Inverted Clast Stratigraphy in an Eolian Archaeological Environment

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Understanding the geomorphic history of eolian basins is important in interpreting the archaeological record and human responses to past environments. One hundred forty soil profiles were excavated and described in southern New Mexico and West Texas. Seven major late Quaternary stratigraphic units were found: La Mesa, eolian Jornada (I, II), eolian Isaacks' Ranch, eolian Organ (I, II, and III), Historical Blowsand, and the playa deposits of Petts Tank and Lake Tank. Each unit represents a period of landscape instability, eolian erosion, and concurrent deposition, followed by landscape stability and soil formation. Eolian erosion can form local surficial lag deposits if materials larger than the competence of the wind are present. However, erosional processes alone cannot explain the presence of older clasts at the surface with intact, younger deposits underneath. We propose a combination of processes: deflation in eolian windows, followed by lateral movement of clasts over areas that have not been deflated. The effects of these processes on artifact stratigraphy and archaeological interpretations could be significant. © 2002 Wiley Periodicals, Inc.

INTRODUCTION

Understanding how eolian processes may affect archaeology is extremely important. The deposition and erosion of sediment by wind can occur in any terrestrial environment. Necessary requirements include a source of unconsolidated sediment, wind with sufficient velocity to mobilize and transport the sediment, and relatively few impediments such as vegetation to prevent erosion or inhibit surface wind velocities. In arid/semiarid and coastal environments, all three of these factors commonly occur. Thus, eolian processes and landforms often dominate these environments. Approximately 35% of the earth's surface today occurs in arid and semiarid climates (Christopherson, 1999). The percentage of eolian environments is even larger if coastal areas are included. Soil science and geomorphology can be an important tool in understanding past environments and landscape evolution and help the archaeologist interpret the archaeological record.

In many eolian environments, the surface is strewn with coarse clasts creating a surficial lag. For archaeologists, these lags often contain artifacts, whose distribution and density can be used to interpret past use of an area. However, geomor-

phic processes may affect these distributions. Thus, understanding the geomorphic history of an area is vital in making accurate archaeological interpretations. Both the processes of eolian erosion and deposition can result in the formation of coarse clasts overlying finer sediments: (1) winnowing of fine sediment can form a deflational surfical lag deposit or (2) in areas where clasts already occupy the surface, eolian accumulation of fine sediment underneath the surface clasts can form a desert pavement (McFadden et al., 1987). In the first process, coarse material overlies finer materials. However, the age of the overlying clasts are stratigraphically correct. They are younger than the underlying fine materials. In the second process, younger fine materials occur beneath the older surface clasts. Other geomorphic processes that can cause older coarse materials to lie above younger fine materials include freeze/thaw, shrink/swell of clay soils, bioturbation (Johnson et al., 1987; Johnson, 1989, 1990, 1993; Johnson and Watson-Stegner, 1990), and/or the lateral movement of clasts across a surface. When any of these processes affect archaeological sites, artifacts with different cultural contexts and ages can occur at the same stratigraphic level. However, in many of these instances, deflation or desert pavement formation is readily apparent, and thus interpretations of the artifact data are adjusted accordingly. This is not the case in this study area (e.g., Carmichael, 1986; Doleman et al, 1992; Leach, 1992; Leach et al., 1998). Although strides have been made to quantify the effect geomorphic processes may have had on archaeology (Doleman, 1992; Leach et al., 1998, Buck et al., 1999), the distribution and age relationship between the surface clasts (and artifacts) and underlying sediment has not been explained.

The surficial lag deposit in this study consists of ancestral Rio Grande pebbles and carbonate fragments from older soil horizons. These older clasts lie at the surface with intact, younger fine sediments beneath. In our study area, we show that geomorphic processes have altered the stratigraphic context of clasts in an eolian environment on a scale of several meters, and in such a way that it is not readily apparent from site to site which process(es) may have dominated. Because the stratigraphic positioning of geologic clasts has been altered, it is highly likely that the positions of artifacts have also been altered. Therefore, both the behavioral and temporal interpretations of groups of artifacts may err significantly. Further, because there is no reason to believe that the geomorphic processes described herein are limited to this area, this study may have important implications for other eolian-dominated landscapes worldwide.

