve the same result.

In this research, aspects of dune mapping methodology and wind direction reconstruction are taken from both studies (Levin and Ben-Dor 2004; Anthonsen et al. 1996). However, given local conditions and dune formations, size of dunes and available imagery, this study has developed a simpler way of mapping dunes and reconstructing paleowind direction.

CHAPTER III

METHODOLOGY

Site Selection

The five study sites were selected using 2003 aerial photos viewed with Arc View GIS combined with soil survey and GAP vegetation maps. Additionally, modern wind data helped in the selection of sites. Recent Mesonet data indicate the predominant wind components across these study sites are from the NW and the S and SW (Fig. 3). Variations in the frequencies of wind blowing from these directions vary from west to east. Therefore, a variation in paleowind direction was expected. This furthered the selection of sites along a longitudinal gradient.

Altogether, the reasons for site selection can be summarized as follows:

1. Clear difference in dune morphology for mapping
2. Proximity to meteorological stations
3. Areas recommended for paleowind reconstruction in Oklahoma (Cordova et al. 2005)

Computer Mapping and GIS Analysis

Computer mapping was completed using ArcGIS with a combination of NAIP images, digital soil maps and the Oklahoma GAP image. The county NAIP image provided the base for digitizing the dunes and analyzing the topography. NAIP images and Oklahoma GAP image were obtained at the Oklahoma Center for Geo Spatial Information (OCGI 2006).

For the analyses of this study, sand dunes were divided into two categories: large dune crests and blowout/crescents. This division is based on size and relative age estimated from their position in the landscape. The large dune crests correspond to hairpin and transverse dunes (Fig. 4), as well as other dunes whose shapes are no longer discernible due to erosion. The blowout-crescent dunes correspond to the two closely related blowout crescent dunes and crescent dunes (Fig. 4). The latter are smaller landforms that seem to form with sand cannibalized from the large, old dunes.

The methodological procedure for each locality is as follows:

1. Assign a numerical identity to each of the five study sites (Table 1).

Table 1 Site numerical identities used in mapping

Site	**Number**
SW Cimarron County	1
NE Cimarron County	2
Beaver Dunes State Park	3
Timber Creek	4
Little Sahara State Park	5

2. For blowouts and crescent dunes, manually outline each visible dune crest creating a polygon of the identified dune (Fig. 5).

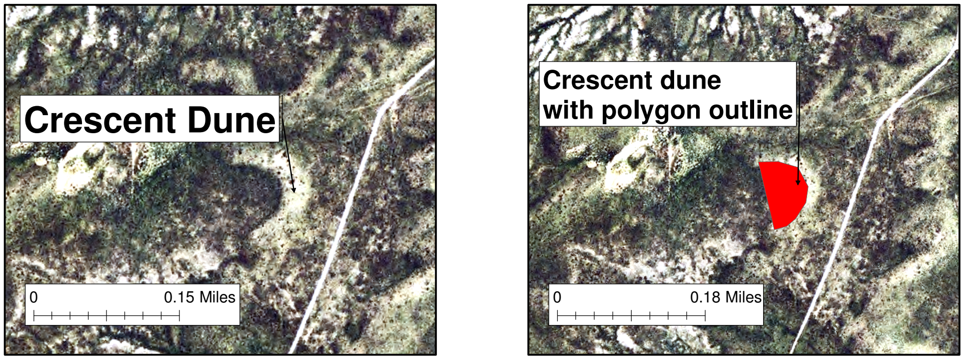

Figure 5 Example of a crescent dune and crescent dune with polygon outline

3. For large dunes manually outline the visible crest with line. (This distinction was necessary to keep the map legible and because many blowouts occur on the large dunes).

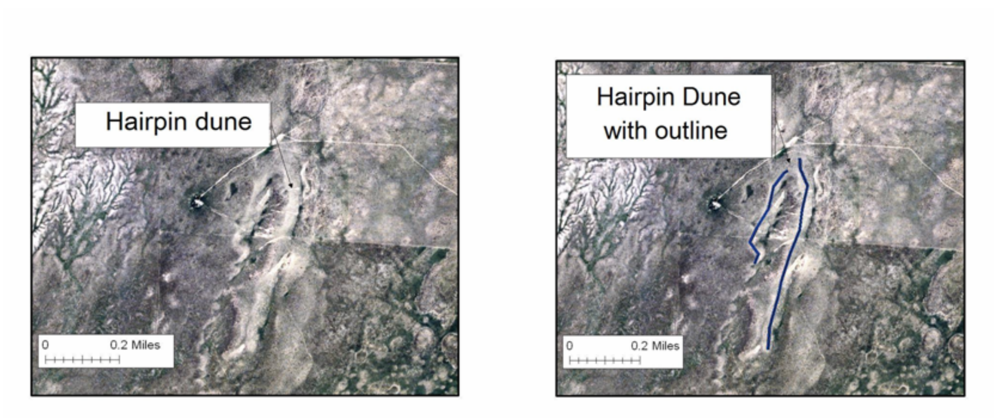

Fig. 6 Example of hairpin dune and the outline
of its crest for paleowind direction mapping

4. Paleowind direction vectors were determined from the mapped dune shapes. Each dune forms were assigned a letter corresponding to the dominant wind direction at the time of activity (Table 2). This process made the digitizing simpler in addition to making the morphology easier to read on the display.

Table 2 Letter designations used in mapping inferred wind vector directions

Name	Predominant forming wind	Compass range in degrees
A	SW quadrant	180°-270°
B	NW quadrant	270°-360°
C	SE quadrant	90°-180°
D	NE quadrant	0°-90°

5. Manually draw a line perpendicular to the center of the crest from the leeward side of the dune (Fig. 7).

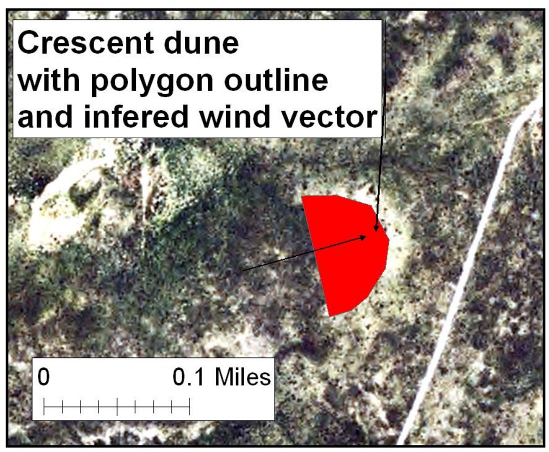

Figure 7 Crescent dune with polygon outline and implied paleowind vector

*Appendix A contains the complete maps (blowout dunes, large dune crests and vectors) for each site.

6. Obtain a direction from the vector arrow (1-360 degrees) using ArcGIS. This process is explained in Appendix B.

7. Cross check each dune map on each study site with the digitized soil map to determine the incidence of each dune type (blowouts/crescent and ridge) dunes on each soil series.

8. Cross check each dune map on each study site with the vegetation map to determine the frequency of dunes within each vegetation type.

9. Using a combination of soil data, vegetation and appearance of the dunes (observable erosion to the dune), define a chronology of generations for each site in the study area.

10. Create a summary wind direction rose for each generation and a total for each site in the study area.

11. Analyze the relation between dune generations and dune types with soil development and vegetation.

Final Analyses

This phase includes a corroboration of dune shape and paleowind vectors with soil development and vegetation. The following Tables include the soil series and vegetation types that are included in the study.

It was expected that older dunes correspond to those soil series with better developed soils. The soil series provided by the soil surveys for the study areas are listed in Table 3. The sequence of soil development goes from barren sand on active dunes (*e.g*., Ac and DUN) through incipient soils (*e.g.,* soil series Jst, DuTH, Tv) to series with more developed soils (*e.g.,* soil series Vb, Pc, OpD).

Table 3 Key of soil series abbreviations

Soil Key	Soil Series
Ac	Dune Land
Dd	Dalhart fine sandy loam, 0-3% slopes
DUN	Dune Land
DuTH	Dune Land-Tivoli complex 3-60% slopes
GcsA	Gracemore loamy fine sand, saline, 0-1%, frequently flooded
JstC	Jester C loamy fine sand, 1-5% slopes
JstF	Jester fine sand, 5-20% slopes
Ln	Lincoln loamy sand, 0-1% slopes, frequently flooded
Ma	Conlen fine sandy loam, 3-5% slopes
Mb	Conlen Loam, 1-3% slopes
Mc	Conlen loam, 3-5% slopes
Md	Conlen Dalhart complex, 1-3% slopes
Me	Conlen Plack complex, 3-12% slopes
OpD	Mobeetie-Devol complex, 3-12% slopes
Pc	Plack Kerrick, 1-3% slopes
Pt	Vona-Tivoli complex, 5-30% slopes
Tv	Tivoli fine sand, 12-30% slopes
TivE	Tivoli loamy fine sand, 5-12% slopes
TivG	Tivoli fine sand, 8-30% slopes
Vb	Vona-Valent complex, 3-5% slopes
Wm	Woodward-Masonic complex, 3-15%

The vegetation types provided by the GAP maps for the five study regions are summarized in Table 4. The sequence of vegetation success from a recently stabilized dune (VEG 134 and VEG136), through early succession phases (VEG136 and VEG 107) to a series of advanced vegetation phases (VEG 67, VEG 109, VEG 147, VEG149, VEG 120 and VEG 163). The most advanced vegetation type observed in dunes is VEG 163.

Table 4 Key of vegetation type codes used in analysis

GAP key code	**Vegetation Type**
VEG 0	Not Available*
VEG 28	Western Bottomland Forests
VEG 67	Sandsage Prairie
VEG 104	Gypsum Grasslands
VEG 107	Midgrass Sand Prairie
VEG 109	Midgrass Sandsage Prairie
VEG 112	Midgrass Prairie
VEG 120	Grama-Buffalograss Prairie
VEG 134	Barren – a majority of the ground is bare
VEG 136	Sandy Areas
VEG 147	Crop "Warm Season"
VEG 149	Improved/Introduced Pasture; Warm Season
VEG 163	Sandsage Savanna

* Information for this type was not available, since it falls outside state boundaries. However, none of the analyzed dunes have this type.

CHAPTER IV

RESULTS

Overview

In the course of this research, a total of 8819 crescent and blowout dunes and 694 large dune crests were mapped in the five study areas. A closer look at the aerial photos and field observations provided evidence that blowout and crescent dunes are a more recent than hairpin and transverse dunes, as well as other large dunes. Based on this interpretation the blowout dunes are used to construct winds of more recent activity periods and the large dune crests are used for interpreting paleowind in the older generations.

Site A: SW Cimarron County

Two generations of sand dune formation were identified at this location. The older dune generation (Generation 1) has a lower density of both blowouts/crescent dunes and large dune crests than the other sites. The dune crests that were observable in the NAIP image were a mix of NW and SW orientation (Fig. 8). Generally the transverse ridge dunes were oriented to from the NW while the hairpin dunes are oriented to the SW. The distribution of paleowind direction reconstructed from Figure 9 shows that there is more influence of winter winds during dune development than the mesonet data (Fig. 3) provided. There is also a significant occurrence between W and SSW, containing 49.2% of the blowout/crescent dune forms.

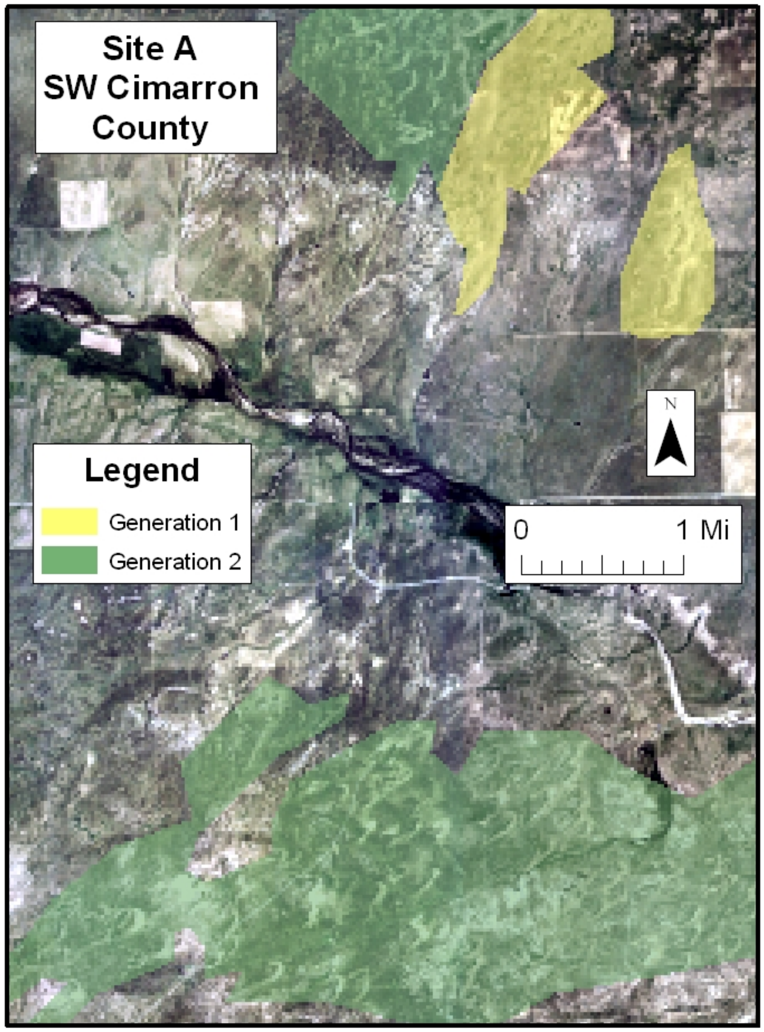

Fig. 8 Map of dune generations at Site A

Overall the distribution of crescent/blowout dunes were in groups from the NW and SW (Fig. 9) Figure 10 shows that there is a much higher incidence of the crescent/blowout dunes with a NW paleowind orientation in the older generation (1) and a relatively small amount of dunes with a SW orientation.

There were numerous blowout and crescent dunes in Generation 2 (fig 11). There is a higher incidence of blowout/crescent dunes with an NW orientation in the Southern group of Generation 2 than the northern grouping. The northern grouping had a relatively higher occurrence of large dune crests with a SW orientation (fig 11).

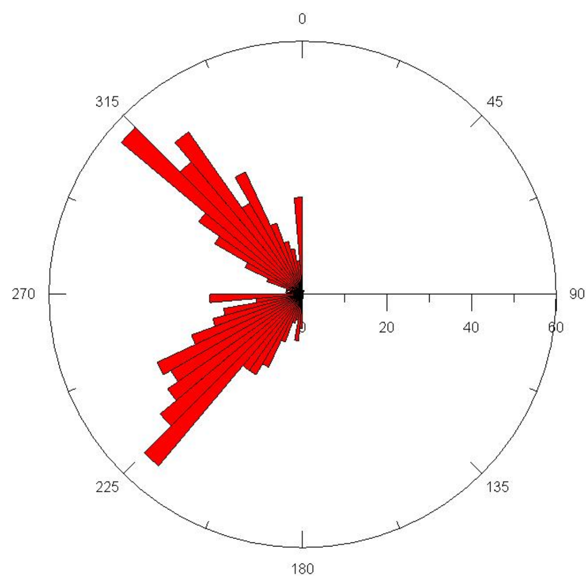

Figure 9 Site A paleowind directions

inferred from mapped blowout/crescent dunes

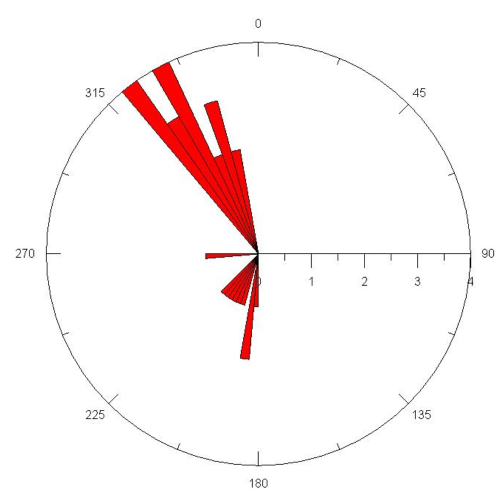

Fig 10 Site A Generation 1 paleowind directions

inferred from blowout/crescent dunes

The second generation (Generation 2) has a higher percentage of dunes in the southwest quadrant than the first generation (Fig. 11). The NW winds directions were skewed slightly more to the west than north in the second generation (Fig. 11).

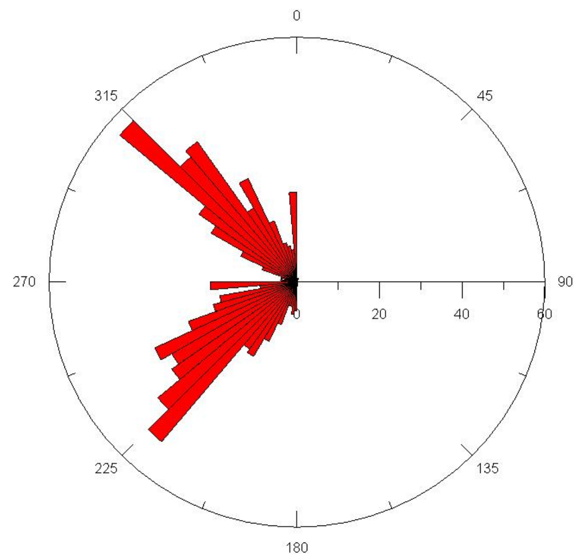

Fig. 11 Site A Generation 2 paleowind directions inferred from mapped blowout/crescent dunes

The distribution of large dune crests has two concentrations; one out of the NW and one out of the SW (Fig. 12). The NW orientation has a higher occurrence overall. In Generation 1 the orientation was predominantly out of the west with lower concentrations occurring in the SW and NNW (Fig. 13).

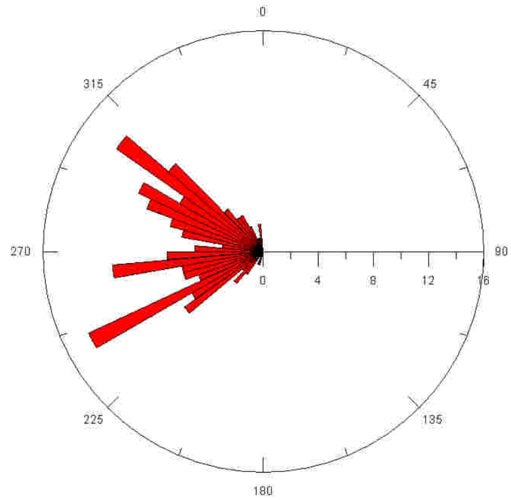

Fig. 12 Site A paleowind directions

inferred from large dune crests

Generation 2 has a more even distribution than Generation 1, with a broader distribution in the SW quadrant (220° and 270°) than the NW quadrant which had occurrence between 280° and 315° (fig. 14). Overall the distribution of paleowinds inferred from the blowout/crescent dunes and the large dune crests were very similar.

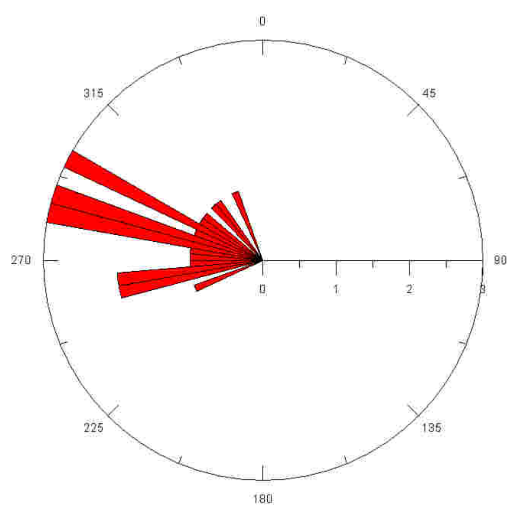

Fig. 13 Site A Generation 1 paleowind

directions inferred from large dune crests

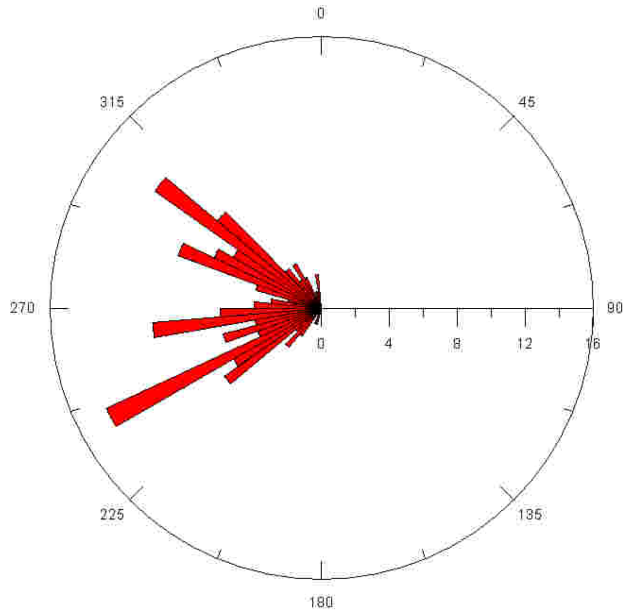

Fig. 14 Site A Generation 2 paleowind

directions inferred from large dune crests

This site had very little difference in the soil series occurrence of blowout/crescent dunes or large dune crests. There was an 85% occurrence of blowouts on the Vona series (Figure 15). Likewise there is an 83.33% occurrence of large dune crests on the Vona series (Fig. 16). The interpretation of these findings is that the soils of this site have eroded to the point at which Vona series is the only sandy soil with enough available material for dune development.