SETTING

The northern Hueco and southern Tularosa basins compose the northernmost extent of the Chihuahuan Desert; Fort Bliss Military Reservation and White Sands Missile Range control land use almost entirely (Figure 1). These basins are bounded by normal faults associated with the Rio Grande Rift. In addition, many north–south trending en echelon intrabasinal faults are found along the basin floor in the southern Tularosa and northern Hueco basins (Seager et al., 1987). The climate is
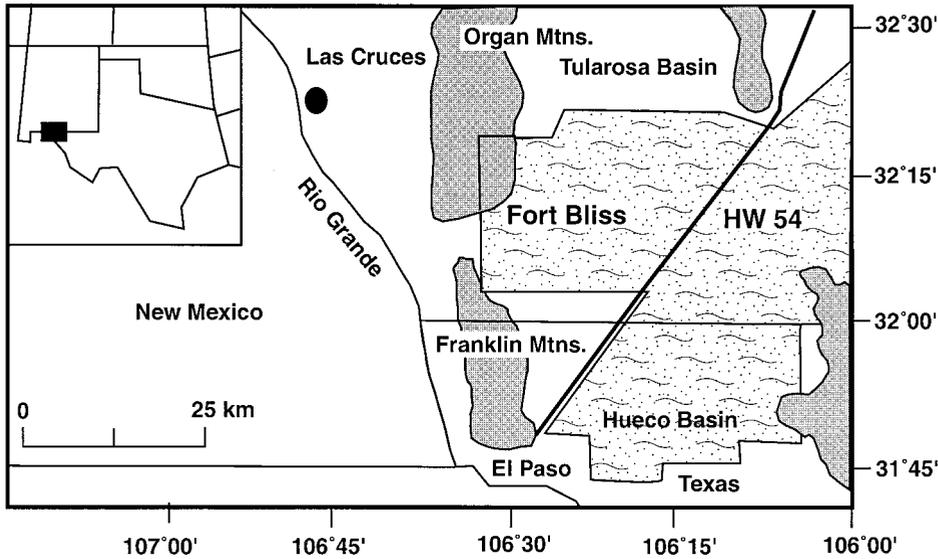
Figure 1. Location of the study area: Fort Bliss Military Reservation, southern New Mexico and West Texas.

characterized by hot, arid conditions (average daily temperatures vary between 13°C and 36°C), and highly variable mean annual precipitation (~24 cm/yr). Most precipitation is derived from intense, highly localized summer thunderstorms originating in the Gulf of Mexico, augmented by some low-intensity winter precipitation resulting from frontal storms over the Pacific Ocean (Gile et al., 1981; Blair et al., 1990). Prevailing winds are from the west and are highest during the winter and spring months. During the summer monsoon, winds are predominantly from the east/southeast but are not as sustained nor strong (Gile et al., 1981; Blair et al., 1990). Pronounced dust storms can occur in the spring when wind speeds are high and soil moisture low (Marston, 1986; Blair et al., 1990). Basin floor elevations range between approximately 1196 and 1250 m, and adjacent mountain ranges are up to 2725 m in elevation.

Eolian deposits and landforms are ubiquitous throughout the Hueco and Tularosa basins, as well as many similar basins in the northern Chihuahuan Desert of the southwestern USA and northeastern Mexico. The landforms in the northern Hueco and southern Tularosa basins are composed primarily of 1–3 m high coppice dunes anchored by mesquite, sandsheets that may or may not be stabilized by grasses, and interdunal deflational areas often covered by a lag of coarse clasts including artifacts (Buck, 1996; Buck et al., 1999; Buck and Monger, 1999). The main source of sediment appears to be derived from eolian reworking of the ancestral Rio Grande alluvium (Monger, 1995; Buck, 1996; Buck et al., 1999), which

Table I. Late Quaternary eolian and playa stratigraphy of the northern Hueco and southern Tularosa basins.

Deposit	Carbonate Morphology	Original Clast Stratigraphy	Age
Historic Blowsand	None	None	100–150 yr (Historical)
Organ III	None	None	100?–1100 yr B.P.
Organ II*	Faint stage I	None	1100–2100 yr B.P.
Organ I	Stage I	None	2200–7000 yr B.P.
Isaacks' Ranch	Stage II	Pedogenic carbonate nodules	8–15 ka (early Holocene to late Pleistocene)
Jornada I and II*	Stage II–III	Pedogenic carbonate nodules or fragments of a petrocalcic horizon	25–400 ka (middle–late Pleistocene)
La Mesa	Stage III–IV	Fragments of a petrocalcic horizon	>760 ka to 2.2 million yr (middle Pleistocene to late Pliocene) (note: La Mesa petrocalcic horizon formed in the constructional top of the Camp Rice Formation)
Camp Rice	N/A	Rio Grande Pebbles	Plio-Pleistocene (0.73–3.4 million yrs)

Playa Deposit	Original Clast Stratigraphy	Age
Lake Tank*	None	Present to Late Pleistocene
Petts Tank*	Rare pedogenic carbonate nodules	Late Pleistocene (25–75 ka)

* Very rare and localized occurrence.

was deposited when the ancestral Rio Grande spilled over Fillmore Pass into the Hueco Basin during the Quaternary (Seager et al., 1987; Mack et al., 1996).

A model has been developed to explain the late Quaternary eolian, alluvial, and fluvial stratigraphy in this region based on soil-geomorphology, stratigraphy, palynologic, isotopic, and radiometric analyses (Ruhe, 1967; Hawley, 1975; Gile et al., 1981; Monger, 1995; Buck et al., 1998; Buck and Monger, 1999). This model suggests that periods of regional erosion and deposition in eolian, alluvial, and fluvial environments are primarily controlled by climatic fluctuations in which decreased precipitation results in decreased vegetative cover, increased erosion, and concurrent deposition-progradation of younger fan surfaces, and Rio Grande aggradation. These arid periods are followed by periods of increased precipitation in which vegetative cover increases, erosion decreases, and stable land surfaces with associated soil development form on the alluvial fans, while subsequent erosion and downcutting occur along the Rio Grande (Gile, 1975; Gile et al., 1981; Monger, 1995). The stratigraphy and timing of erosional and depositional events along the Rio Grande river basin and surrounding mountain ranges has been well docu-

mented (Gile et al., 1981). However, the stratigraphy and landscape evolution of the eolian basin floors has only recently been documented (Buck et al., 1999; Buck and Monger, 1999; Gile, 1999). These eolian basin floors have an extensive archaeological record (Basehart, 1974; Beckes et al., 1977; Whalen, 1977, 1978; Pigott, 1978; Carmichael, 1986; Anschuetz et al., 1990; Doleman, 1991, 1992; Doleman and Swift, 1991; Camilli and Ebert, 1992; Doleman et al., 1992; Burgett et al., 1996a, 1996b). It is, therefore, vital to understand how or if the eolian geomorphic history has affected this record (Buck et al., 1999).

METHODS

One hundred and forty soil profiles were excavated and described throughout the southern Tularosa and northern Hueco basins on Fort Bliss Military Reservation to determine the stratigraphy and eolian evolution of these basins. In 96 of these trenches, the presence or absence of a surficial lag was noted and surficial lags described in detail. In the remaining 44 trenches, details on surficial lag were not recorded. Measurements and descriptions of four hundred and one randomly chosen clasts were taken at four sites across the basin. In addition, nine limited protection zones (a total of approximately 10 km^2) on Fort Bliss Military Reservation were mapped using geomorphic features and vegetation to determine the potential for stratigraphically intact archaeological sites. Texture on specific profiles was determined by feel according to the flow chart by Thien (1979). Soil color was determined using the Munsell soil color chart. Radiocarbon dating of specific samples was performed by Beta Analytic, Inc. Carbonate morphogenetic sequences were based on the classification of Gile et al. (1966). Stratigraphic units were compared and correlated with those used on the adjacent alluvial fans of the Organ Mountains (Gile et al., 1981; Monger, 1995).

STRATIGRAPHY AND LANDSCAPE EVOLUTION

Previous work described in detail the eolian stratigraphy of the northern Hueco and southern Tularosa basins (Table I) (Buck, 1996; Buck et al., 1998; Buck et al., 1999; Buck and Monger, 1999). For approximately the past 2 million years, these basins have been dominated by eolian processes, which winnowed and reworked ancestral Rio Grande sediments. Evidence for the presence of the ancestral Rio Grande is found throughout the basin and as far north as White Sands Missile Range Main Post (Seager et al., 1987). These fluvial sediments include the Plio-Pleistocene Camp Rice Formation (Table I). Pumice-clast conglomerates indicate that the river was present in the Hueco Basin at approximately 2.22 Ma (Mack et al., 1996). At some time after that, the river was again diverted back through Fillmore Gap (Seager et al., 1987) and into the Mesilla Basin where it remains today. Since that time, eolian processes have dominated these basins. No permanent or intermittent streambeds occupy the basin floors.

The constructional top of the Camp Rice Formation forms the La Mesa geomorphic surface, which extends across the entire basin floor except in areas where

normal faulting has resulted in uplift and erosion (Monger, 1993; Buck et al., 1998). The La Mesa surface (middle–early Pleistocene) is characterized by a massive petrocalcic horizon (stage III, IV, or V carbonate morphology; Gile et al., 1966; Machette, 1985; Table I). Although alluvial Jornada I and II deposits are common along nearby alluvial fans, their eolian facies are not common within the Hueco and Tularosa basins. These deposits are middle–late Pleistocene and are usually preserved only near intrabasinal normal faults, where downward movement along the fault has resulted in high sedimentation rates and preservation. Where present, these deposits contain a well-developed argillic horizon with either an incipient petrocalcic horizon (stage III, Jornada I) or stage II nodules in a calcic horizon (Jornada II) (Table I). The next youngest deposit within these basins is the Isaacks' Ranch (Table I), which aggraded between 15,000 and 8000 yr B.P. (Gile et al., 1981; Gile, 1995). The eolian facies of the Isaacks' Ranch is a distinctive unit with a sandy loam texture, containing stage II carbonate nodules between 0.5 and 4 cm in diameter. Although this unit can be found throughout the basin, in many areas, it has been severely deflated or is missing entirely, and only these stage II nodules remain as evidence of its prior existence. The major deflation event is thought to have happened in the early Holocene, approximately 8000 yr B.P. (Gile et al., 1981; Buck et al., 1998; Buck and Monger, 1999). This deflation removed the finer particles in the Isaacks' Ranch deposit, leaving a lag at the surface, which in many places throughout these basins was later buried and today can be found as a paleolag deposit (Figure 2). This paleolag was then buried by the Organ deposits. On the piedmont slope of the adjacent alluvial fans, Organ deposits are divided into three distinct units: Organ I, II, and III (Gile et al., 1981). Organ I deposits have been dated between 7500 and 2200 yr B.P., Organ II between 2200 and 1100 yr B.P., and Organ III between 1100 yr B.P. and approximately 150 years ago (Table I) (Gile, 1975; Gile et al., 1981). Within the Hueco Basin, the three Organ units are distinguished by their carbonate morphology, texture, and relationship to the other stratigraphic units within a profile. Generally, Organ I sediments contain ready visible, strong stage I carbonate filaments. Organ II sediments, which are not always present, contain weakly developed, faint stage I filaments. Organ III deposits within these basins often overlie Organ I sediments. Organ III sediments are characterized by the absence of carbonate filaments with little to no stratification. All Organ deposits within these basins have a loamy sand texture and contain no indigenous geologic or pedogenic clasts.