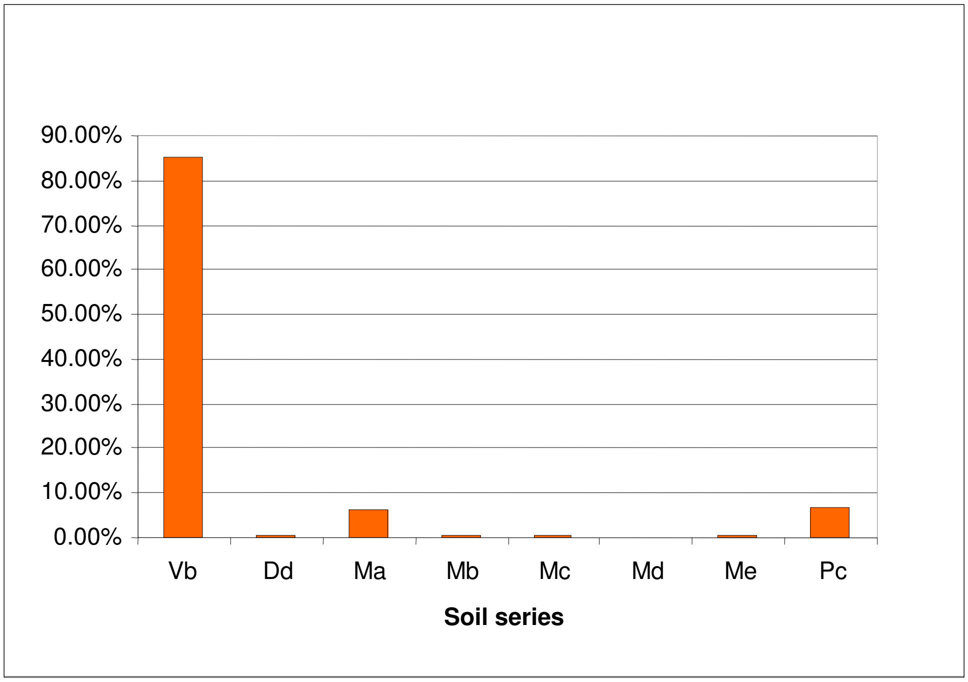

Fig 15 Site A blowout/crescent dune occurrence on soil series

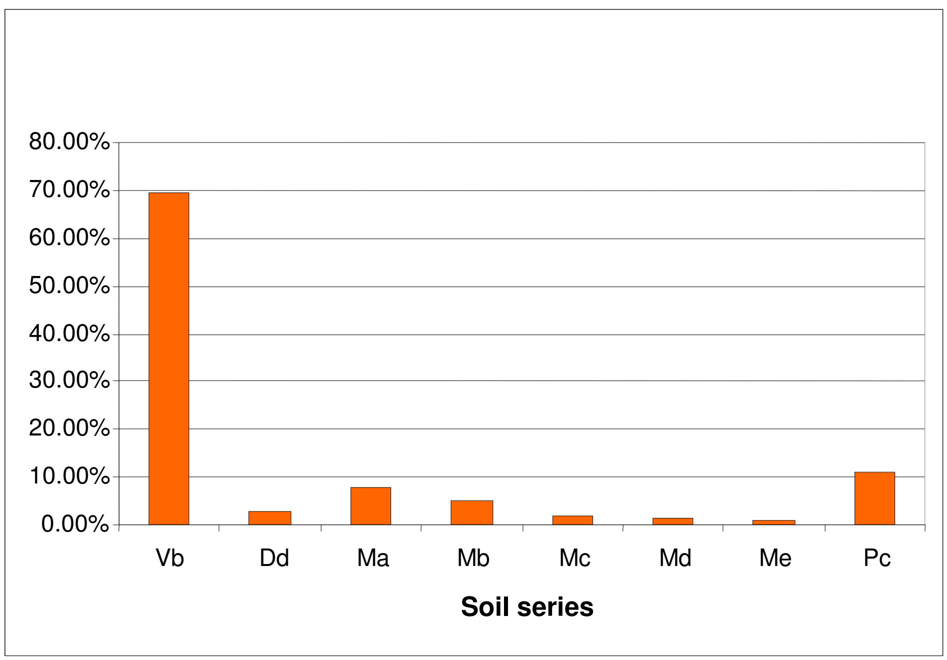

Fig. 16 Site A large dune crest occurrence on soil series

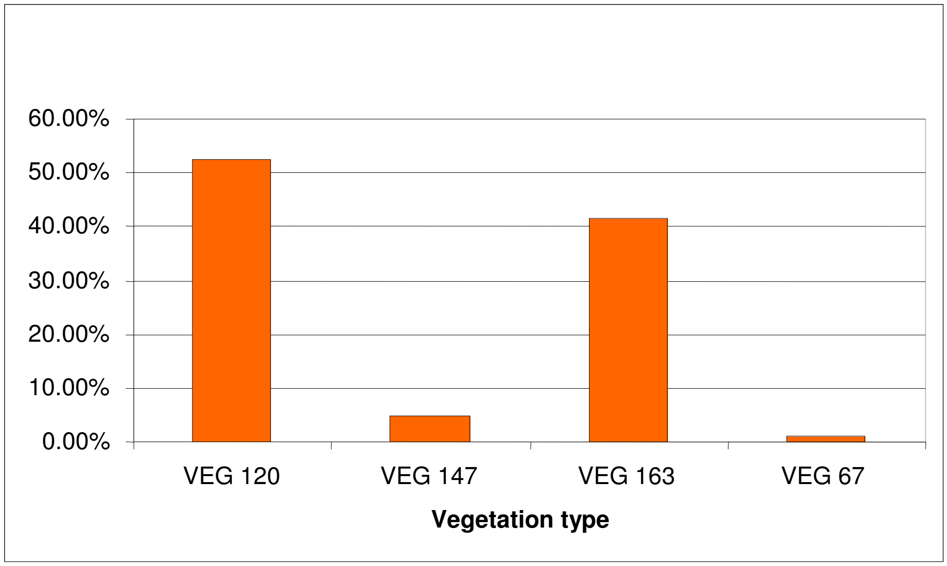

Fig. 17 Site A blowout/crescent dune occurrence on vegetation type

The majority of the blowout and large dune groups are split between the gramma-buffalograss prairie (VEG 120) and the sandsage savanna (VEG 163) (Figs. 17 and 18).

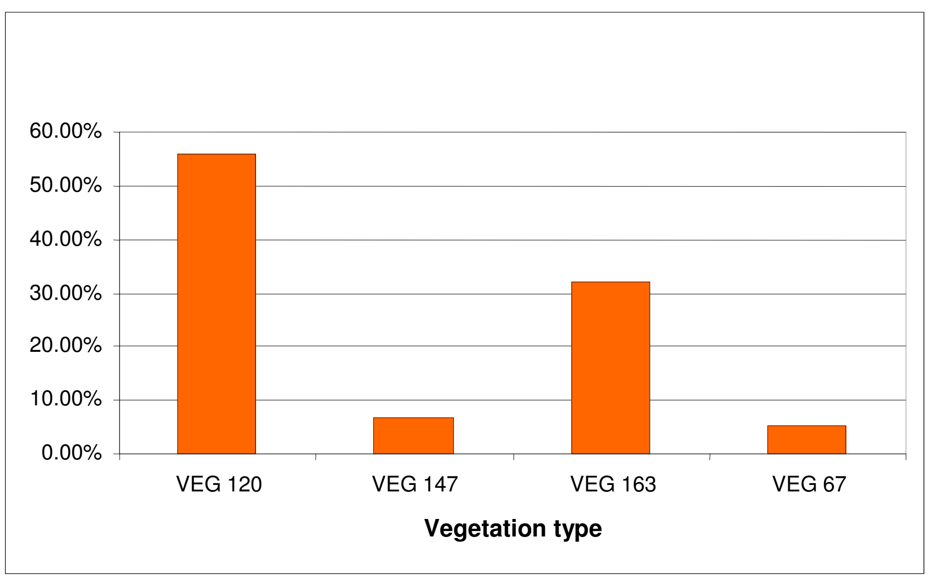

Fig. 18 Site A large dune crest occurrence on vegetation type

As expected that younger dunes are associated with gramma-buffalograss prairie where as the older generations are associated with the sand sage savanna. Over 50% of the dunes in Generation 1 occurred in VEG 163 (sandsage savannah), while the rest were split between the other three vegetation types (Fig. 19). Generation 2 occupies over 50% of VEG 120 with lesser amounts of the other three vegetation types (Fig. 20). This is significant because this supports the interpretation of the chronology of the generations. That is to say that more developed vegetation (eg. Type 163) would be indicative of older dunes.

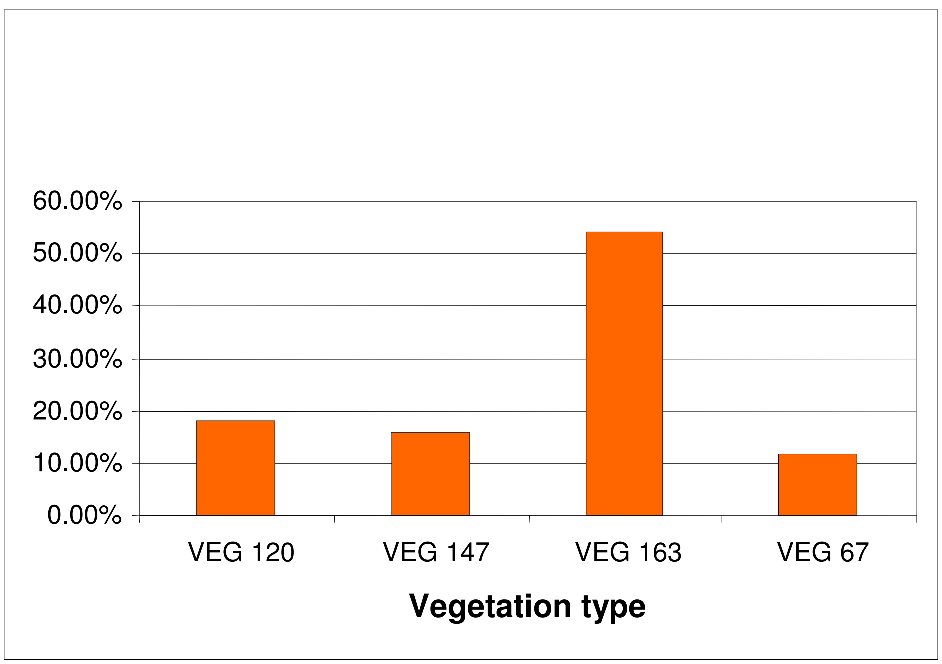

Fig. 19 Site A Generation 1 vegetation distribution

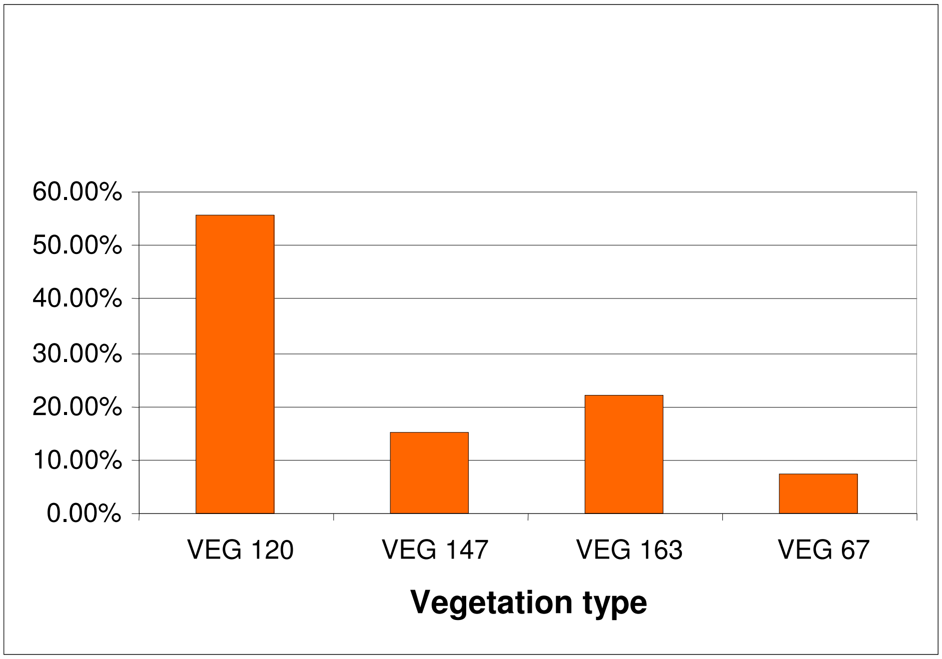

Fig. 20 Site A Generation 2 vegetation distribution

Site B NE Cimarron County

At this location three generations of sand dunes were identified (Fig. 21). Paleowind directions out of the north to west-north-west made up 57.18% of the total dune orientation while WSW to SSW accounted for 32.37% of mapped dune forms across the entire site (Fig. 22). The blowout and crescent dunes of Generation 1 have a predominant paleowind direction out of the NW with lesser amounts from the SW (Fig. 23).

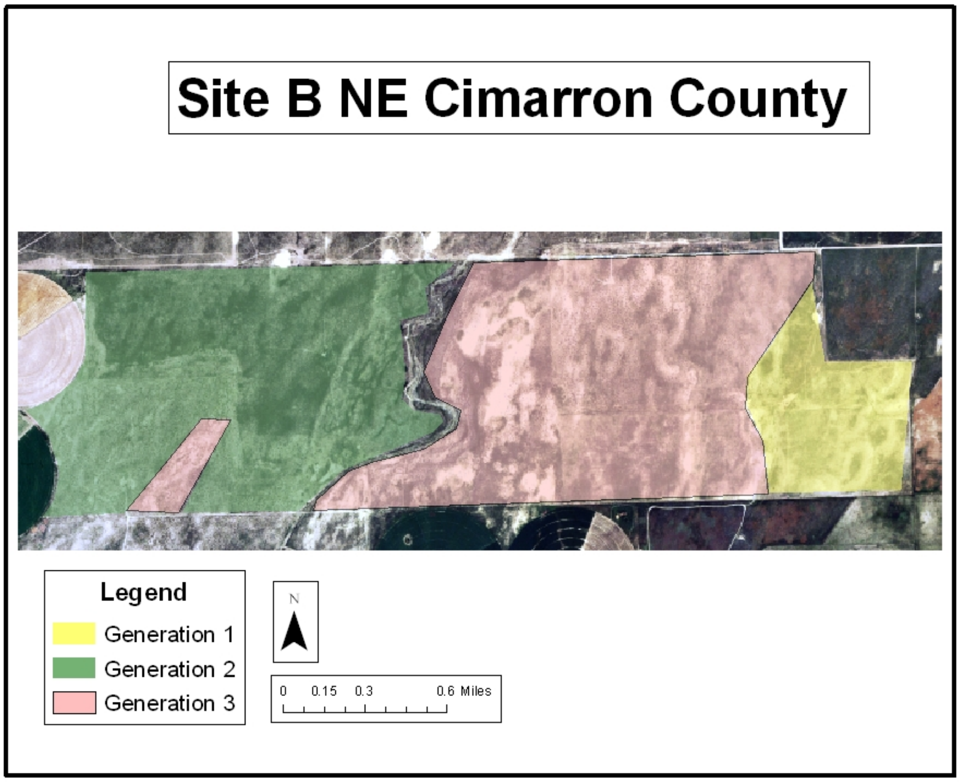

Fig. 21 Map of dune generations at Site B

Blowout and crescent dunes of Generation 2 also has predominantly NW paleowind direction, although more concentrated between 315° and 325° (Fig. 24). Generation 3 is predominantly in the NW paleowind direction with a smaller grouping in the SW (Fig. 25)

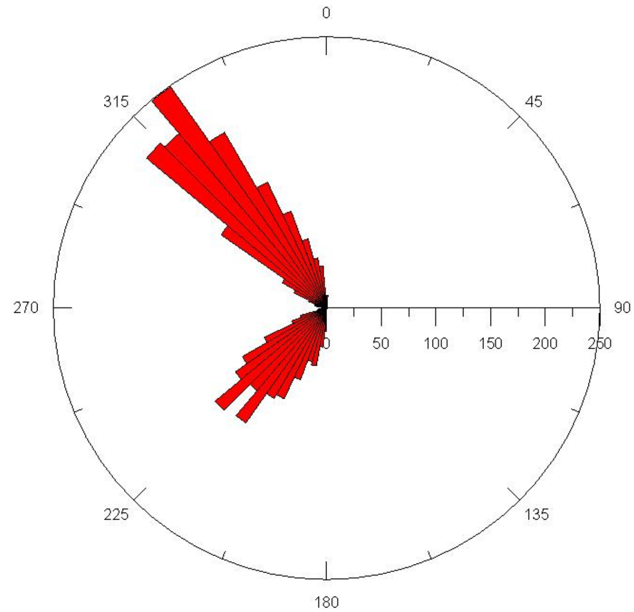

Fig.22 Site B paleowind directions inferred

from mapped blowout/crescent dunes

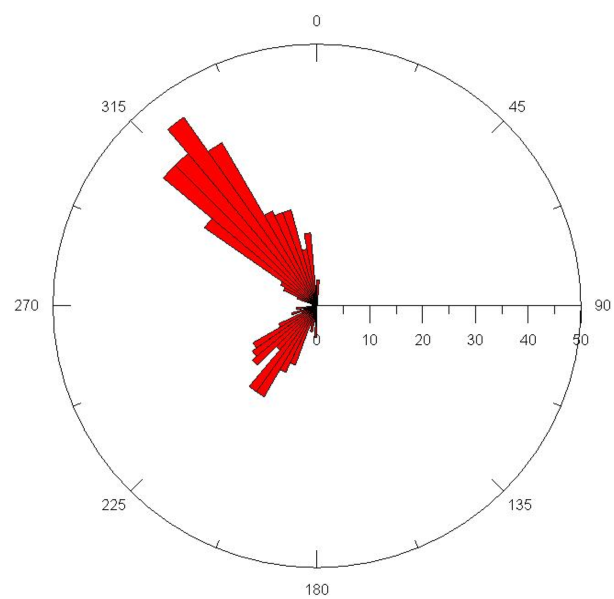

Fig.23 Site B Generation 1 paleowind directions

inferred from blowout/crescent dunes

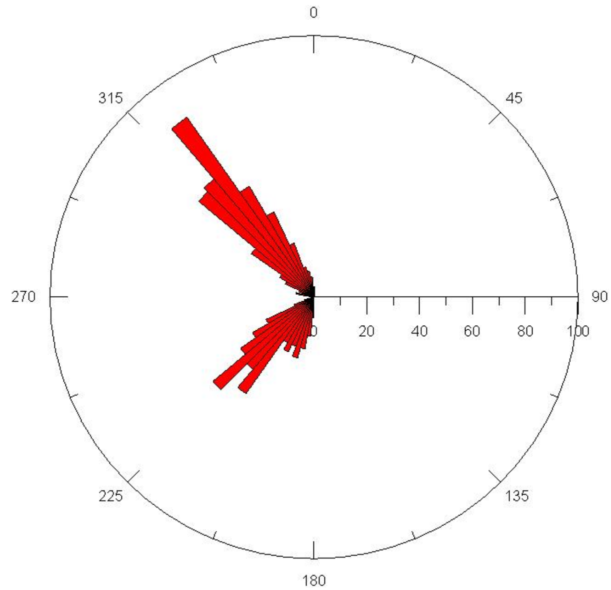

Fig. 24 Site B Generation 2 paleowind directions
inferred from blowout/crescent dunes

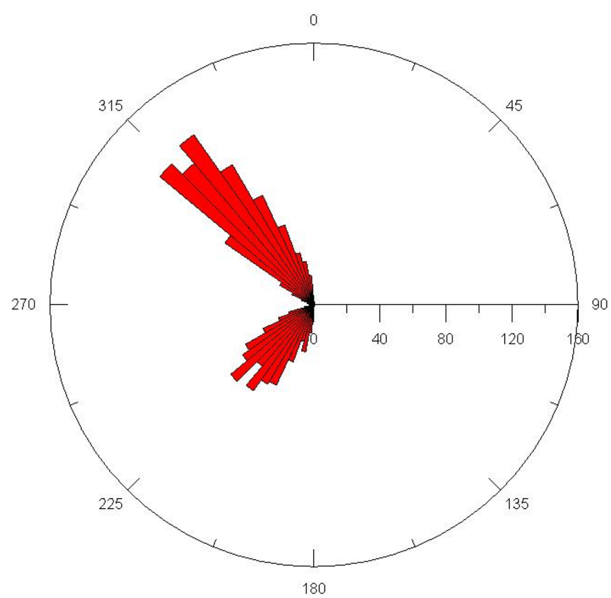

Fig. 25 Site B Generation 3 paleowind directions
inferred from blowout/crescent dunes

Distributions of the paleowind vectors of the large dune crests were concentrated in the NW quadrant, with higher percentages between 290° and 315° (fig. 26). Generation 1 had the fewest large dune crests mapped which are distributed was between 230° and 350° and concentrated between 295° and 325° (Fig. 27).