The Historical Blowsand deposit covers most of the surface of the basin today. It is characterized by coppice dunes and interdunal sandsheets composed of stratified loamy sand containing no carbonate filaments. This deposit formed within approximately the last 150 years (Table I) as a result of overgrazing and/or a possible recent increase in aridity, which caused decreased vegetative cover and erosion of underlying deposits (Buffington and Herbel, 1965; Gile, 1975; Blair et al., 1990). Interdunal deflational areas contain a modern surficial lag composed of Rio Grande pebbles, fragments of carbonate from the stage III and IV petrocalcic horizon of the La Mesa surface (and/or in rare instances a Jornada I deposit), and
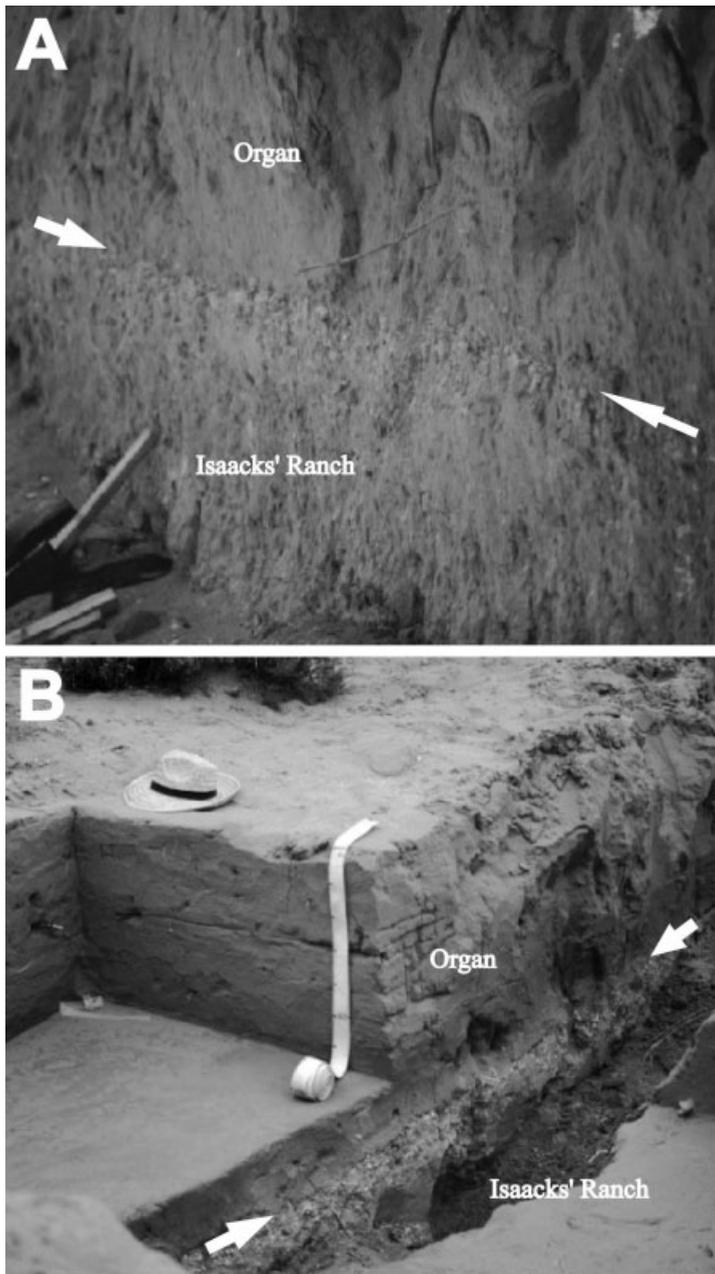
Figure 2. Photos of the buried ~8 ka paleolag, formed from deflation of the Isaacks' Ranch deposit: (A) soil trench; (B) archaeological site.

stage II nodules from the Isaacks' Ranch (or, rarely, a Jornada II deposit) (Figures 3 and 4). This lag also contains artifacts, which may have originated from any of the underlying units within the basin.

Playa deposits are rare but are characterized by sandy clays with or without gypsum; they are found in closed depressions and/or fault-bounded depressions (Monger, 1995; Buck, 1996; Buck et al., 1998). These fine-grained sediments correlate to the Petts Tank and/or the Lake Tank deposits of the Desert Project (Gile et al., 1981). Petts Tank usually correlates with Jornada II deposits on the alluvial fans, but, in places, it contains well-developed stage III carbonate morphology, which suggests it is older. Lake Tank deposits are similar in lithology to Petts Tank but are younger, usually early Holocene (Table I).

CLAST STRATIGRAPHY

Generally, eolian environments such as this one lack pebble-sized or larger clasts unless they were transported laterally through some other process or were brought into the basin through anthropogenic activities. However, pedogenic processes in this basin have created soils that, with increasing age, contain increasing amounts of pedogenic carbonate (Monger and Buck, 1995). In some of the older deposits, pedogenic carbonate formed hard, durable clasts (Table I). Geologic and pedogenic clasts in these basins included (1) Rio Grande pebbles from the Camp Rice Formation, composed of numerous lithologies, (2) broken fragments of the La Mesa petrocalcic horizon (stage III and/or IV; Gile et al., 1966), and (3) nodules of pedogenic carbonate (stage II) from primarily the Isaacks' Ranch deposit. In rare and localized instances, some stage II or incipient stage III carbonate was derived from the Jornada I and II or the Petts Tank deposits. Anthropogenic clasts include numerous artifacts and burnt caliche (Figure 3). Most of the clasts range in size from < 1 cm up to nearly 4 cm in diameter. Included with this surficial lag of clasts is a thin (< 5 mm) sheet of coarse sand (Figure 3).

RESULTS

Stratigraphy of Clasts and Locations

Of the 140 excavated trenches, 96, both with and without surface lag, were selected for study to gain a better understanding the subsurface stratigraphy. This may help archaeologists predict areas where intact stratigraphy (and thus archaeological sites) may occur. Sites for all 96 trenches were randomly selected within the basin floor in either interdunal blowouts, sandsheets, or adjacent to coppice dunes. (Five surface distinctions were mapped based on the presence and amount of surficial clasts and vegetation. Approximately one-fifth of the trenches were randomly placed in each map unit.) Of these, 18 (19%) contained no surficial lag, and 78 (81%) contained a surficial lag that varied between few clasts to very abundant clasts (Figures 3 and 4). Of those trenches with a surficial lag, 87% contained Rio Grande pebbles, 97% contained stage II carbonate nodules, 82% contained stage III/ IV fragments of a petrocalcic horizon, and 13% contained limestone clasts derived
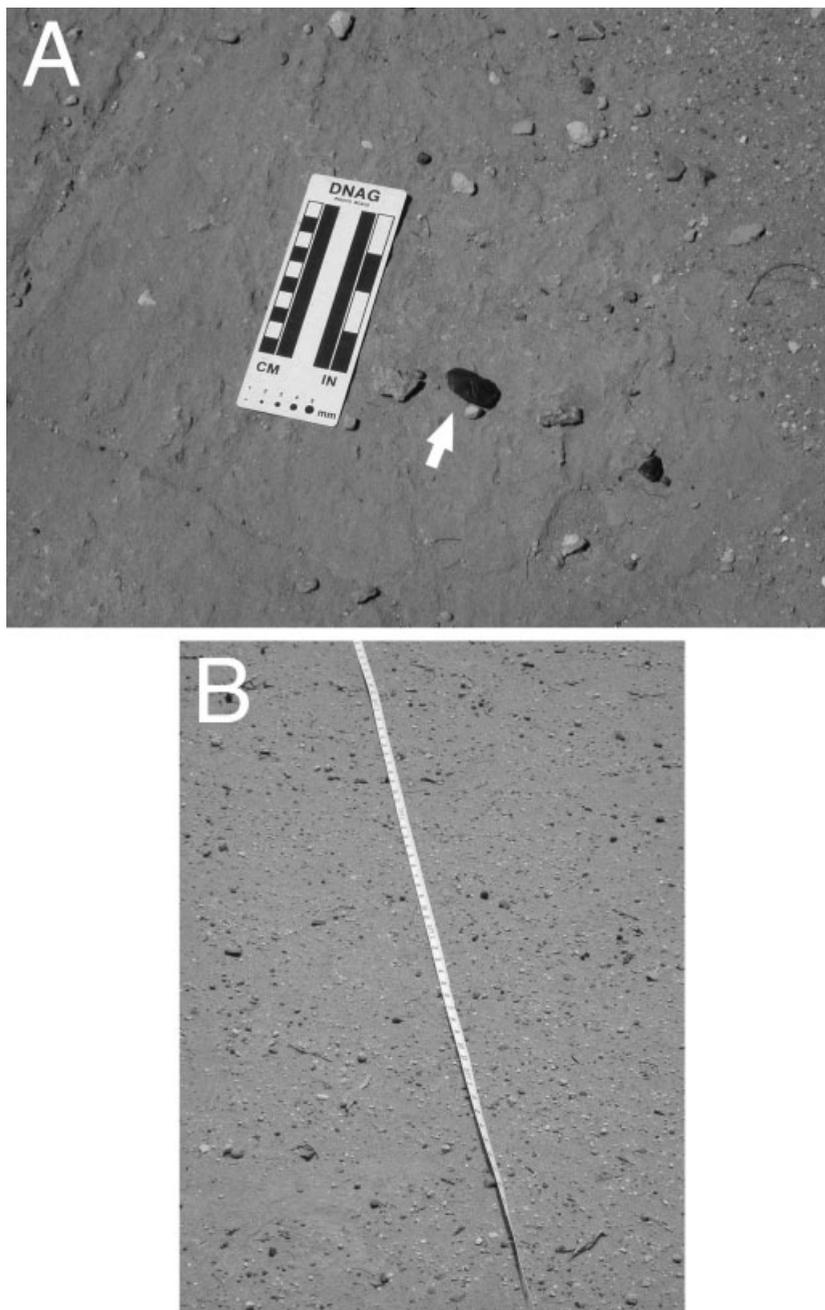
Figure 3. Modern surficial lag deposits containing Rio Grande pebbles, fragments of pedogenic carbonate, and artifacts (Note: arrow pointing to artifact in photo A). Photo B vertical field of view is ca. 5 ft.
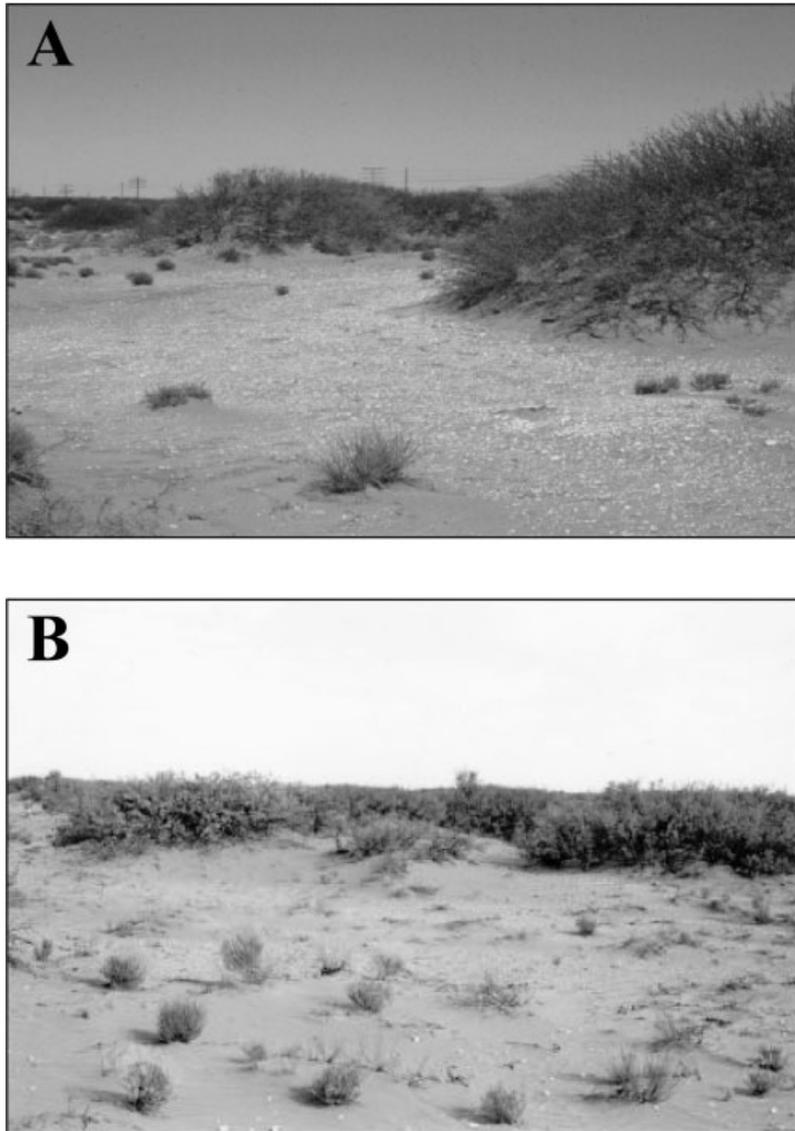
Figure 4. Modern surficial lag deposits in interdune areas.