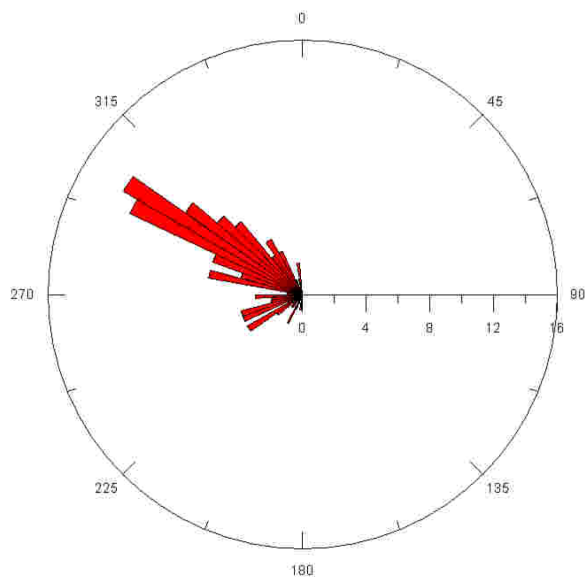

Fig. 26 Site B paleowind directions inferred from large dune crests

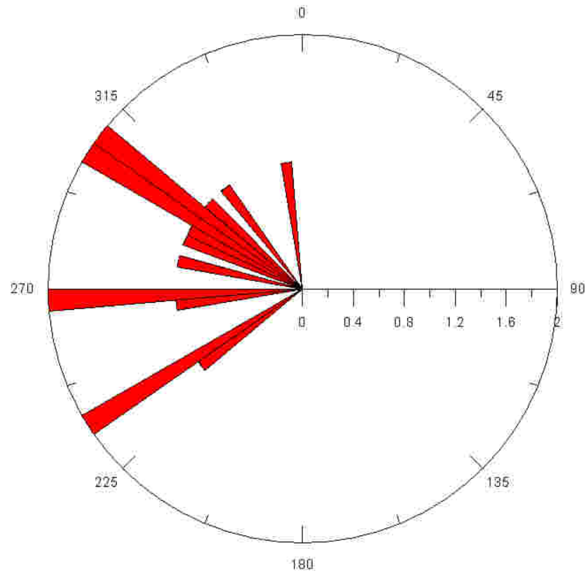

Fig. 27 Site B Generation 1 paleowind

directions inferred from large dune crests

The large dune crests of Generation 2 are concentrated in the NW quadrant with the highest occurrence between 295° and 330° (Fig. 28), while those of Generation are concentrated in the NW quadrant between 295° and 315° and a lower percentage in the SW quadrant between 225° and 270° (Fig. 29). The inferred paleowind distribution had a similar pattern in the mapped blowout/crescent dunes and the large dune crests.

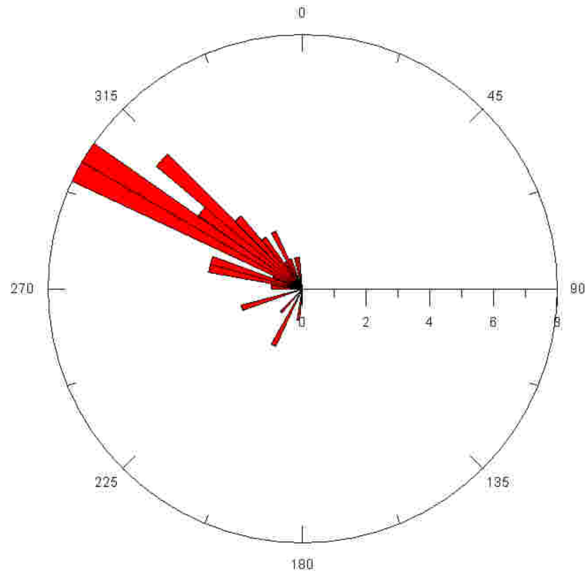

Fig. 28 Site B Generation 2 paleowind

directions inferred from large dune crests

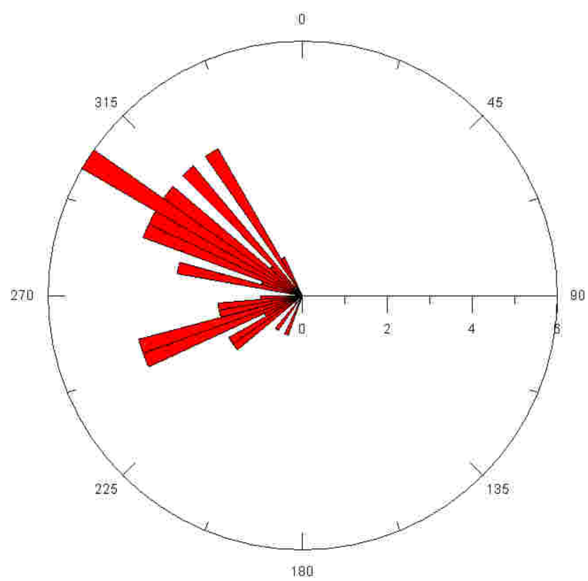

Fig. 29 Site B Generation 3 paleowind

directions inferred from large dune crests

Blowout/crescent dunes and large dune crests at this site predominate in the Vona Series. Blowout/crescent dunes occurred at 94.2% (fig. 30) and large dune crests occurred at 93% (Fig.31) in the Vona series. The soil at this site was not a good indicator of relative age since the majority of mapped dunes all occurred on the Vona series.

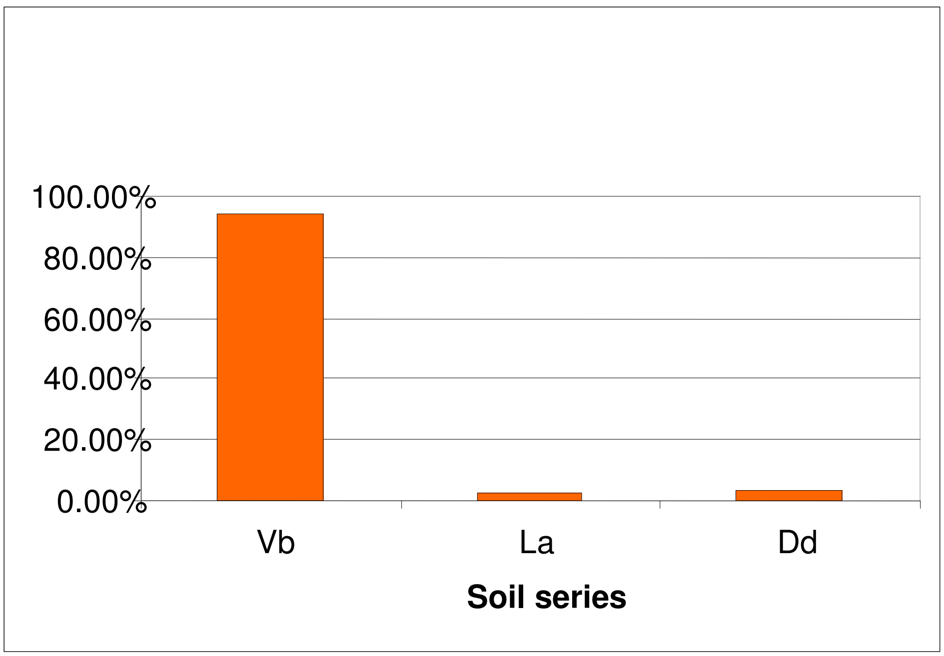

Fig. 30 Site B blowout/crescent dune occurrence on soil series

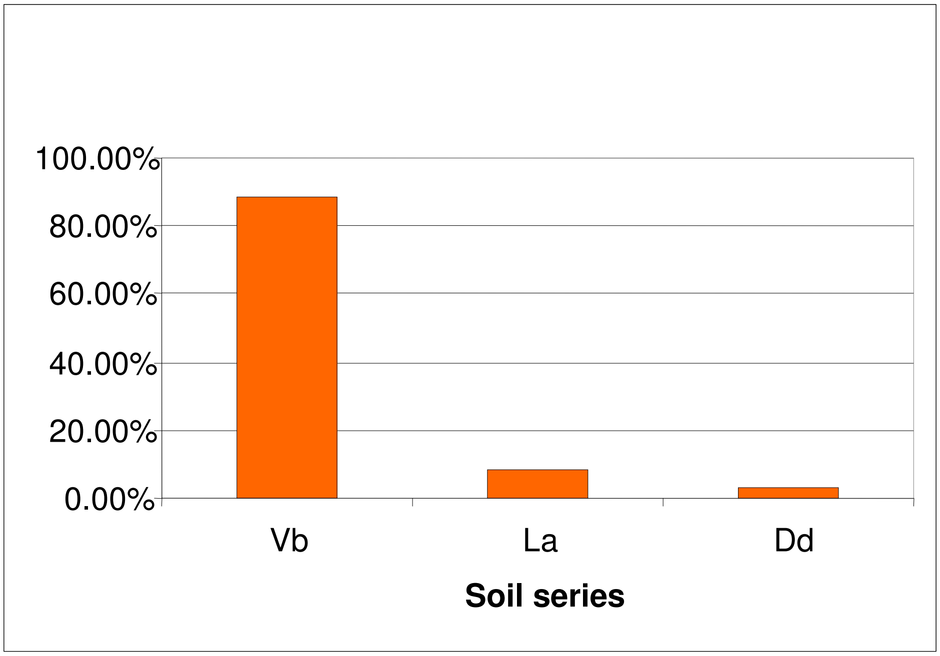

Fig. 31 Site B large dune crest occurrence on soil series

Dunes within this site occurred on two main vegetation types. The majority of dunes in the site were mapped on "Crop-warm season" (VEG 147) with the only other significant occurrence being on gramma-buffalograss prairie (VEG 120) (figs. 32 and 33). These vegetation types are both indicators of relatively long periods without disturbance. It is possible that the close proximity of agricultural activity has had an effect on the relationship of the dunes to the vegetation. All dunes of Generation 1

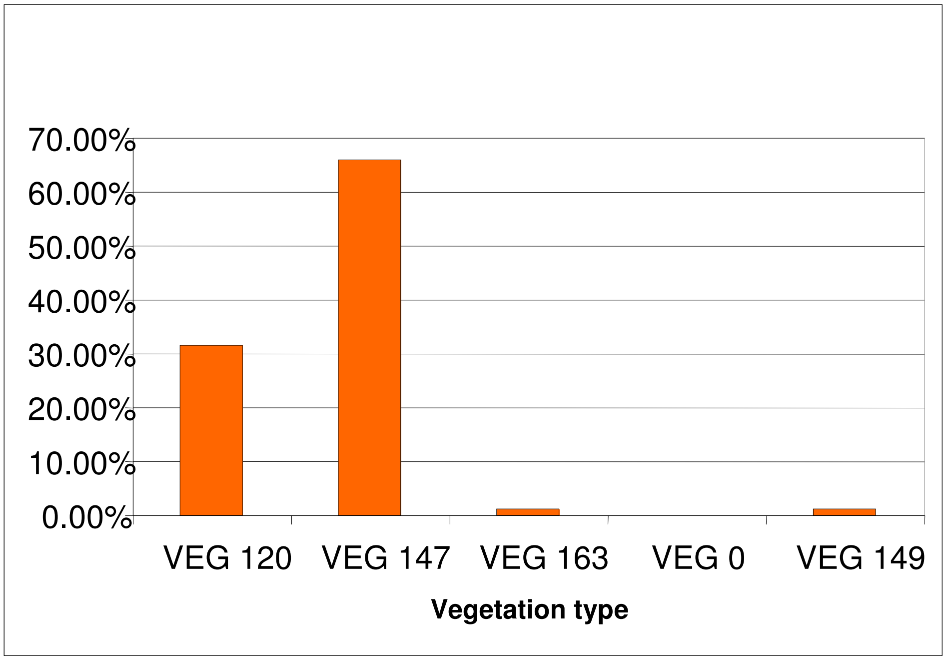

Fig. 32 Site B blowout/crescent dune occurrence on vegetation type

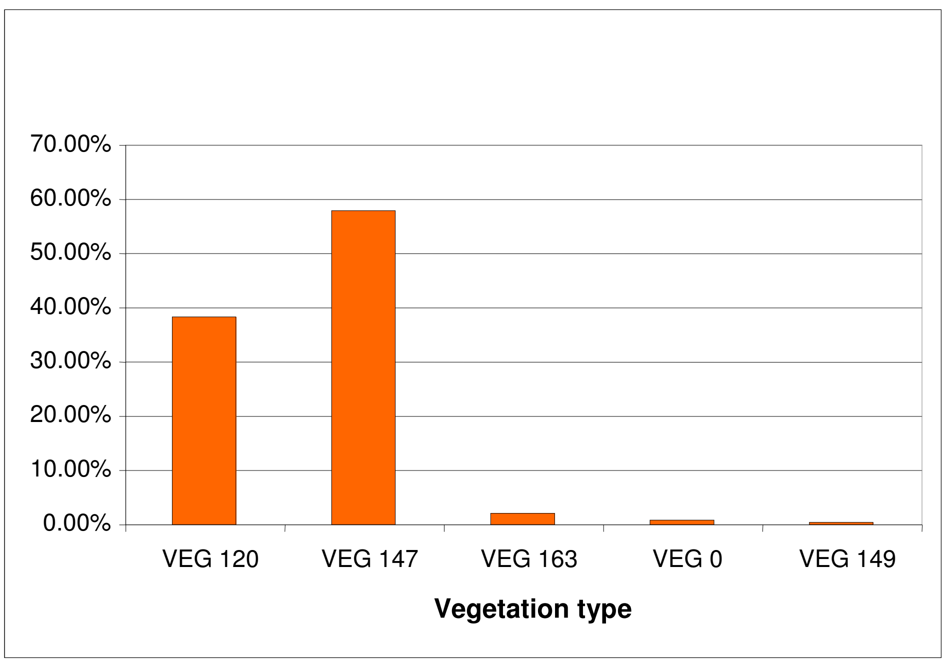

Fig. 33 Site B large dune crest occurrence on vegetation type

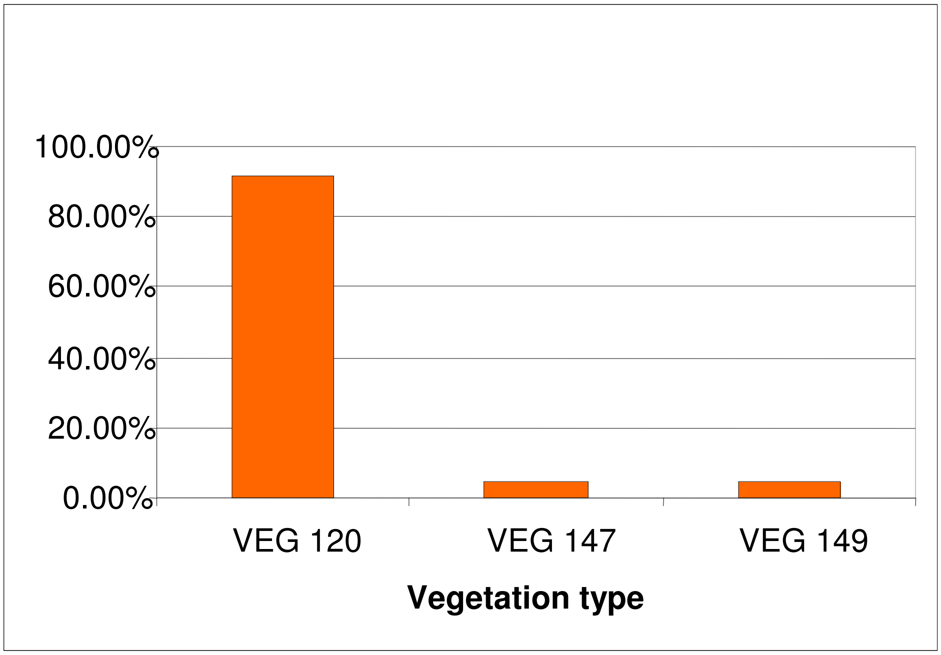

Fig. 34 Site B Generation 1 vegetation distribution

have a 90% occurrence of dunes on VEG 120 and less than 5% each on VEG 147 and VEG 149 (Fig. 34). No dunes were found on VEG 163. The dunes of Generation 2 have a nearly 71% occurrence on VEG 147, and almost 30% on VEG 120 (Fig. 35). The dunes of Generation 3 have a wider distribution across vegetation type than the other two generations. Vegetation occurrence was 57% in VEG 120, 21% in VEG 147, and 10% in VEG 163 and VEG 149 (Fig. 36). This distribution pattern was not expected, these vegetation types are indicative of a more recent disturbance than other generations. Presumably, disturbance by agricultural activity affected this distribution pattern.

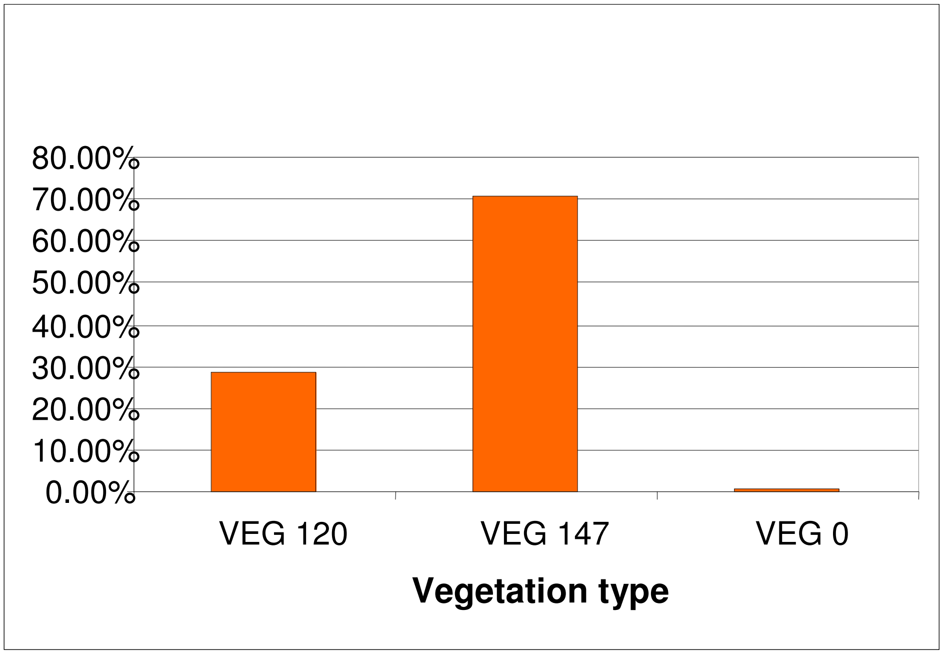

Fig. 35 Site B Generation 2 vegetation distribution

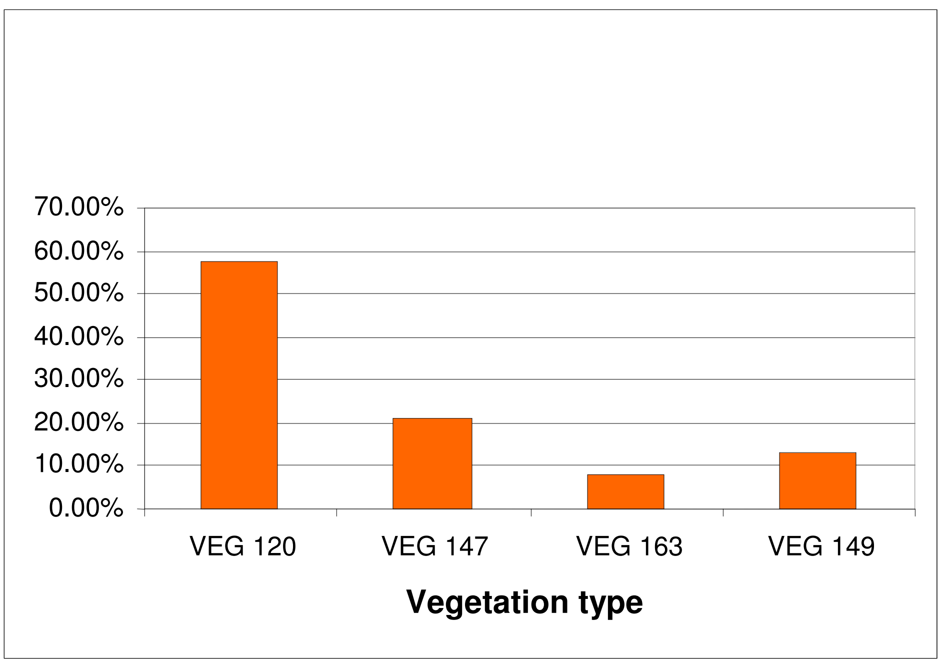

Fig. 36 Site B Generation 3 vegetation distribution

Site C Beaver Dunes State Park

There were three generations found in this site. Generation 1 is located in the northern end of the site outside the park, Generation 2 is located in the area within the park boundary, closer to the Beaver River to the south and Generation 3 is the area of active dune located in the park (Fig. 37). Generation 3 consists of fully active dunes with no vegetative cover.

Paleowinds inferred from mapped blowout/crescent dunes at this locality are concentrated in the NW, particularly around 330° (Fig. 38). However, a considerable number of paleowind directions were found in the SW (Fig. 38). Blowouts and crescents in Generation 1 have a majority of their paleowind directions occurring in the NW, with a concentration from 310°-315° and 320°-325° (Fig. 39), and a SW component directions between 220° and 215° (Fig. 39). Generation 2 has a higher concentration of paleowind direction in the NW and a sizeable occurrence in the SW (Fig. 40). The dunes in Generation 3 are not visible in the NAIP image because there is no color contrast or texture on the bare sand. Therefore, these dunes were not mapped in this study and there is no wind rose associated with Generation 3.

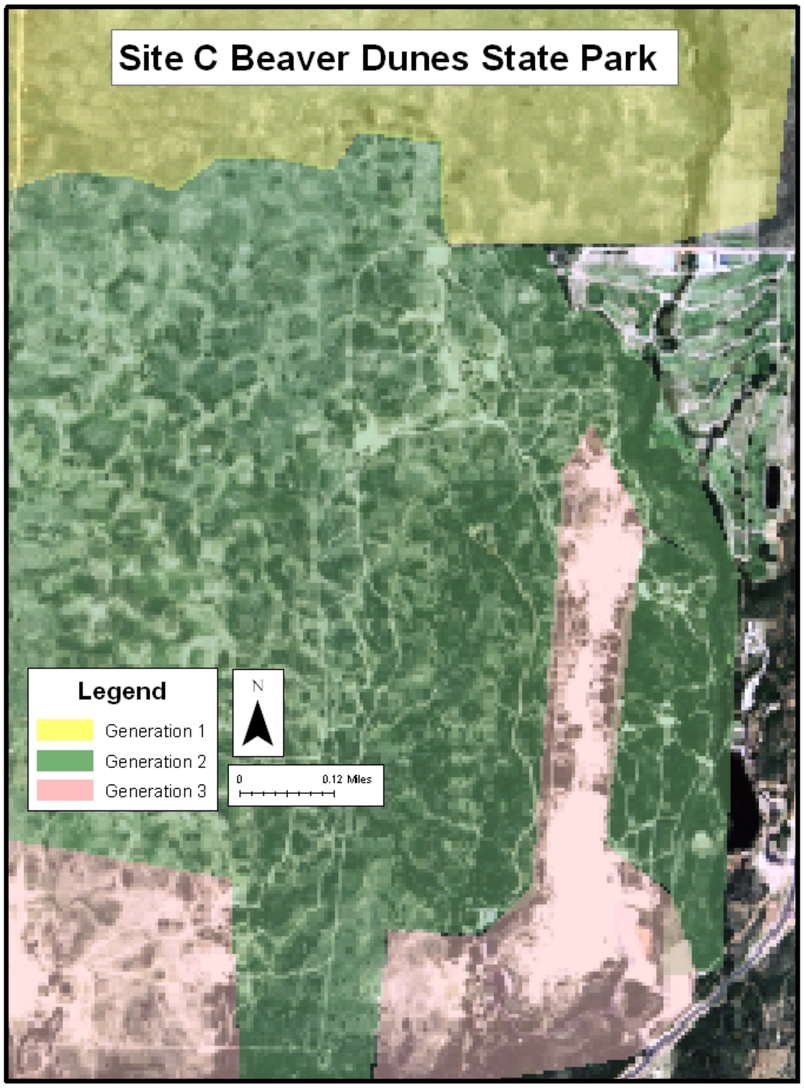

Fig. 37 Map of dune generations at Site C

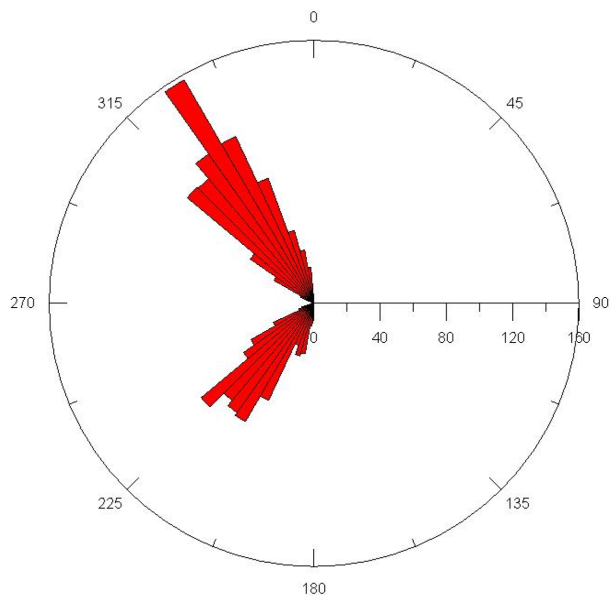

Fig. 38 Site C paleowind directions inferred

from mapped blowout/crescent dunes

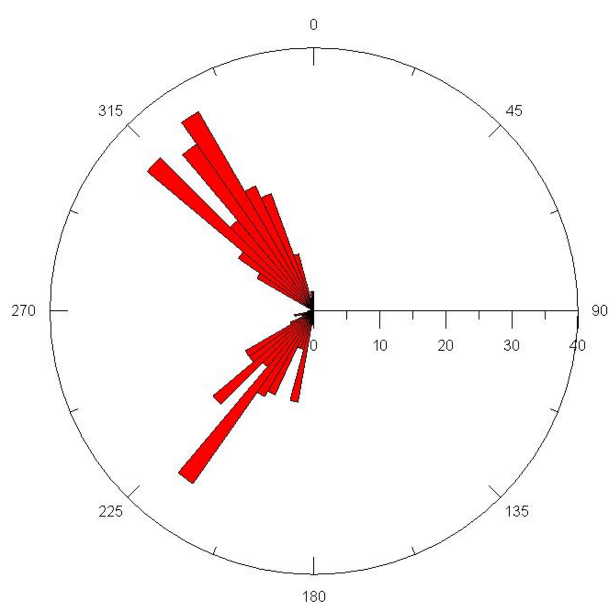

Fig. 39.Site C Generation 1 paleowind directions

inferred from blowout/crescent dunes

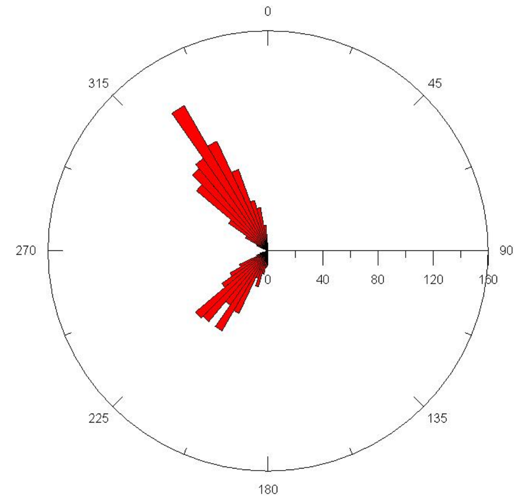

Fig. 40 Site C Generation 2 paleowind directions

inferred from blowout/crescent dunes

Paleowinds inferred from large dune crests in Site C distributed between the NW and SW quadrants with a higher percentage in the SW (Fig. 41). Large dune crests in Generation 1 have a majority of paleowind directions occurring in the SW, with a concentration between 200° and 245° (Fig. 42). There were also large dune crests mapped at 290° and between 310° and 360° (Fig. 42). The large dune crests of Generation 2 have a higher concentration of paleowind directions in the NW and a sizeable occurrence in the SW (Fig. 40). Large dune crests in Generation 3 are not visible in the NAIP image because there is no color contrast or texture on the bare sand.

Site C is in contrast to the previous two sites in that the inferred paleowind directions differ from the two series of mapped dunes. The blowout/crescent group has a higher overall percent in the NW quadrant where as the large dune crest group has a higher percentage in the SW quadrant.

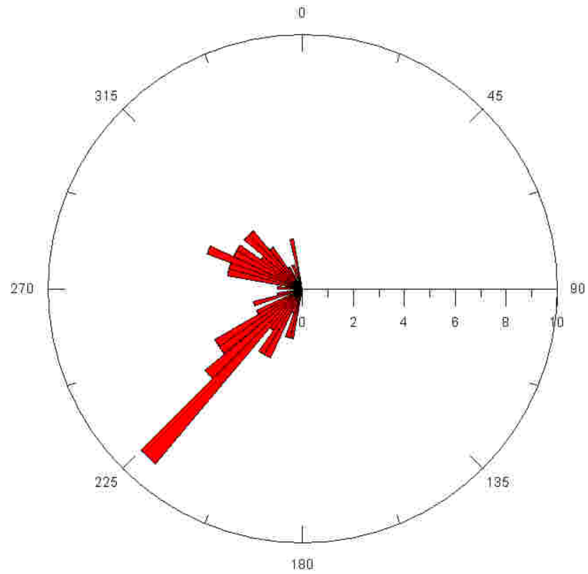

Fig. 41 Site C paleowind directions inferred

from large dune crests

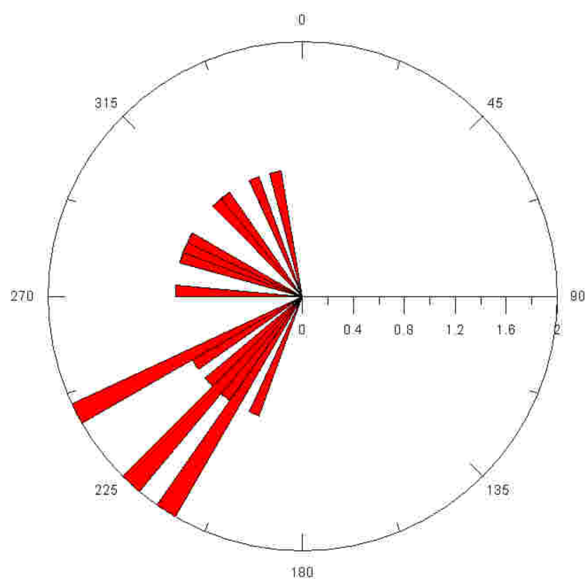

Fig. 42 Site C Generation 1 paleowind directions

inferred from large dune crests

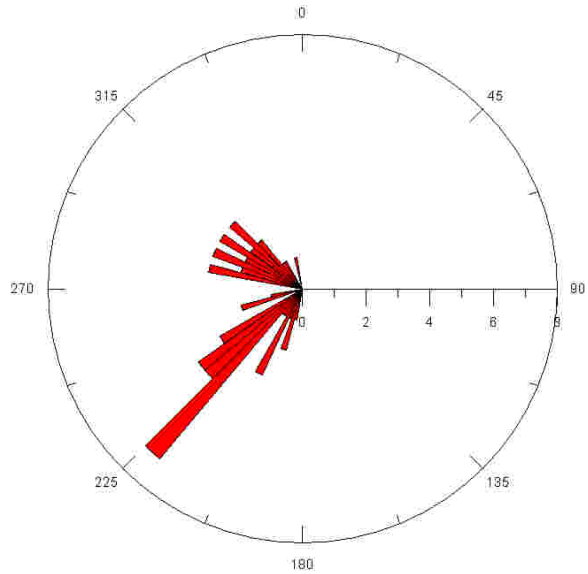

Fig. 43 Site C Generation 2 paleowind directions

inferred from large dune crests

Overall the Tivoli soils (Tv) contained the largest number of mapped dunes (Figs. 44 and 45). Vona-Tivoli (Pt) complex and dune land soils (Ac) also had areas of visible dunes. All dune types at Site C occurred on the Tivoli series, with 70% of blowout and crescent dunes and 67% of large dune crests (Figs. 44 and 45). Only 21% of the large dune crests occurred on the Vona-Tivoli soil series. Because of the high concentration of soils on the Tivoli series, they are not a good indicator of the age of the dunes on this site.

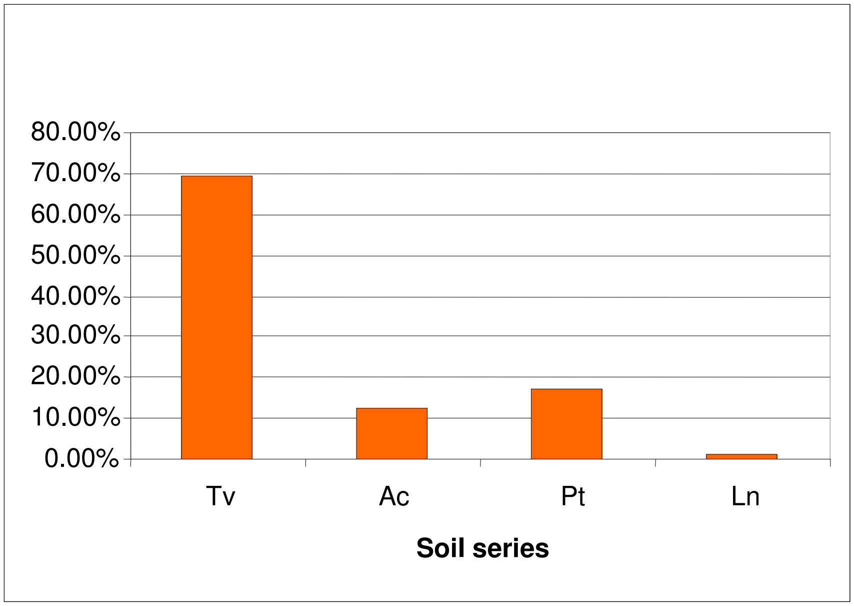

Fig. 44 Site C blowout/crescent dune occurrence on soil series

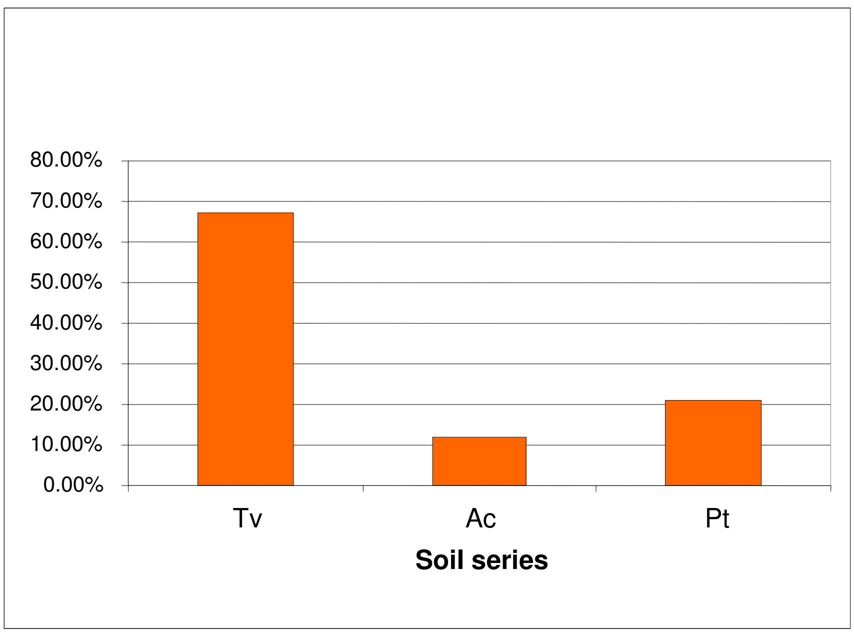

Fig. 45 Site C large dune crest occurrence on soil series

All of the dune types are concentrated on Sandsage Savanna (VEG 163) at 54% but the rest are distributed evenly among the other vegetation types (Fig. 46, 47). Other

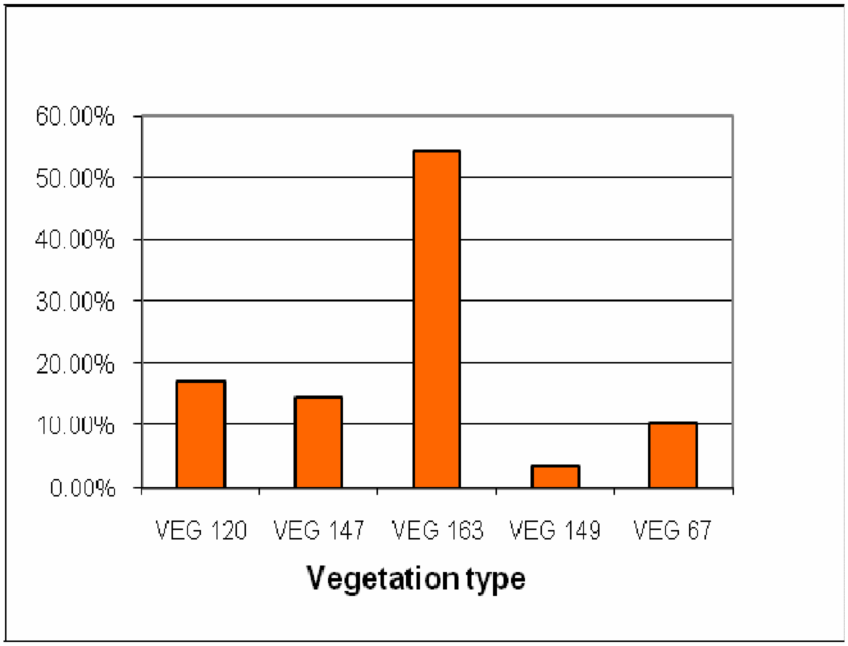

Fig. 46 Site C blowout/crescent dune occurrence on vegetation type

vegetation types with noteworthy incidence of dunes were Gramma-buffalograss prairie (120) and sand sage savanna (67) with a lesser amount of the Crop warm season (VEG 147) (figs. 46 and 47).

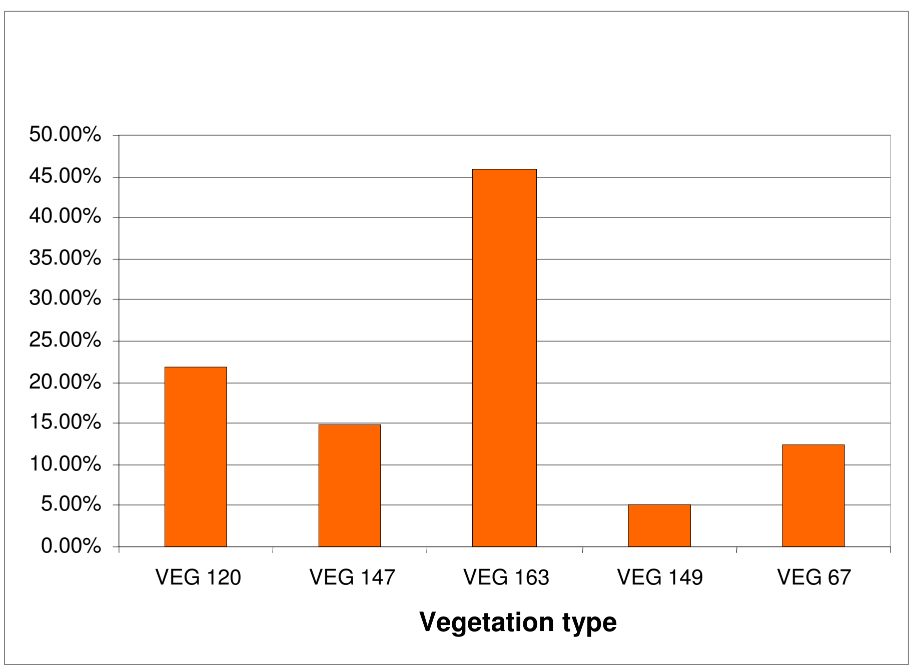

Fig. 47 Site C large dune crest occurrence on vegetation type

There is not much difference in the distribution of dune types among the vegetation types. The major difference in vegetation occurrence can be seen when the dunes are split into the two generations. The dunes of Generation 1 have a 57% occurrence associated with VEG 67 and 30% with VEG 163 (Fig. 48). The sandsage vegetation type would be indicative of a longer period of stability than a grass cover. The dunes of Generation 2 had a 43% coverage of VEG120, VEG 147 and VEG 163 at 16%,

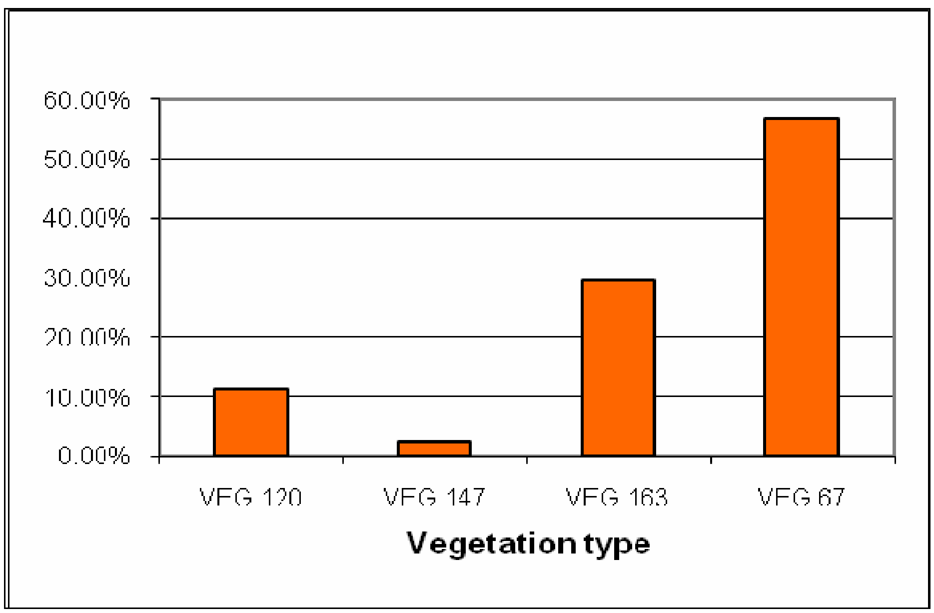

Fig. 48 Site C Generation 1 vegetation distribution

VEG 149 and VEG 67 at 12% and 13% (Fig. 49). VEG 120 (gramma-buffalograss) would be indicative of an early stage of vegetation succession in the stabilization process. The dunes of Generation 3 are active and do not have vegetative cover.