from the adjacent Hueco Mountain alluvial fans. Many of these limestone clasts may be anthropogenic in origin because fire-cracked rock is common throughout these basins (Leach, 1992). Of the 78 trenches with a surficial lag, 100% contain younger sediments below the surface clasts. For example, stage IV (early Pliestocene) petrocalic fragments may overlie late Holocene Organ III deposit (Figure 5).

Of the 96 trenches with detailed descriptions of the surficial lag, 78 were excavated to the La Mesa petrocalcic horizon. Of these 78 trenches, 30 contained Isaacks' Ranch deposits (38%), 56 contained Organ I deposits (72%), 15 contained Organ II deposits (19%), and 44 contained Organ III deposits (56%). Only 4 of these 78 trenches (5%) contained a complete stratigraphy of Isaacks' Ranch, Organ I, II, and III deposits. No correlation was found between the surficial lag or vegetation, and the subsurface stratigraphy.

Four hundred and one clasts were randomly chosen in four sites within the basin. The average diameter of all clasts was 0.8 cm. The average size of each lithology are as follows: ancestral Rio Grande clasts: 0.9 cm; limestone fragments: 1.8 cm; La Mesa fragments: 0.7 cm; Isaacks' Ranch nodules: 0.6 cm. Three artifacts were identified and measured out of the 401 clasts measured. Their average size was 1.1 cm in diameter. All clasts ranged from well rounded to subangular. The largest clast was a Rio Grande pebble, 3.8 cm in diameter.

DISCUSSION

Climatic fluctuations are the driving forces behind eolian erosion and deposition within these basins (Gile et al., 1981; Monger et al., 1998; Buck and Monger, 1999; Buck et al., 1999). Using the modern landscape as an analog, vegetation types and densities control eolian processes, and thus, the degree of erosion/sedimentation is very localized. This results in a stratigraphic record within the basin floor that is extremely erratic in both time and space. Areas within a few meters of each other may have experienced erosion or deposition to different degrees as seen in the complexity of the stratigraphy in each of the 140 profiles studied. Despite our attempt to use vegetation and/or surficial clasts as indicators for subsurface stratigraphy, what lies on the surface does not correlate with stratigraphic units in the subsurface nor with the thickness of each deposit. Further, areas that have a surficial lag and those that do not, show no correlation in subsurface stratigraphy. In either area, determining from the surface what stratigraphic units lie underneath or how thick the units may be is impossible. Typically, however, those areas that do not have a surficial lag are found in areas with interdunal sandsheets, often anchored by grasses. These areas may be more stable and therefore, less likely to show evidence of modern deflation.