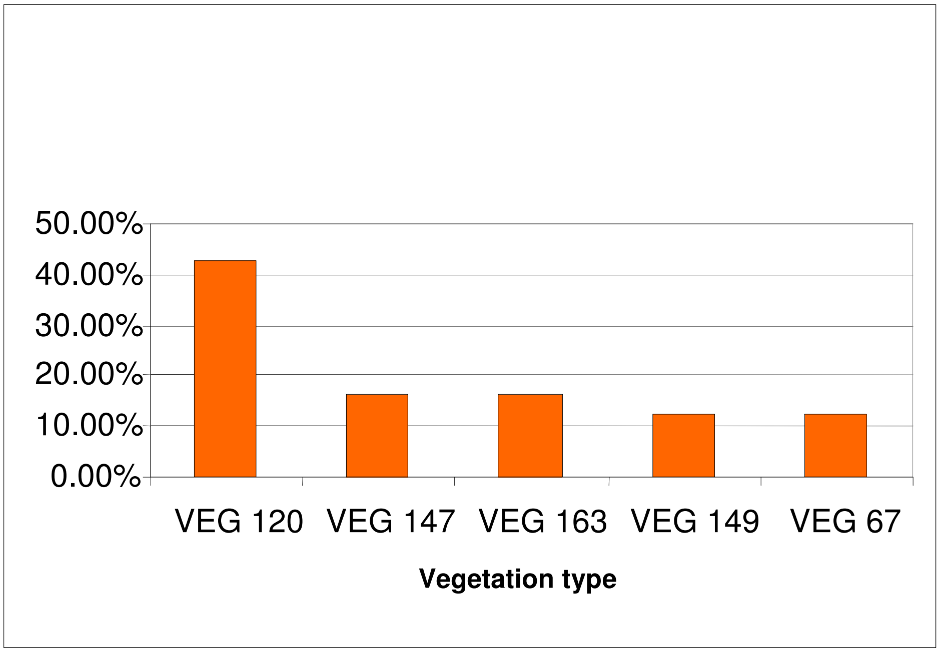

Fig. 49 Site C Generation 2 vegetation distribution

Site D Timber Creek Site

Inferred paleowind directions from blowout/crescent dunes at this location have a predominant direction in the NW and a lesser concentration in the SW (Fig. 50). Two generations resulted in the mapping of this site (Fig. 50). Generation 1 is located on the east side of the Timber Creek drainage area and Generation 2 is to the west (Fig. 50).

Overall blowout and crescent dune paleowind distribution shows a higher concentration in the NW (Fig. 51). Blowout and crescent dune paleowind distributions in the two generations differ in that Generation 1 has a higher incidence of NW dominant winds (Fig. 52). The blowout and crescent dunes of Generation 2 hahave a majority of occurrence in the NW quadrant but a higher incidence in the SW quadrant (Fig. 53) than Generation 1 (Fig. 52).

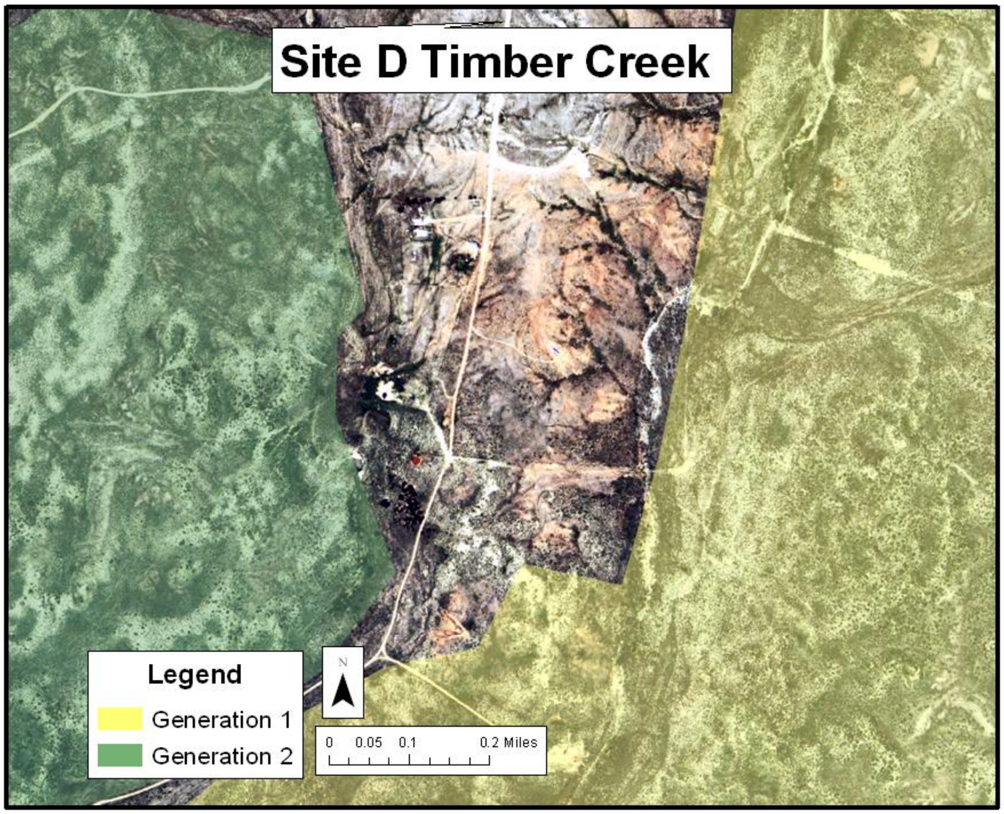

Fig. 50 Map of dune generations at Site D

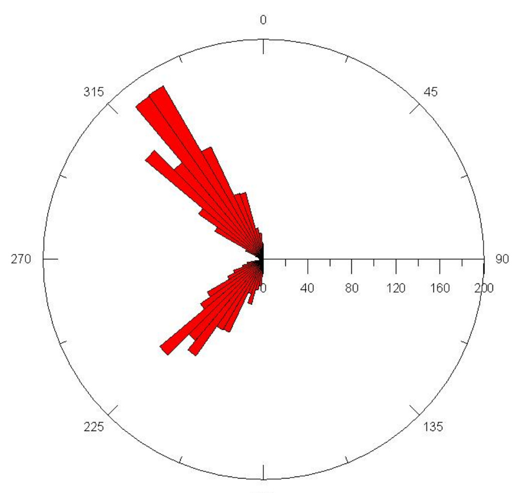

Fig. 51 Site D paleowind directions inferred

from mapped blowout/crescent dunes

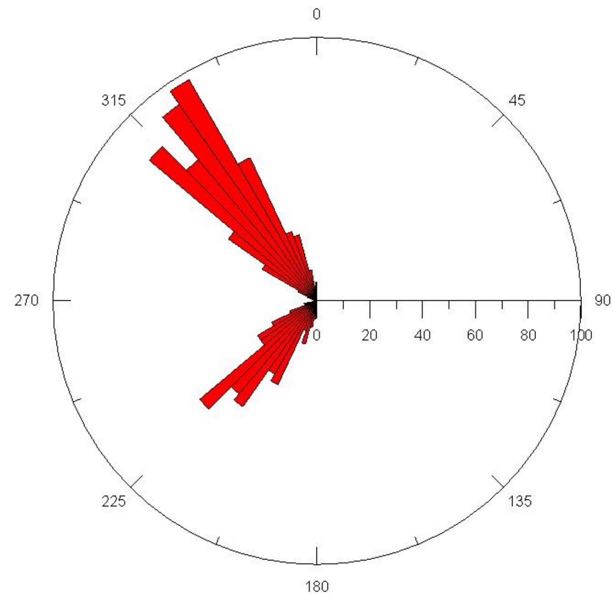

Fig. 52 Site D Generation 1 paleowind directions

inferred from blowout/crescent dunes

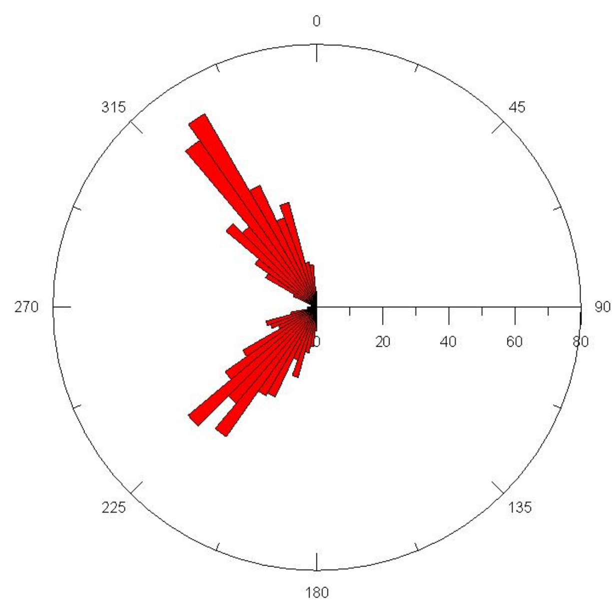

Fig. 53 Site D Generation 2 paleowind directions

inferred from blowout/crescent dunes

Overall inferred paleowind distribution from large dune crests show a higher concentration in the NW quadrant. Generation 1 has a higher incidence of paleowind directions between 275° and 325° (Fig. 54). Generation 2 has a majority of occurrence between 290° and 320° with a low occurrence in between 180° and 230° (Fig. 55). The distributions of paleowinds between the two mapped dune groups were both similar at Site D.

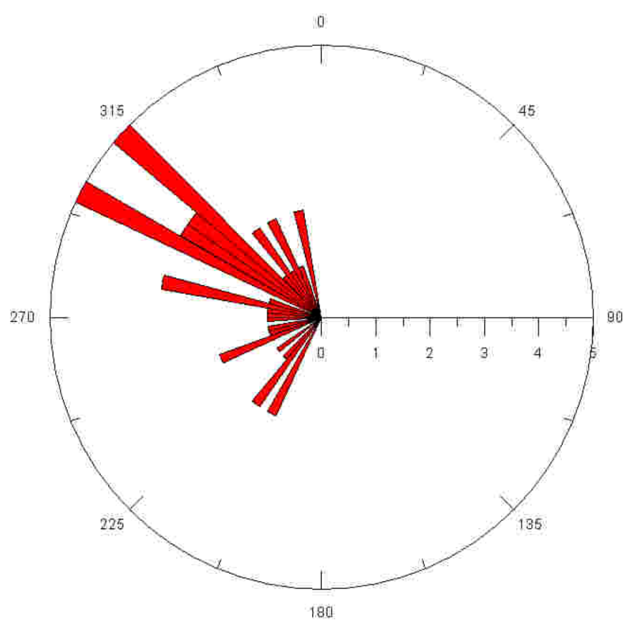

Fig. 54 Site D paleowind directions inferred

from large dune crests

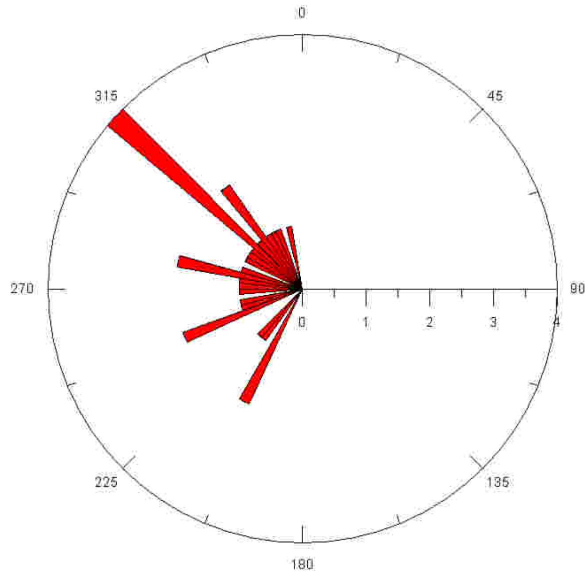

Fig. 55 Site D Generation 1 paleowind directions

inferred from large dune crests

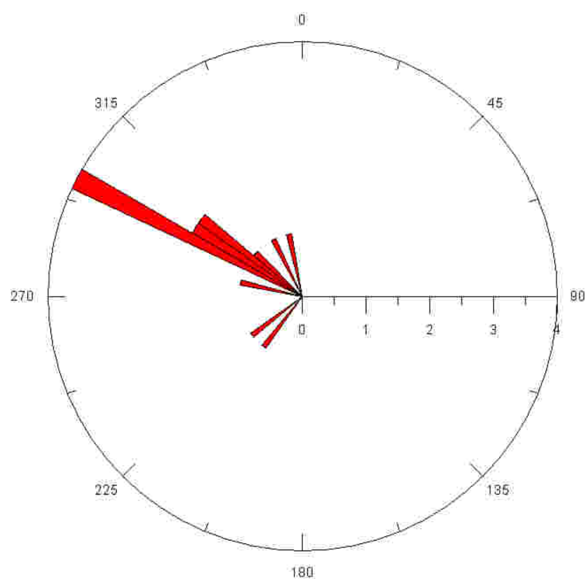

Fig. 56 Site D Generation 2 paleowind directions

inferred from crests

The Tivoli series has the majority of the mapped dunes at this site (Figs. 57 and 58). 51% of the blowout dunes occurred in the Tivoli (Tv) series and 26% on the Vona-Tivoli complex (Pt). 65% of large dune crests occurred in the Tivoli series (Fig. 58). There is no evidence that soil would be an indicator of dune age in this site, since most dunes are concentrated in one soil series.

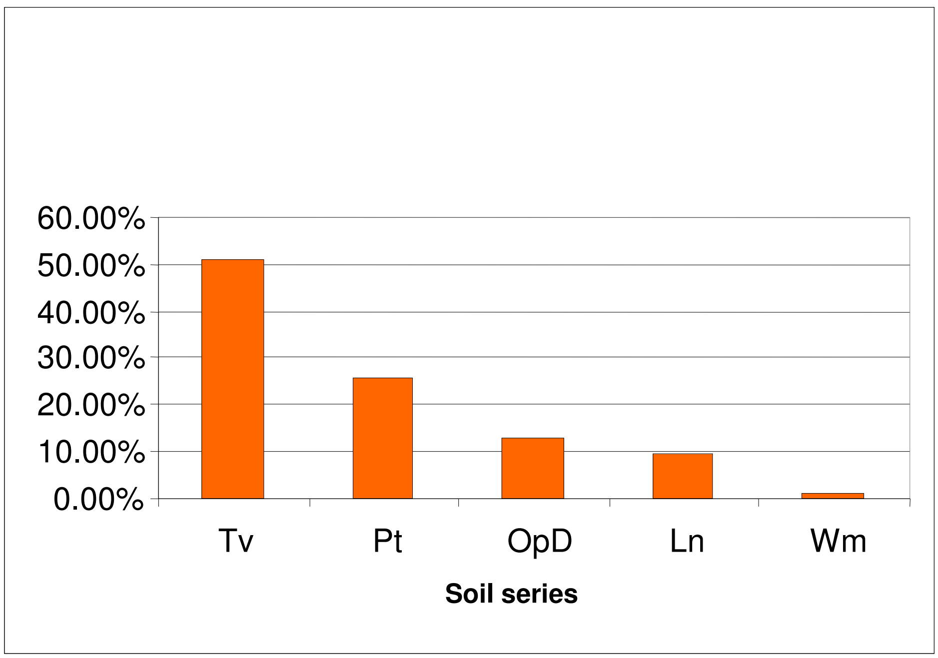

Fig. 57 Site D blowout/crescent dune occurrence on soil series

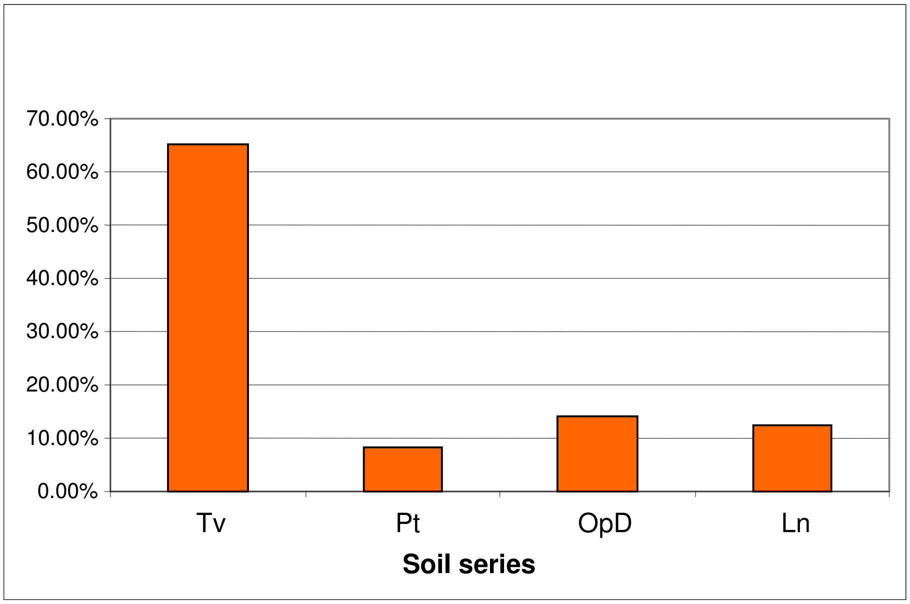

Fig. 58 Site D large dune crest occurrence on soil series

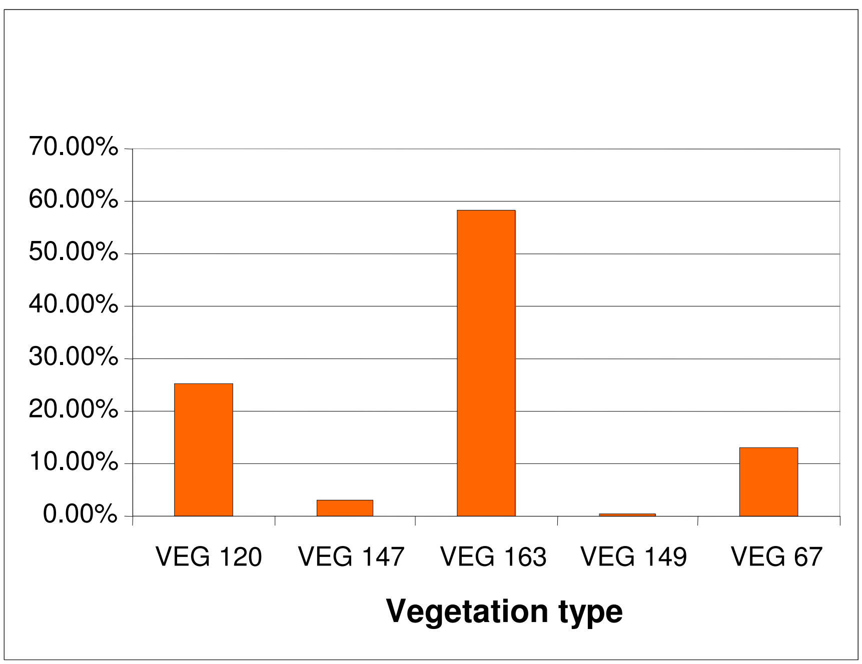

Fig. 59 Site D blowout/crescent dune occurrence on vegetation type

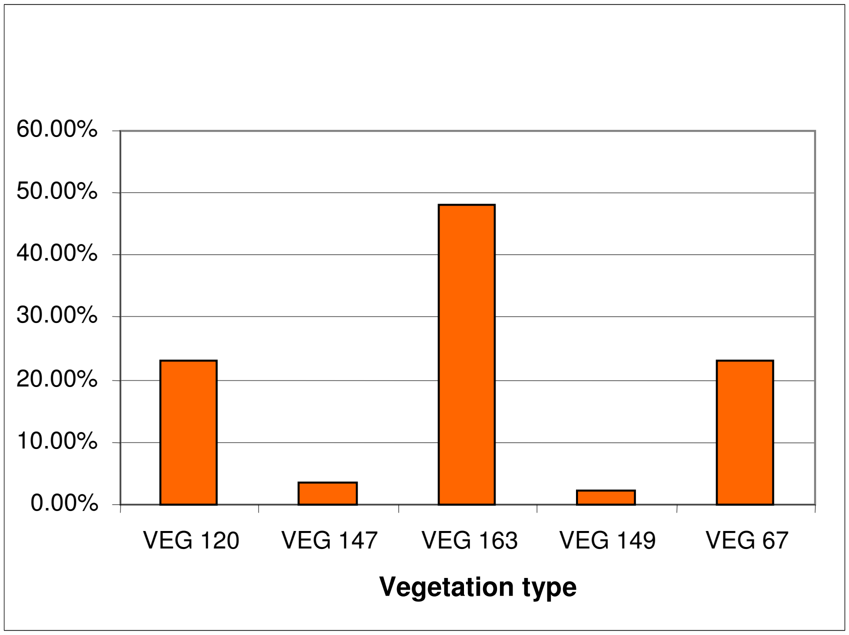

Fig. 60 Site D large dune crest occurrence on vegetation type

At site D, 69% of blowout dunes occur in Sandsage Savanna (VEG 163) and 25% occur in Gramma-Buffalo grass Prairie (VEG 120) (Fig. 59). Large dune crests are concentrated in Sandsage Savannah (VEG 163) with lower concentrations on croplands (VEG 147) and in Sandsage Prairie (VEG 67) (Fig 60).

In general, the relationship between dune generations and vegetation types do not support linear chronology as in the previous sites (Figs. 61, 62). Generation 1 has a 47%

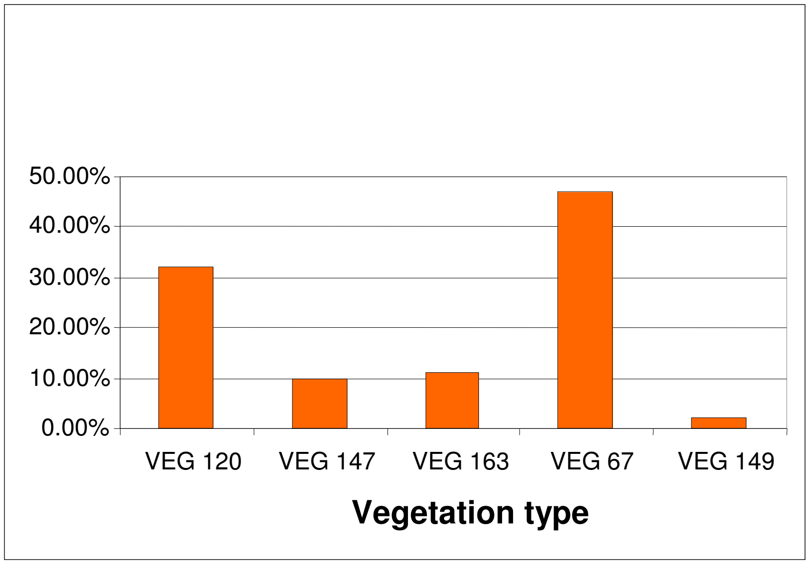

Figure 61Site D Generation 1 vegetation distribution

occurrence within VEG 67 and a 33% occurrence in VEG 120 (Fig. 61). VEG 67 would be expected in the older generation but VEG 120 indicates that there may have been disturbance and eolian activity at some point. Generation 2 has a 42% incidence of VEG 67 as well as 27% VEG 163 and 25% of VEG 120 (Fig. 62). VEG 163 and VEG 67 are indicative of longer periods without disturbance.

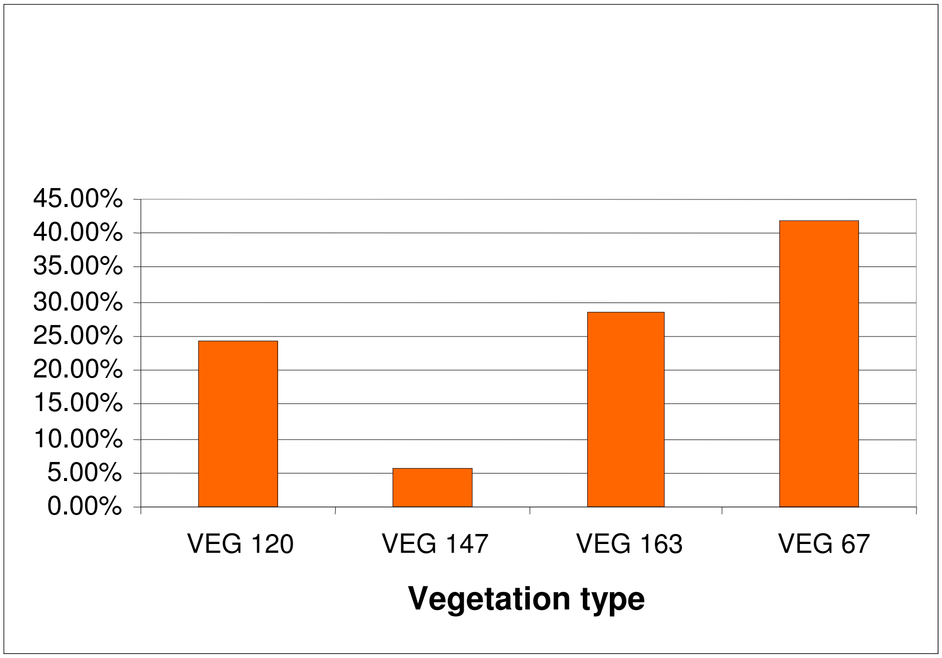

Figure 62 Site D Generation 2 vegetation distribution

Site E Little Sahara State Park

Four generations were found at this site (Fig. 63). Generation 1 is in the area north of the park boundary, Generation 2 is in the area to the east and NE of the active dunes in the park and Generation 3 is located to the west of the active recreation area in the park (Fig. 63). Generation 4 consists of the area in the park with active dunes.

The distribution of dominant paleowind directions inferred from blowout/crescent dunes across this site is predominantly in the NW quadrant with a smaller occurrence in the SW (Fig. 64). The blowout and crescent dunes of Generation 1 have a majority occurrence in the NW quadrant, with a strong vector from 310° to 315° and a lesser occurrence in the SW quadrant (Fig. 65). The blowout and crescent dunes of Generation 2 have the highest occurrence between 310°and 324° in the NW and a lesser amount in the SW (Fig. 66). The blowout and crescent dunes of Generation 3 (Fig. 66) have a similar occurrence to those of Generation 2 (Fig. 65) with a lower concentration in the 315° - 324 ° and a wider occurrence in the SW.

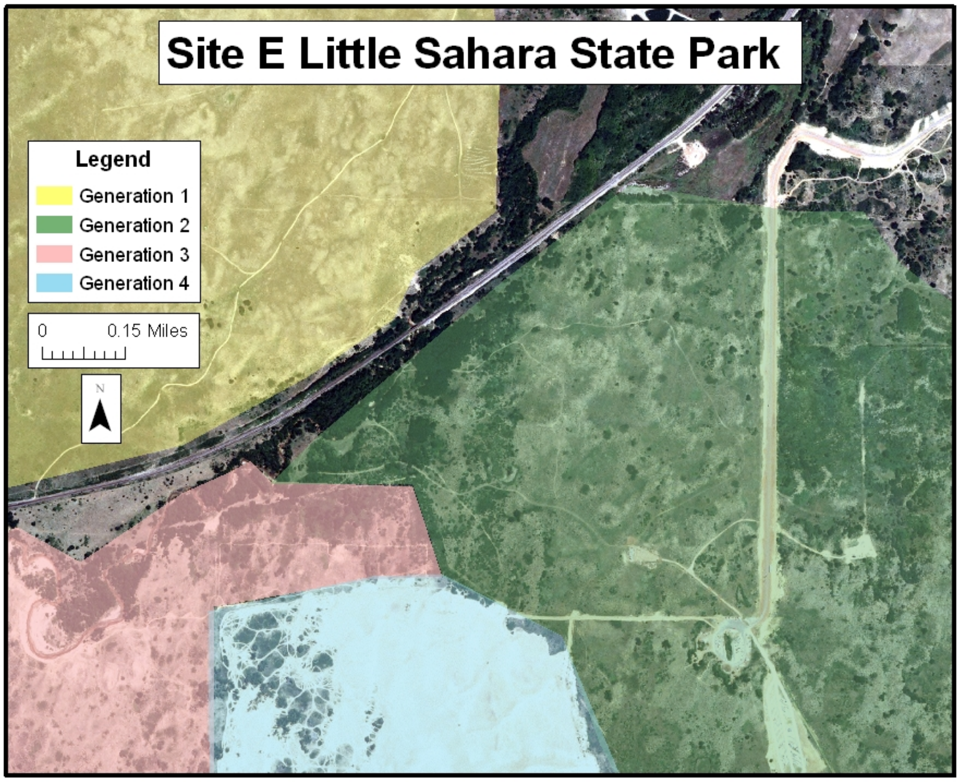

Fig. 63 Map of dune generations at Site E

Generation 4 had less mapped blowout and crescent dune forms than the other generations (Fig. 68). The distribution is more concentrated in the SW with a small component in the NW. These dunes may be affected by local winds created by the larger transverse ridge dunes, all of which are active.

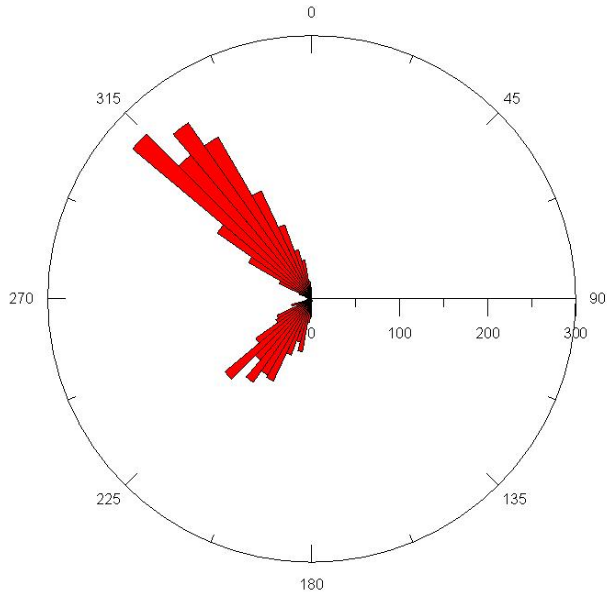

Fig. 64 Site E paleowind directions inferred

from mapped blowout/crescent dunes

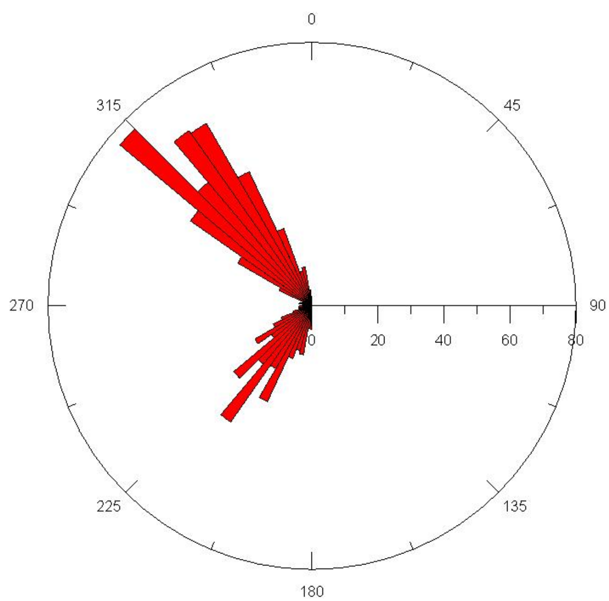

Fig. 65 Site E Generation 1 paleowind directions

inferred from blowout/crescent dunes

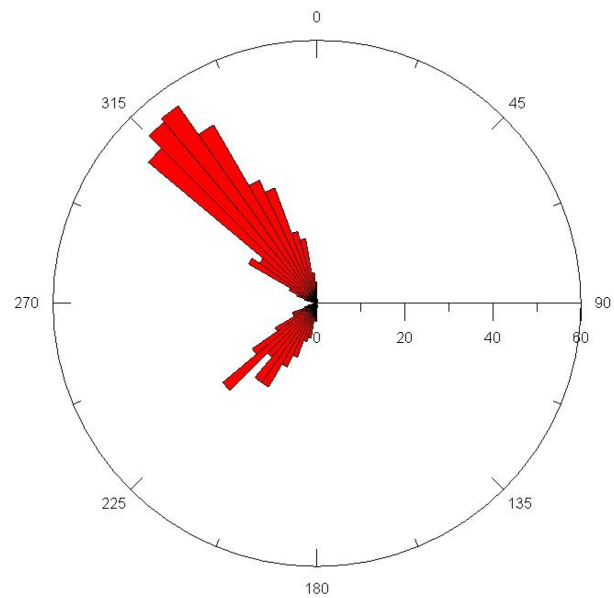

Fig. 66 Site E Generation 2 paleowind directions

inferred from blowout/crescent dunes

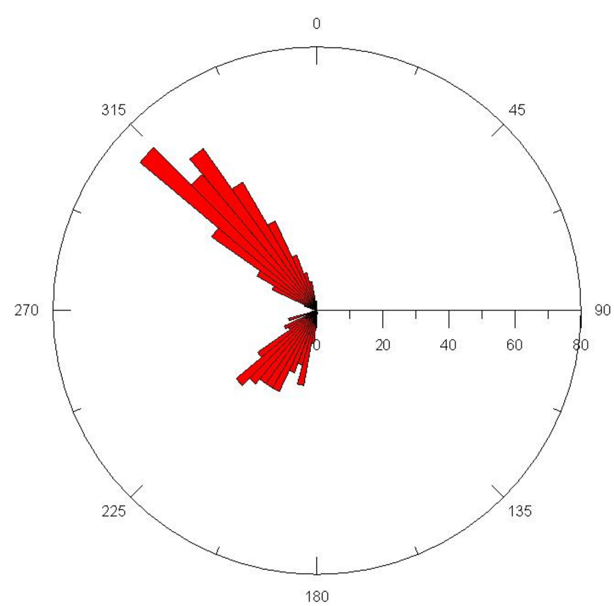

Fig. 67 Site E Generation 3 paleowind directions

inferred from blowout/crescent dunes

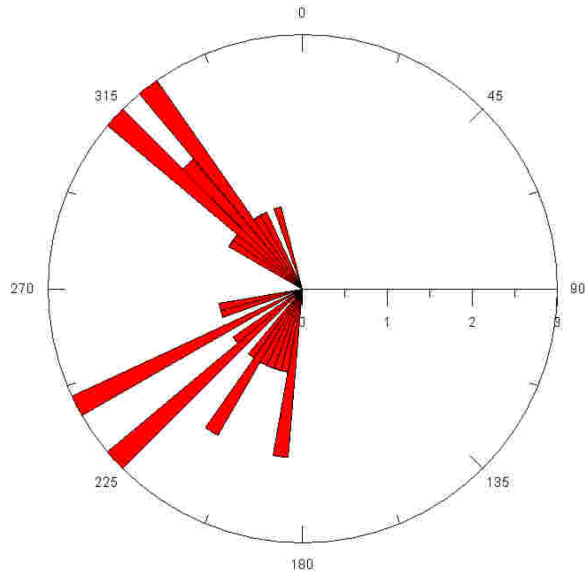

Fig 68 Site E Generation 4 wind directions

inferred from blowout/crescent dunes

The distribution of large dune paleowind directions across this site is predominantly between 270° and 320° (Fig. 69). The large dune crests of Generation 1 have a majority occurrence in the NW quadrant, with a strong vector from 270° to 320° and a lesser occurrence in the SW quadrant (Fig. 70). The large dune crests of Generation 2 have the highest occurrence between 280°and 340° and a lesser amount in between 190° and 250° (Fig. 71). The large dune crests of Generation 3 have a similar occurrence to Generation 2 with a lower concentration in between 290° and 320 ° and a small occurrence in the SW (Fig. 72). The large dune crests of Generation 4 have an even distribution between 180° and 280° (Fig. 73). The distribution of inferred paleowind in the two mapped dune groups was similar in all but Generation 4. The large dune crests of Generation 4 have their entire occurrence in the SW, while the other generations had the highest percentage in the NW.

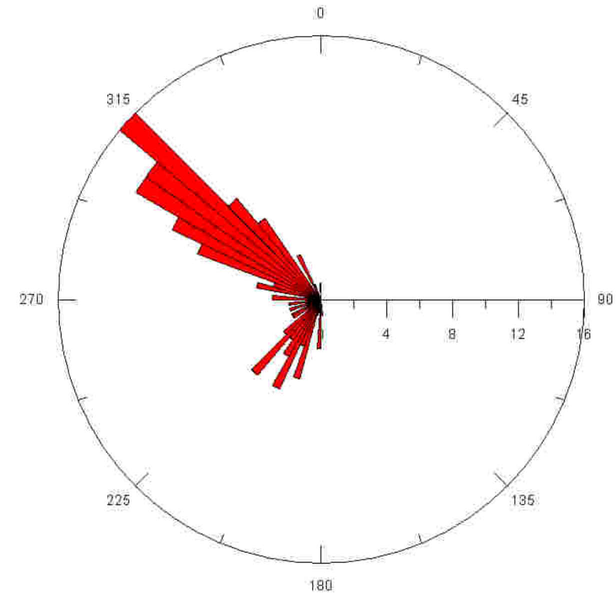

Fig 69 Site E paleowind directions inferred

from large dune crests

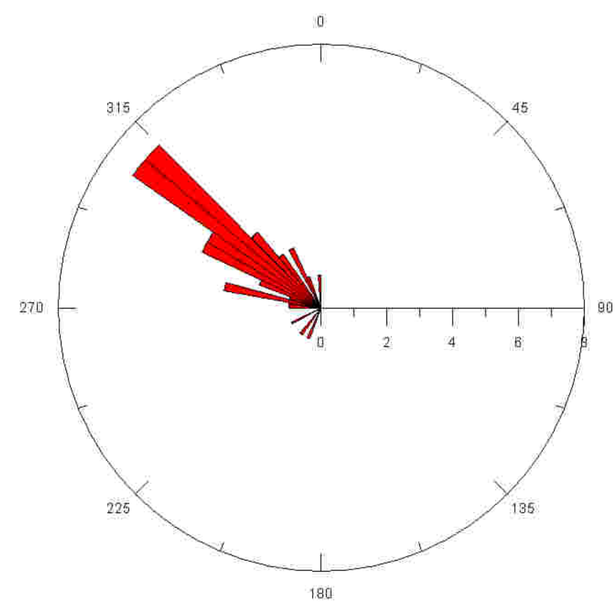

Fig. 70 Site E Generation 1 paleowind directions

inferred from large dune crests

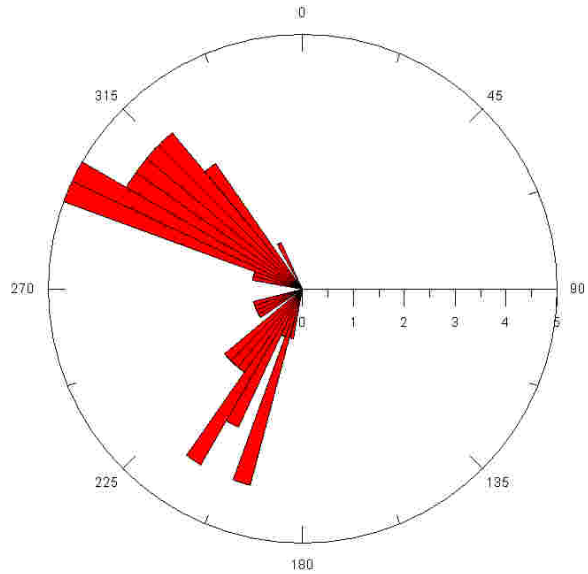

Fig. 71 Site E Generation 2 paleowind directions

inferred from large dune crests

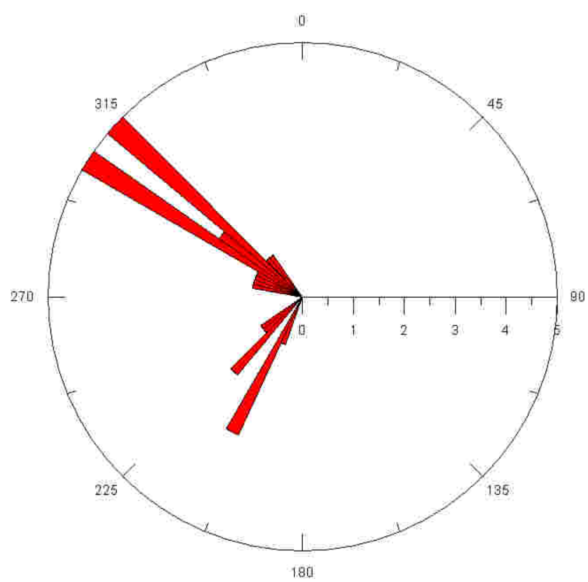

Fig. 72 Site E Generation 3 paleowind directions

inferred from large dune crests

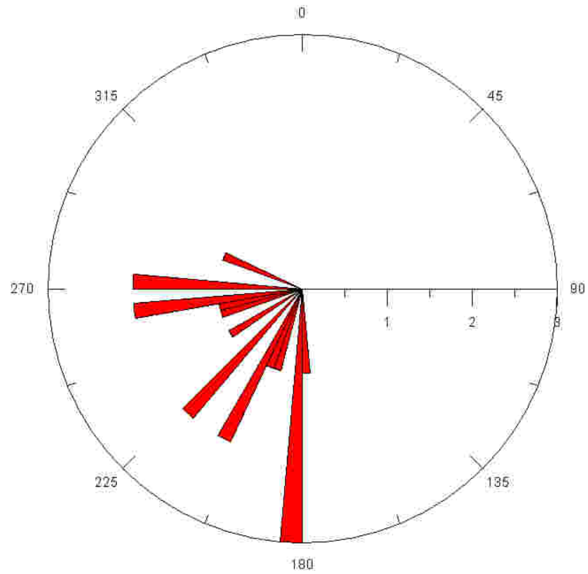

Fig. 73 Site E Generation 4 wind directions

inferred from large dune crests

70.54% of the mapped blowout dunes occurred on Tivoli series, divided 39.34% on Tivoli G and 31.20% on Tivoli E (Fig. 74). 17.23% of the blowout dunes are on the dune land-Tivoli complex (Fig. 74). Large dune occurred 71% on Tivoli soils; 39% on Tivoli G and 32% on Tivoli E (Fig. 75). There is an 8.06% incidence on the dune land-Tivoli complex series (fig 75).