Tectonic and anthropogenic processes also affect local stratigraphy. Often the most complete stratigraphy within the basin lies near one of the numerous north-south trending intrabasinal fault complexes (Buck, 1996; Buck et al., 1998; Buck and Monger, 1999). These normal faults episodically create minor depressions, which encourages increased water run-in, increased vegetation, and thus increased
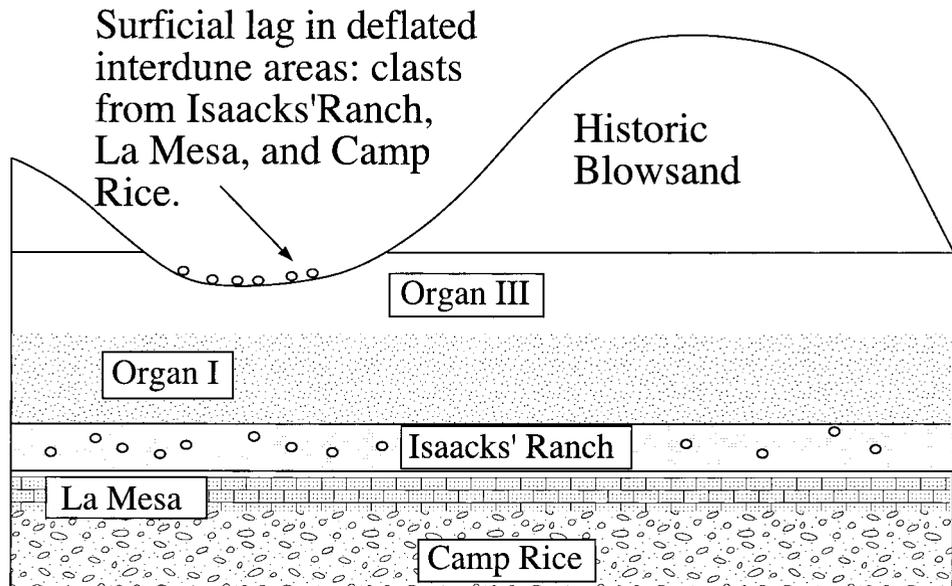
Surficial lag in deflated
interdune areas: clasts
from Isaacks'Ranch,
La Mesa, and Camp
Rice.

Historic
Blowsand

Organ III

Organ I

Isaacks' Ranch

La Mesa

Camp Rice

Figure 5. Typical late Quaternary stratigraphy in the northern Hueco and southern Tularosa basins, with a modern surficial lag deposited composed of older clasts overlying younger, intact sediments.

eolian sedimentation. Additionally, we found previously unknown playas that occurred in these depressions during the late Pleistocene (Figure 6). These playas may have been important sources of water for human and animal inhabitants of the area and, as such, may contain important archaeological records. Their possible archaeological significance, combined with their potential for intact stratigraphy, has made playas useful in paleoclimatic and landscape evolution studies (Buck and Monger, 1999) and should be considered for future archaeological investigations.

Recent anthropogenic effects upon the basins' stratigraphy include overgrazing and military activity. Overgrazing approximately 150 years ago caused a major change in the landscape across these basins (Buffington and Herbel, 1965). Eolian erosion formed many interdunal deflational areas between small (1–3 m in height) coppice dunes anchored by mesquite. Some areas also contain sandsheets, usually anchored by patches of grasses. Military activity continues to modify the modern landscape. Tracks indicate that vehicles have cut coppice dunes in half; tanks have disturbed the stratigraphy up to 30 cm deep in certain parts of the basin. Although tectonic processes have modified climatic fluctuations throughout the late Quaternary, overgrazing may have had the most profound effect on the stratigraphy within the Hueco Basin during the last 8000 years.