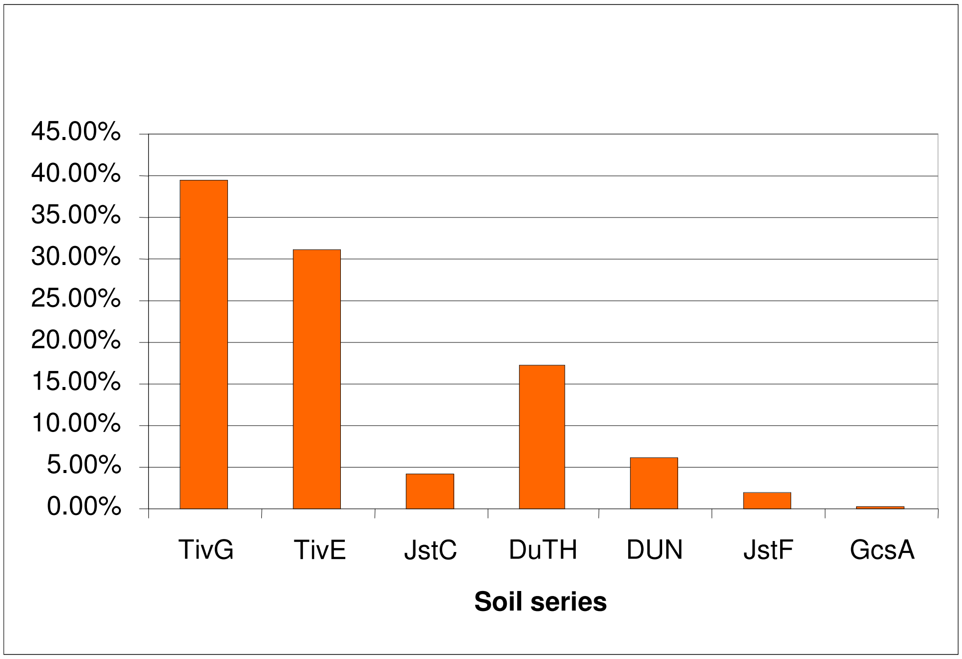

Fig. 74 Site E blowout/crescent dune occurrence on soil series

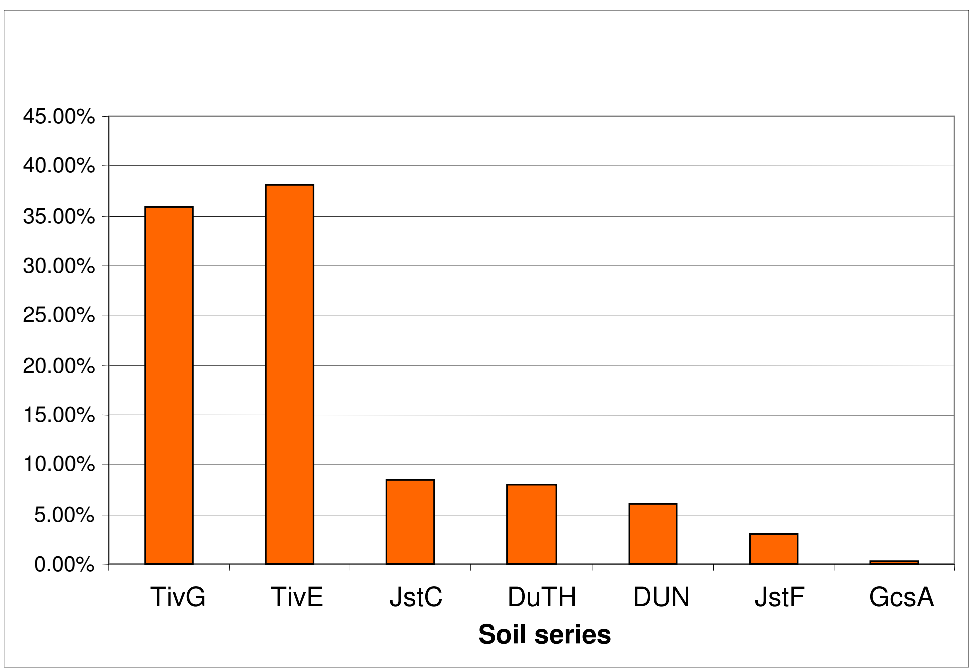

Fig. 75 Site E large dune crest occurrence on soil series

Blowout and crescent dune occurrence was 46% on VEG 67 and 21% on VEG 109 (midgrass Sandsage Prairie) and 12% on VEG 107(Midgrass Sand Prairie) (Fig. 76). The large dune crests have an 33% occurrence on VEG 109, 32% on VEG67, 7% on VEG 107 and 11% on VEG 112 (Fig. 77).

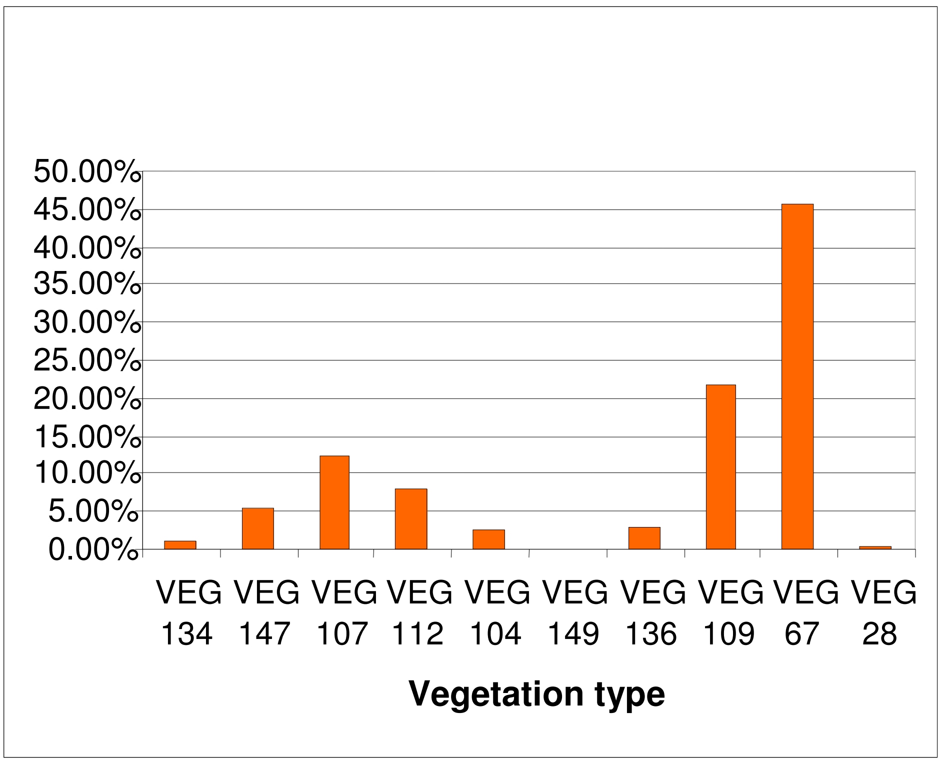

Fig. 76 Site E blowout/crescent dune occurrence on vegetation type

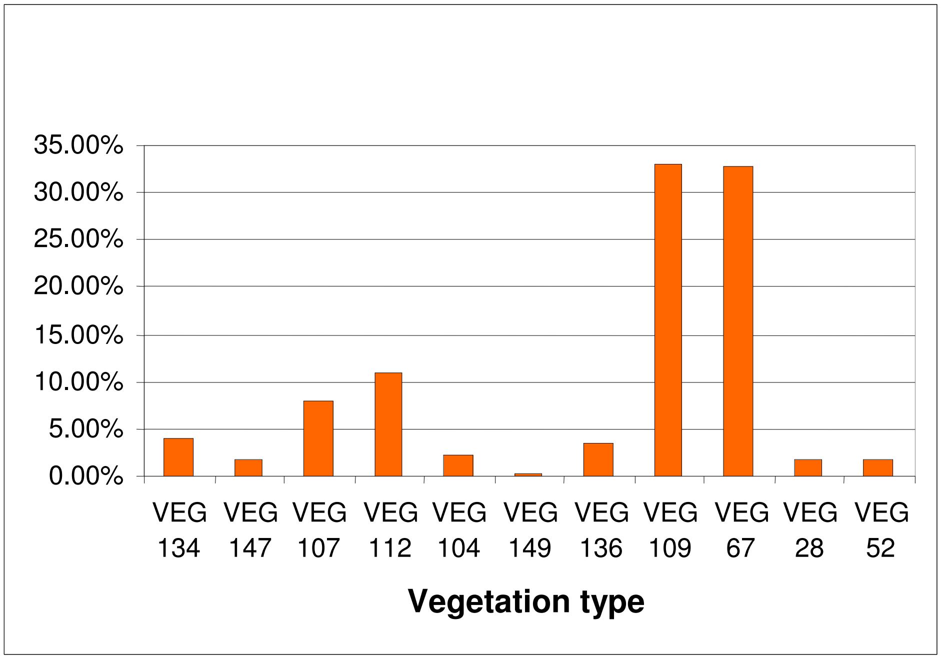

Fig. 77 Site E large dune crest occurrence on vegetation type

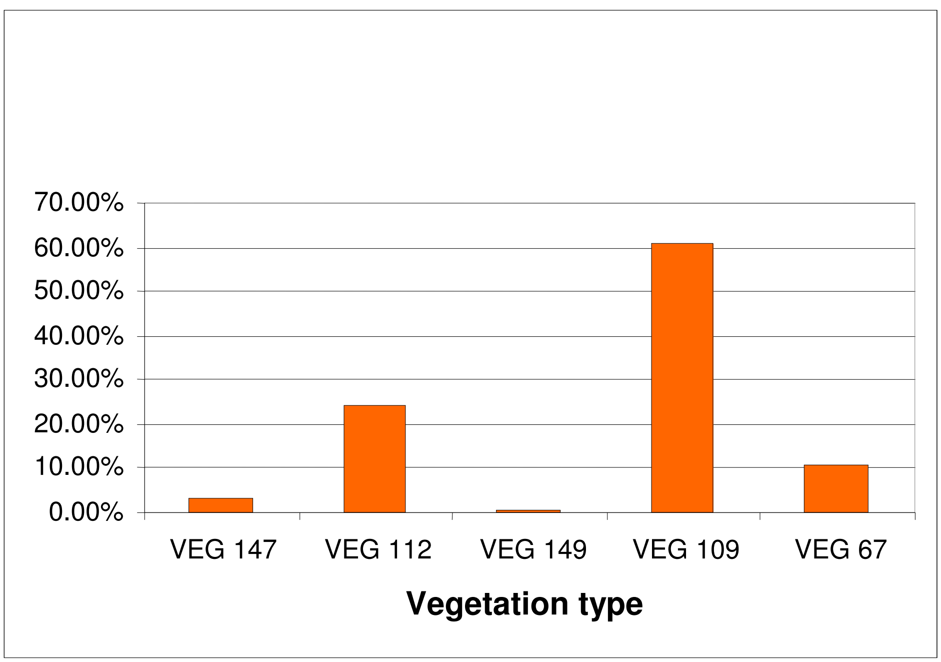

Fig. 78 Site E Generation 1 vegetation distribution

Vegetation within Generation 1 was 61% on VEG 109, 25% on VEG 112, and 11% on VEG 67 (Fig. 78). Within Generation 2, 51% of the vegetation was VEG 109 and 19% was VEG 67 (Fig. 79). The other vegetation types in Generation 2 were below 10%. Within Generation 3 VEG 112 had the highest representation (at 28%) (fig 80). VEG 107 (mid-grass Sand prairie) and VEG 147 (Crop-Warm Season) were at 14% each, VEG 136 (Sandy Areas) were at 13% and VEG 109 was 10%. No other coverage was above 10%. Generation 1 has more VEG 112 and VEG 109 than Generations 2 and 3. Generation 2, while it had a high incidence of VEG 112 also had a relatively high occurrence of VEG 67. These coverages should be indicative of a longer period of stability for Generations 1 and 2 than the mix of vegetation cover on Generation 3. Generation 4 consists of active dunes and bare sand, there is no significant occurrence of vegetation in this generation.

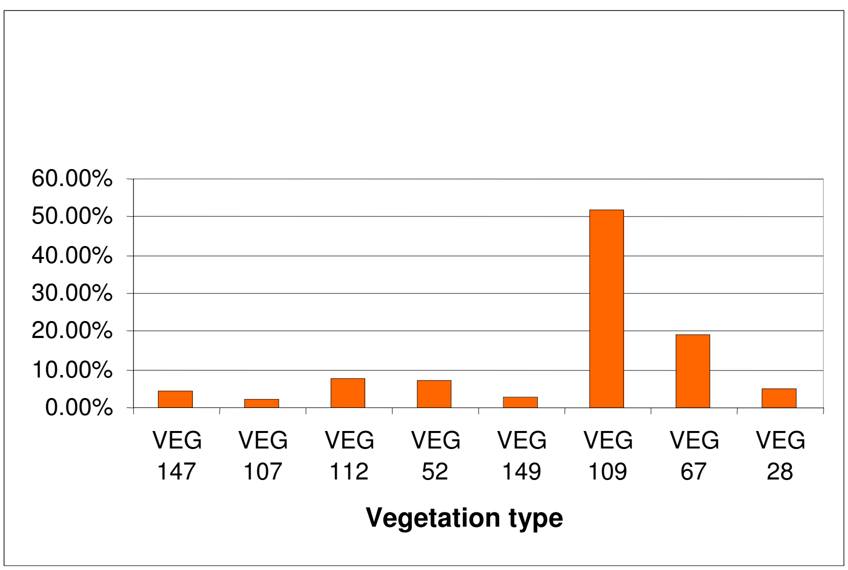

Fig. 79 Site E Generation 2 vegetation distribution

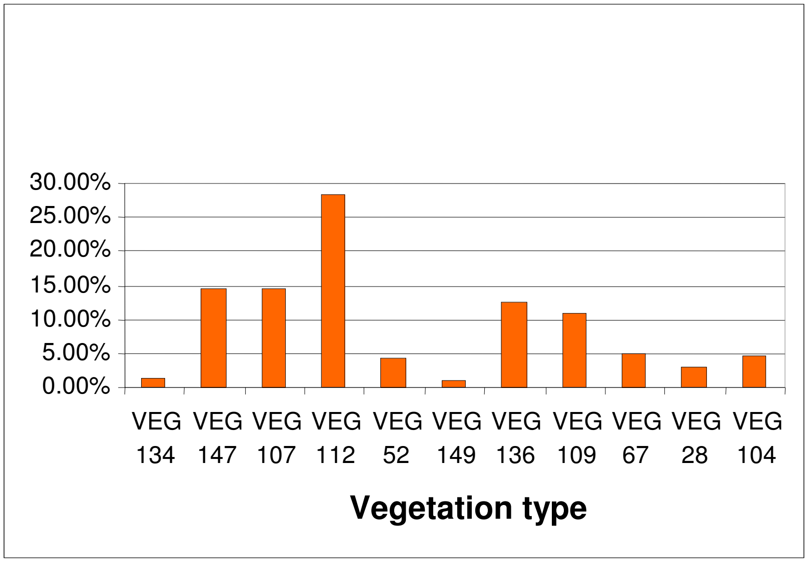

Fig. 80 Site E Generation 3 vegetation distribution

Final Interpretation of Data

Inferred paleowind direction patterns are similar among the five sites. The NW component is more prevalent in all of the sites, except for Site A (southwest Cimarron County), where the NW and SW have similar frequencies. The SW component becomes smaller in site E (Little Sahara). However, variations to this rule exist when focusing on dune types.

The mapped blowout/crescent group had a similar distribution to the mapped large dune crest group with the exception of all generations in Site C and Generation 1 in Site E Generation 4 (Fig 74). The latter corresponds to the currently active dunes inside the Little Sahara State Park, which are representative of modern wind directions. The blowout/crescent group has a higher percentage of wind directions in the NW quadrant, whereas the large dune crest group has a higher percentage in the SW quadrant. In general, this pattern contrasts with the modern wind directions (Fig. 3) in that the NW component is not as prevalent in the modern wind. Nonetheless, the presence of a SW component in Site A corresponds with the modern wind component for the region (Fig. 3.3) as do the Site C large dune crests.

It is possible that the modern component in which S and SW winds predominate is that of the modern, rather wet conditions which do not promote widespread dune formation. The NW component in the paleowind may be indicative of wind predominance in times of prolonged drought (megadrought) and dune formation periods of the past. This pattern varies with generations as in all sites except Site D.

The pattern of large dune crests and blowout dunes was consistent throughout all five study sites. The large dune crests have been modified by the blowout dunes and in some cases crescent dunes. There are no large dune crests in this study area that did not have some occurrence of a blowout or crescent dune on the large dune. With the exception of the active dunes in Site C and Site E, the large dune crests generally had a more eroded appearance than the blowout and crescent dunes. Although they are eroded, some of the large dune crests are nearly as long as the mile sections visible on the aerial photos, these are visible in Sites A and B. This would suggest that the large dune crests are older than the majority of blowout and crescent dunes. It is likely the large dune crests are relicts of megadroughts, where conditions would have been more conducive for dunes of this size. Site A had crescent dunes in the southern part of the site that is an elongated shape similar to a hook. This is the only occurrence of this shape across the five study sites. The modern winds and paleowinds have a strong SW component that is apparent in the crescent dune morphology at Site A. The blowout dunes and majority of crescent dunes present in these five sites are likely a more recent occurrence and a product of shorter droughts.

CHAPTER V

CONCLUSION

Paleowind directions obtained from stabilized sand dunes in northwestern Oklahoma show a consistent direction from the northwest and the southwest. In all of the study sites, except site C and the currently active dunes of Site E, the mapped paleowind directions concentrate in the northwest quadrant. Site C large dune crests had a higher occurrence of SW orientation in total as well as both of the assigned generations. These dunes, however, appear still active in aerial photographs as late as 1966, and a few in 1995. The active dunes at Site E (Generation 4), which are modern dunes and not paleodunes, did follow the patterns of the modern wind roses (Fig. 3). The modern winds show a stronger vector from the south and less from the southwest, except for Cimarron County, where the southwest component is more prominent than the southern component. The paleowind directions obtained from map dunes show a high tendency to directions from the NW. This suggests that during periods of prolonged drought, which derive in eolian activity, winds are more likely to blow from the northwest, while still important from the southwest.

Seasonality during dune formation is another factor possibly involved in the development of paleodunes. In modern wind roses, the southern and southwestern component is more common during the late spring and summer months, while the northwestern component is more common in the winter months. Accordingly, a period of winter drought would produce dunes oriented from the northwest and a summer drought would produce the southwestern oriented dunes. However, this is still an untested hypothesis. Defining seasonality during dune formation periods in the past would be a difficult task, unless meteorological data are available. Each sand dune generation presents a recurrent pattern in dune types.

Transverse ridge, hairpin and large crescent dunes are usually older and blowout dunes are younger. This suggests that the major periods of dune formation, it is probable that mega-droughts resulted in widespread dune mobilization resulting in large forms (i.e., transvers ridge, hairpin and larger crescent dunes). Blowouts correspond to shorter periods of stabilization, perhaps resulting from destabilization caused by shorter drought periods.

This pattern seems to correspond to the mega-drought chronology established by reconstruction of droughts using tree rings. Muhs and Holliday (1995) suggest that several mega-droughts occurred in the past 500 years, but not a major one occurred after the 1850s (Fig 81). In other words, the 1930s and 1950s droughts, although known for their severity, are by no means mega-droughts. Furthermore, it is during these periods that widespread blowouts were formed (Cordova et al. 2005).

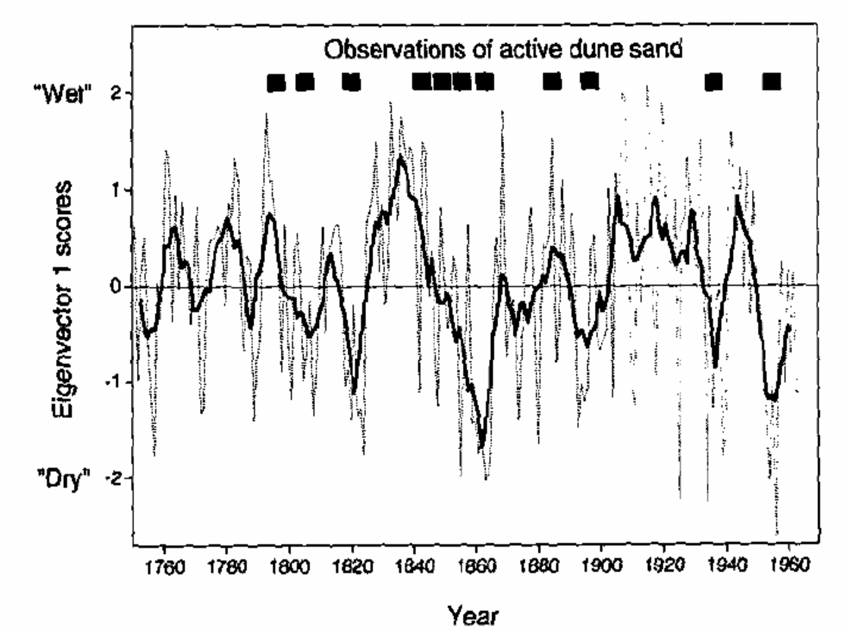

Fig. 81 Historic accounts of dune activity based on Meko's 1991 Tree-ring climate reconstruction from Muhs and Holliday (1995)

Analyses of stabilized dunes divided by generation and type proved to be a successful methodology for the purpose of creating a relative chronology. The two variable used for this purpose were soil development and vegetation. Thus, more developed soils and vegetation types in more advanced succession stage would indicate older dunes, or dunes that have not been active for a longer period of time. Overall, the data in this study showed a consistency of soil and vegetation development in relation to the pre-determined sand dune generations, and dune types.

Of the two variables, vegetation type was the most reliable for determining paleodune relative ages. Soils, on the other hand, present difficulties due to differential patterns of erosion, particularly when dunes are reactivated, usually in the form of blowouts.

This information can be used for planning the collection of samples for absolute dates. Since a relative chronology now exists for northwestern Oklahoma dune fields, OSL dates, as well as phytolith and pollen samples from paleosols can be obtained from the different generations. OSL can help establish accurate ages for periods of dune activity, while pollen and phytoliths could help determine the vegetation present at the time of activity as well as the periods of inactivity. The combination of these techniques will contribute to our knowledge of climate change in western Oklahoma and the North American Great Plains.

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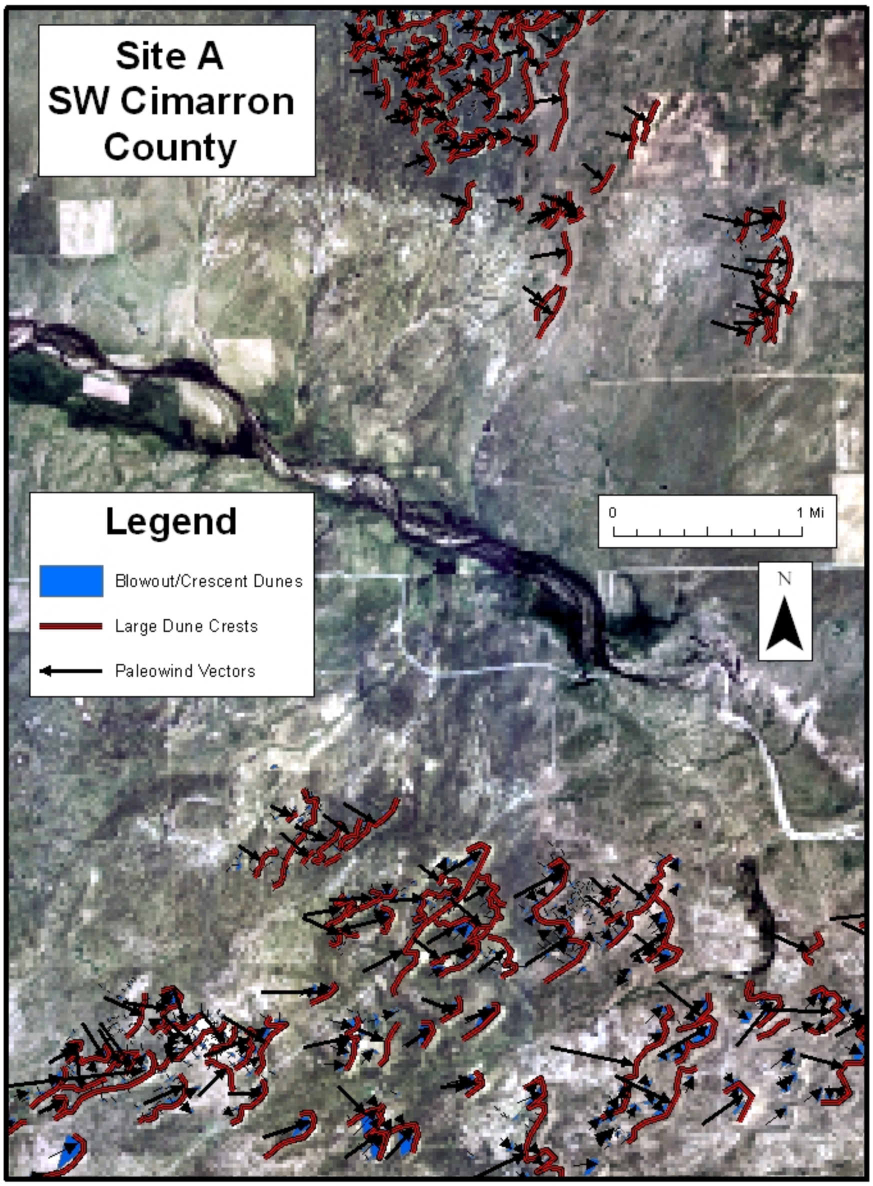
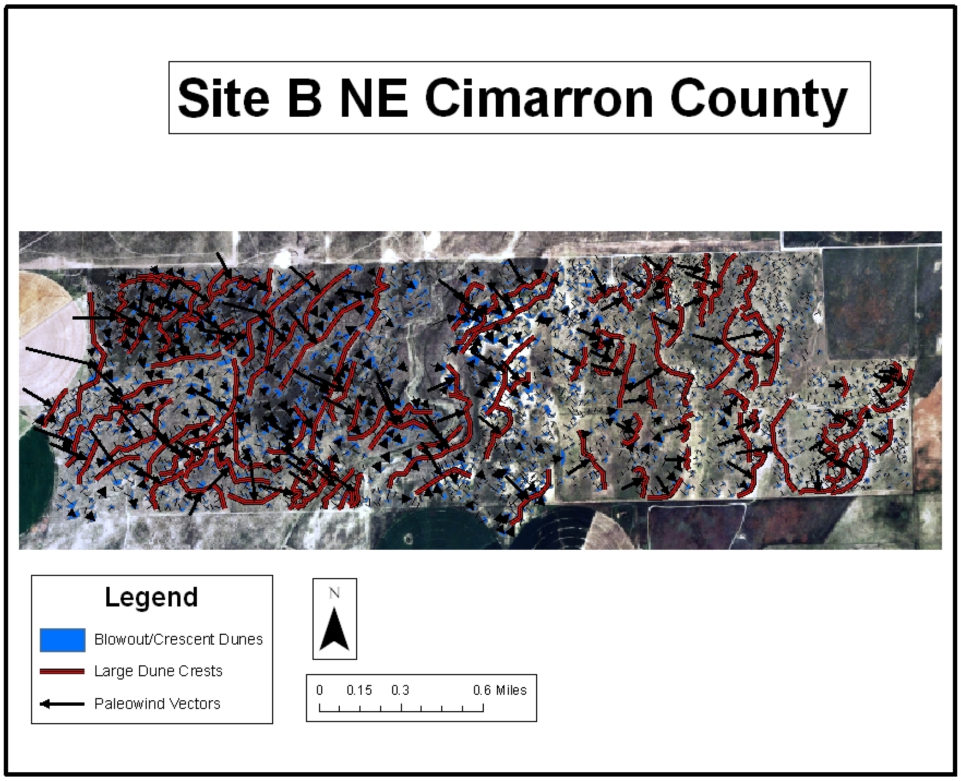
United States Dept. of Agriculture (b) 2007. National Resources Conservation Service, in cooperation with Oklahoma Agricultural Experiment Station and Oklahoma

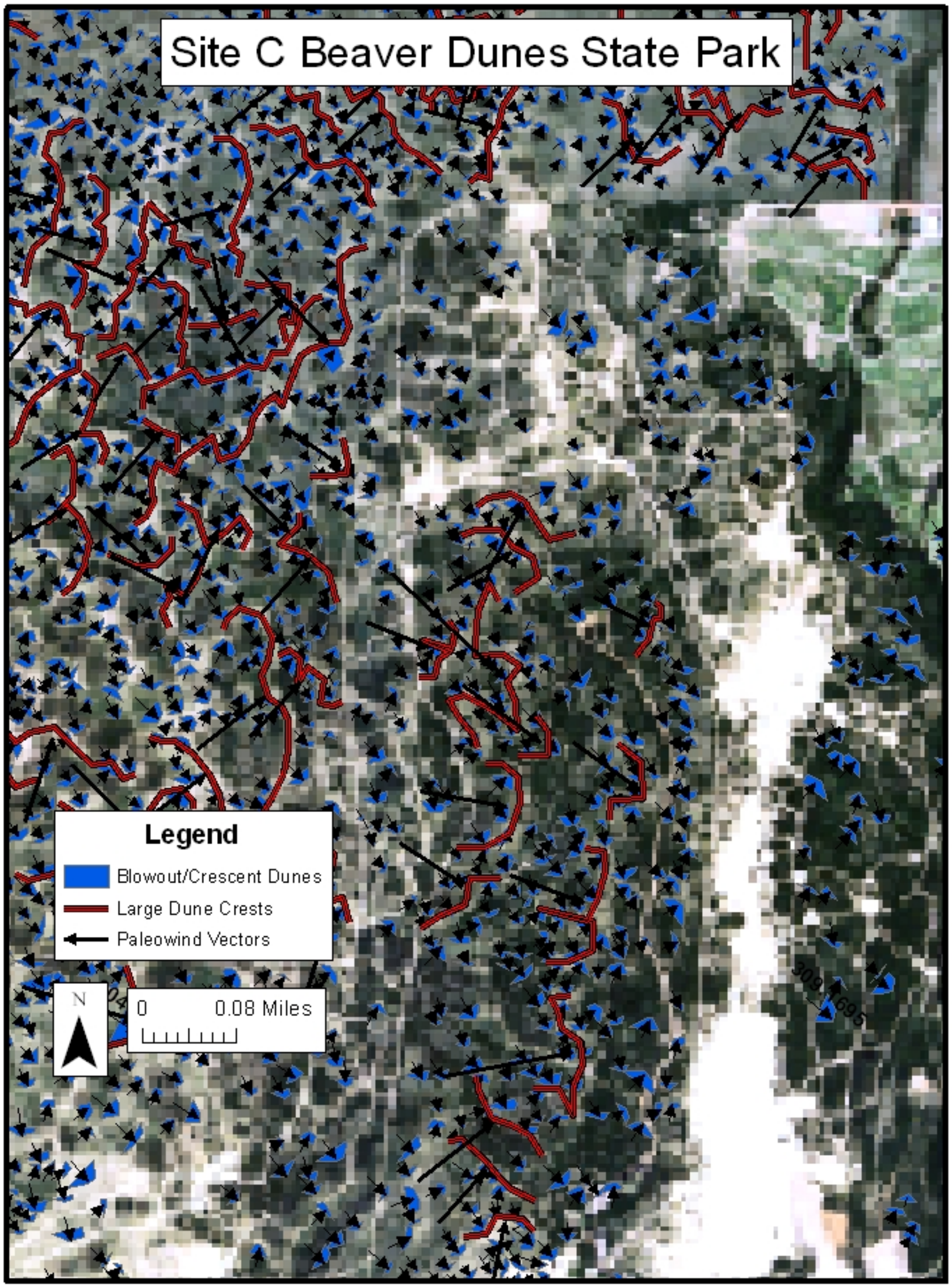
Conservation Commission. “Supplement to the Soil Survey of Woods, Co. Oklahoma.” Last accessed October 29, 2007. Available: http://soildatamart.nrcs.usda.gov/Manuscripts/ok151/0/Woods.pdf

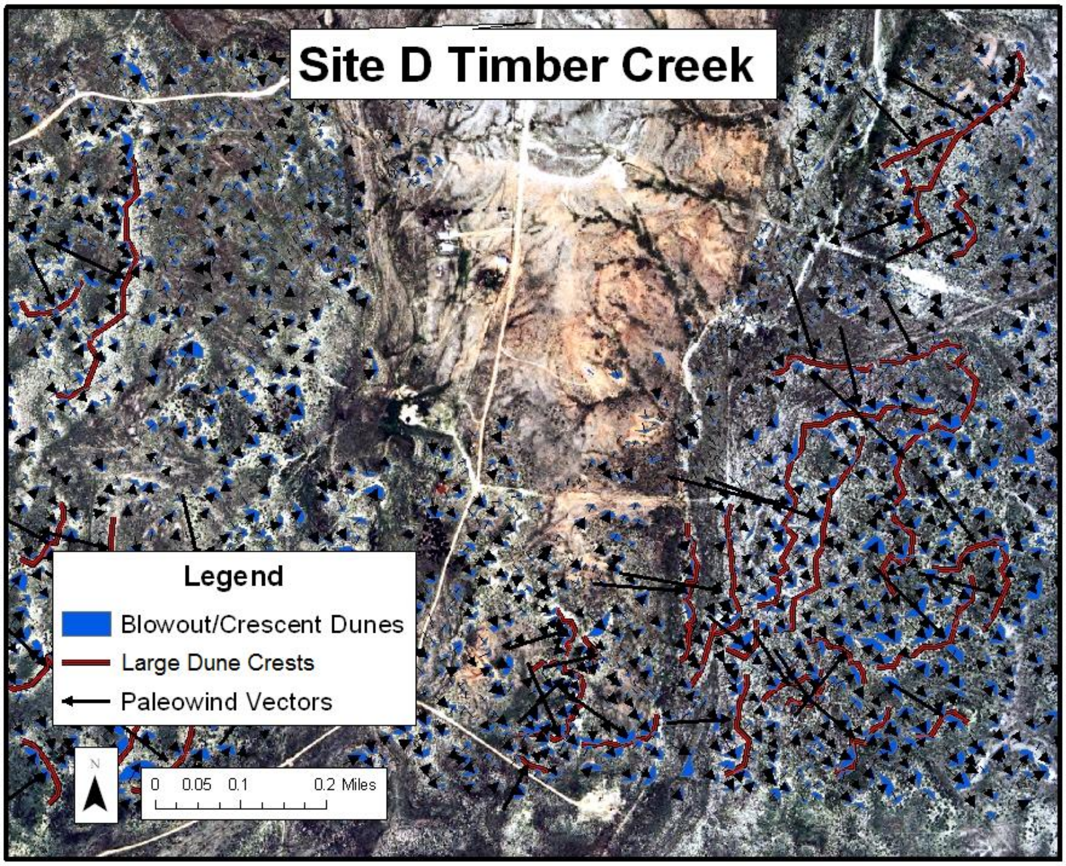
APPENDIX A

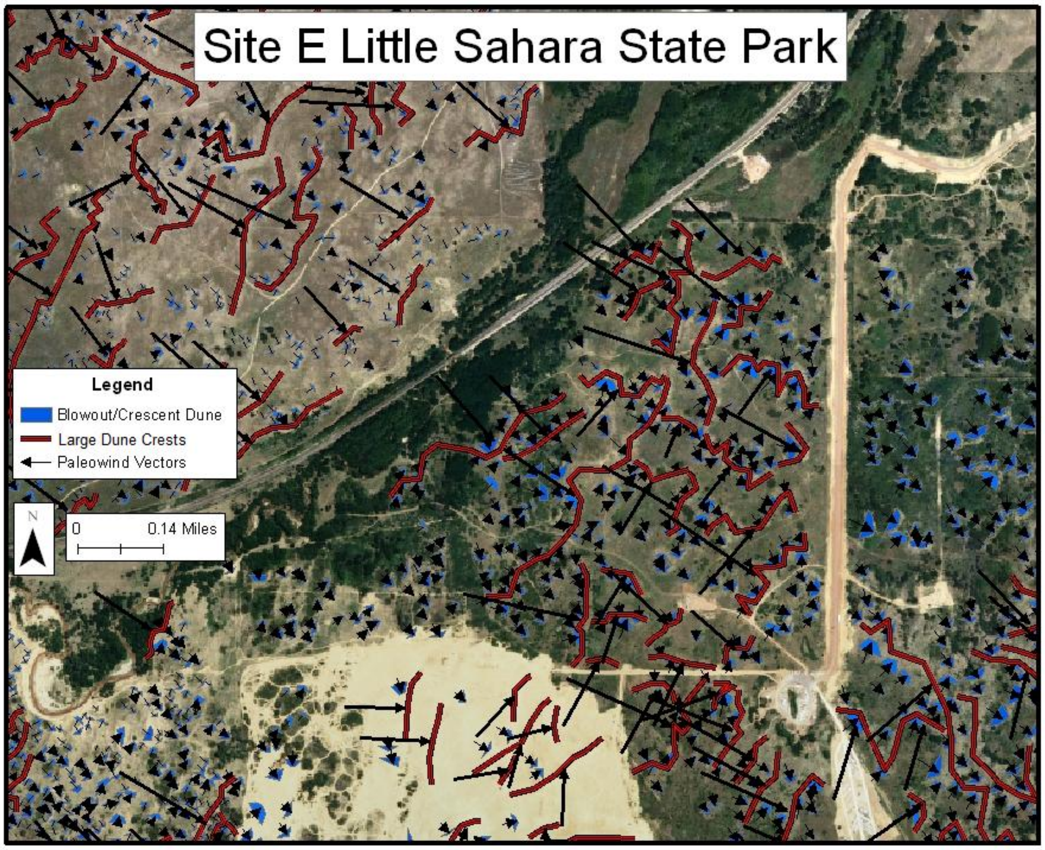
Site maps of blowout/crescent dunes, large dune crests and paleowind vectors




Site B NE Cimarron County
Legend
Blowout/Crescent Dunes
Large Dune Crests
Paleowind Vectors
N
0 0.15 0.3 0.6 Miles


Site C Beaver Dunes State Park
Legend
Blowout/Crescent Dunes
Large Dune Crests
Paleowind Vectors
N
0
0.08 Miles


Site D Timber Creek
Legend
Blowout/Crescent Dunes
Large Dune Crests
Paleowind Vectors
N
0 0.05 0.1 0.2 Miles


Site E Little Sahara State Park
Legend
Blowout/Crescent Dune
Large Dune Crests
Paleowind Vectors
N
0
0.14 Miles

Appendix B.

Process for extracting compass direction from mapped vector in ArcGIS (provided by Dr. Hongbo Yu).

1. Open attribute table for selected layer
2. Open options then add a new field and name this field
3. Highlight new field, right click, the use the calculate function.
4. Load expression

```
Dim pPtColl As IPointCollection

Dim pLine As ILine

Set pPtcoll = [Shape]

Set pLine = New Line

Dim pPt1 As IPoint

Dim pPt2 As IPoint

Set pPt1 = pPtColl.Point(0)

Set pPt2 = pPtColl.Point(1)

pLine.PutCoords pPt1, pPt2

Dim TempValue As Double

dim Value as double

TempValue = pLine.Angle * 180 / 3.1415

if TempValue<0 then value=90-TempValue

if TempValue>=90 then value=450-TempValue

if TempValue>0 and TempValue<90 then Value=90-TempValue
```

VITA

Brad Curtis Rogers

Candidate for the Degree of

Master of Science

Thesis: MORPHOLOGY OF FIXED SAND DUNES FOR PALEOWIND RECONSTRUCTION IN NORTHWESTERN OKLAHOMA

Major Field: Geography

Biographical:

Personal Data: Born in Tacoma, Washington, April 6, 1972, the son of John and Jane Rogers.

Education: B.S. Environmental Science 2000
Completed the requirements for the Master of Science or Arts Geography at Oklahoma State University, Stillwater, Oklahoma in December, 2007.

Experience: Employed by Northern Oklahoma College, Stillwater OK as an adjunct lecturer and lab instructor of Earth Science, 2006 to present. Employed by Oklahoma State University, Stillwater OK as a teaching assistant for the Physical Geography lab, fall of 2005 through spring 2007. Employed by Cooper's Bicycle Center, Stillwater OK as a Service Manager where I repaired bicycles and exercisers, trained and supervised other mechanics, instructed clinics for repair and riding skill, 1993 to present. Volunteer for Stillwater Parks and Recreation, Lake McMurtry Multiuse Trail System, Stillwater OK, as a Land use and Trail Development Consultant, worked as a member of a team to plan and develop a sustainable multi-use trail system at Lake McMurtry City Park, 1994 to present. Employed by Oklahoma Department of Career and Technology Education, Stillwater OK as a Contract Technical Writer, for Unit 1 of Instruction for the Introduction to Automotive Service Curriculum, August 2000. Oklahoma Department of Career and Technology Education, Stillwater OK, as a Contract Technical Writer for creating Career Development Activities Curriculum for Science at the Elementary and High School levels.

Name: Brad Rogers Date of Degree: December, 2007

ADVISER'S APPROVAL: Dr. Carlos Cordova

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: MORPHOLOGY OF FIXED SAND DUNES FOR PALEOWIND RECONSTRUCTION IN NORTHWESTERN OKLAHOMA

Pages in Study: 91 Candidate for the Degree of Master of Science

Major Field: Geography

Scope and Method of Study: This study selected five areas of visible dune topography along the Beaver River and Cimarron River in Cimarron County, Beaver County and Woods County by using existing maps, digitized aerial photos (NAIP images), and digital soil surveys. Sand dune crests were manually mapped over the digitized aerial photos in ArcGIS. Wind vectors were inferred were from mapped crests to establish wind directions at the time of dune formation. Relative age was established by assigning generation numbers to dune fields based on visible forms and vegetation development. The corroboration of this relative age was performed using a combination of soil series and vegetation associations as well as visible erosion on dunes. Each generation comprised a period of major eolian activity, presumably resulted from a dry phase.

Findings and Conclusions: Paleowind directions obtained from stabilized sand dunes in northwestern Oklahoma show a consistent direction from the northwest and the southwest. In all of the study sites, except site C and the currently active dunes of Site E, the mapped paleowind directions concentrate in the northwest quadrant. Site C large dune crests had a higher occurrence of SW orientation in total.. These dunes, however, appear still active in aerial photographs as late as 1966, and a few in 1995. The active dunes at Site E (Generation 4), which are modern dunes and not paleodunes, follow the patterns of the modern wind roses, whose main direction is south and southwest, and to a lesser extent northwest. The modern winds show a stronger vector from the south and less from the southwest, except for Cimarron County, where the southwest component is more prominent than the southern component. The paleowind directions obtained from map dunes show a high tendency to directions from the NW. This suggests that during periods of prolonged drought, which derive in eolian activity, winds are more likely to blow from the northwest, while still important from the south and southwest.

ADVISER'S APPROVAL: Dr. Carlos Cordova