The most common deposit found in our trenching (excluding the modern Historic Blowsand, which is found within the entire basin either in the form of sandsheets or coppice dunes) is the Organ I unit that buries the ~8 ka paleolag surface. Of
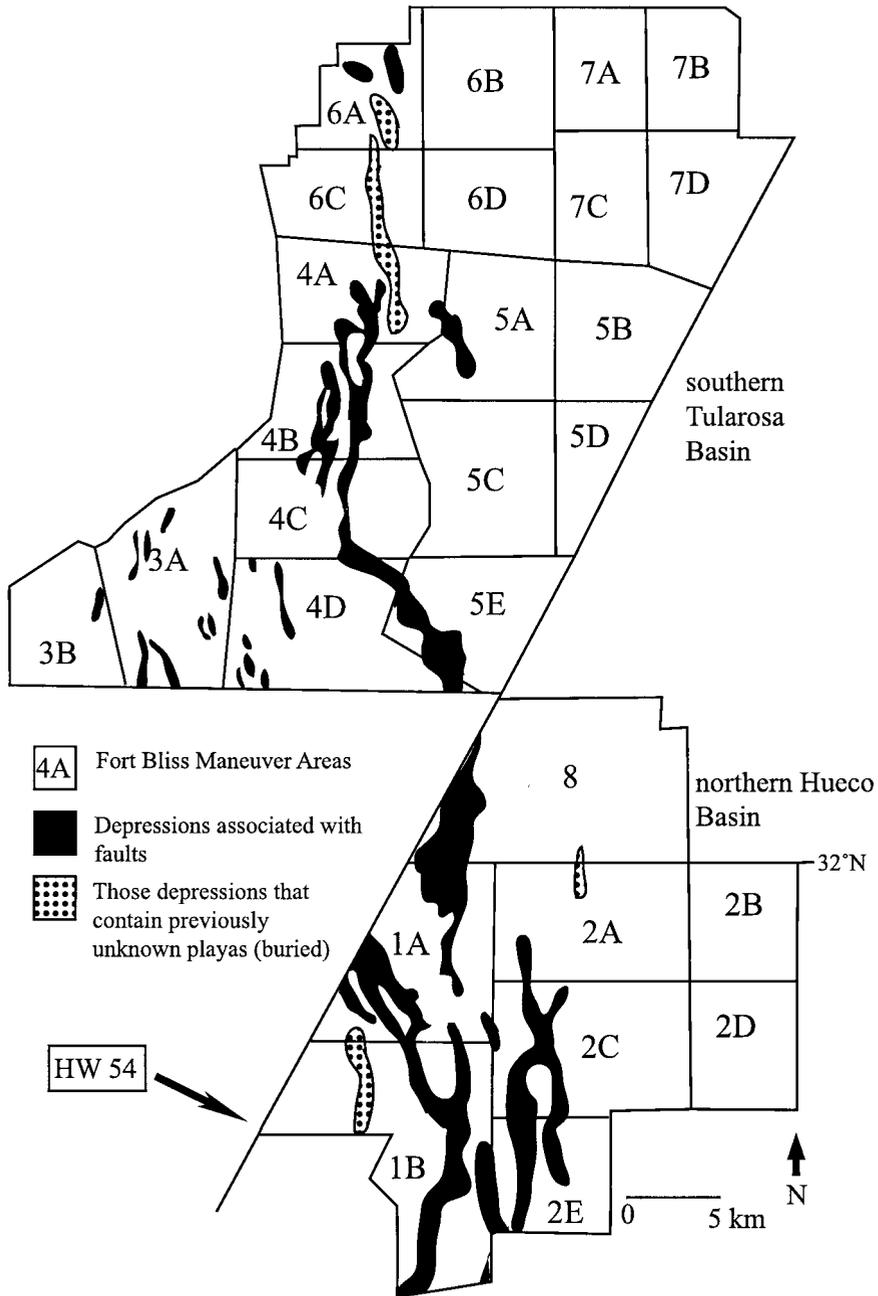
Figure 6. Map of fault-related depressions on Fort Bliss Military Reservation, and those that have been found to contain playa deposits, which may have been a source of water for late Pleistocene faunas and human inhabitants.

the 78 profiles that were excavated to the depth possible by the backhoe (top of the La Mesa petrocalcic horizon), 78% contained at least some Organ I deposit. In contrast, the Organ II deposit is the least common deposit within the basin, comprising only 19% of the 78 profiles. This may be due to climate: the arid period that was responsible for the formation of the Organ II unit along the alluvial fans was not severe enough to affect the entire basin floor (Buck and Monger, 1999). The percentage of Organ III deposits within the 78 profiles is harder to verify because the most recent deflation (~150 yrs ago) may have eroded it in many places. Therefore, the absence of the Organ III unit in many profiles cannot be attributed solely to nondeposition. The only major trend across these basins in the stratigraphy is the evidence for major erosion of the Isaacks' Ranch unit along the east side of the Hueco Basin. The Isaacks' Ranch deposit was found in 38% of the 78 profiles, but when the locations of the Isaacks' Ranch unit are plotted, a pattern emerges. No Isaacks' Ranch deposits were found along the east side of the northern Hueco Basin (Figure 7). Stage II nodules (presumably from the Isaacks' Ranch deposit), however, are found throughout this area on the modern surface, although extensive trenching did not reveal any Isaacks' Ranch unit in the subsurface. This suggested that the major erosion at approximately 8 ka (Buck and Monger, 1999; Buck et al., 1999) was more extensive along the east side of the basin and resulted in the complete removal of this unit in this area, leaving only the stage II nodules behind as a surface lag. These stage II nodules now lie at the surface with younger, intact Organ deposits beneath them. Explaining how these older clasts came to be stratigraphically inverted is the primary focus of this study.

There are several processes that can move older, subsurface clasts upward through sediments to the surface, including freeze/thaw, shrink/swell, and animal burrowing. In addition, McFadden et al. (1987) showed how on desert pavement surfaces, clasts that begin on the surface can remain there while finer sediments accumulate beneath them. All of these processes can result in stratigraphically older clasts overlying younger sediments. The possible role of each of these processes is reviewed in the following discussion.

Upward Movement Through Bioturbation, Freeze/Thaw, and/or Shrink/Swell

Out of the 78 trenches that contained a surficial lag deposit, 100% had younger intact stratigraphy beneath the surficial lag. Out of 140 trenches excavated, clasts were almost always found either stratigraphically in place (in the unit in which they were formed pedogenically or deposited geologically) or within one of the deflational lags: at the 8 ka paleosurface (Figure 2) or the modern surface. A few trenches (< 3.5%) showed some evidence for the upward movement of clasts through younger sediments. Even in these cases, the evidence was only one or, rarely, two clasts found suspended in the profile within one of the Organ deposits. Many of these trenches were excavated to 15 m long, yet even in these long cross-sections, clasts were not shown to have worked their way to the surface. Clasts
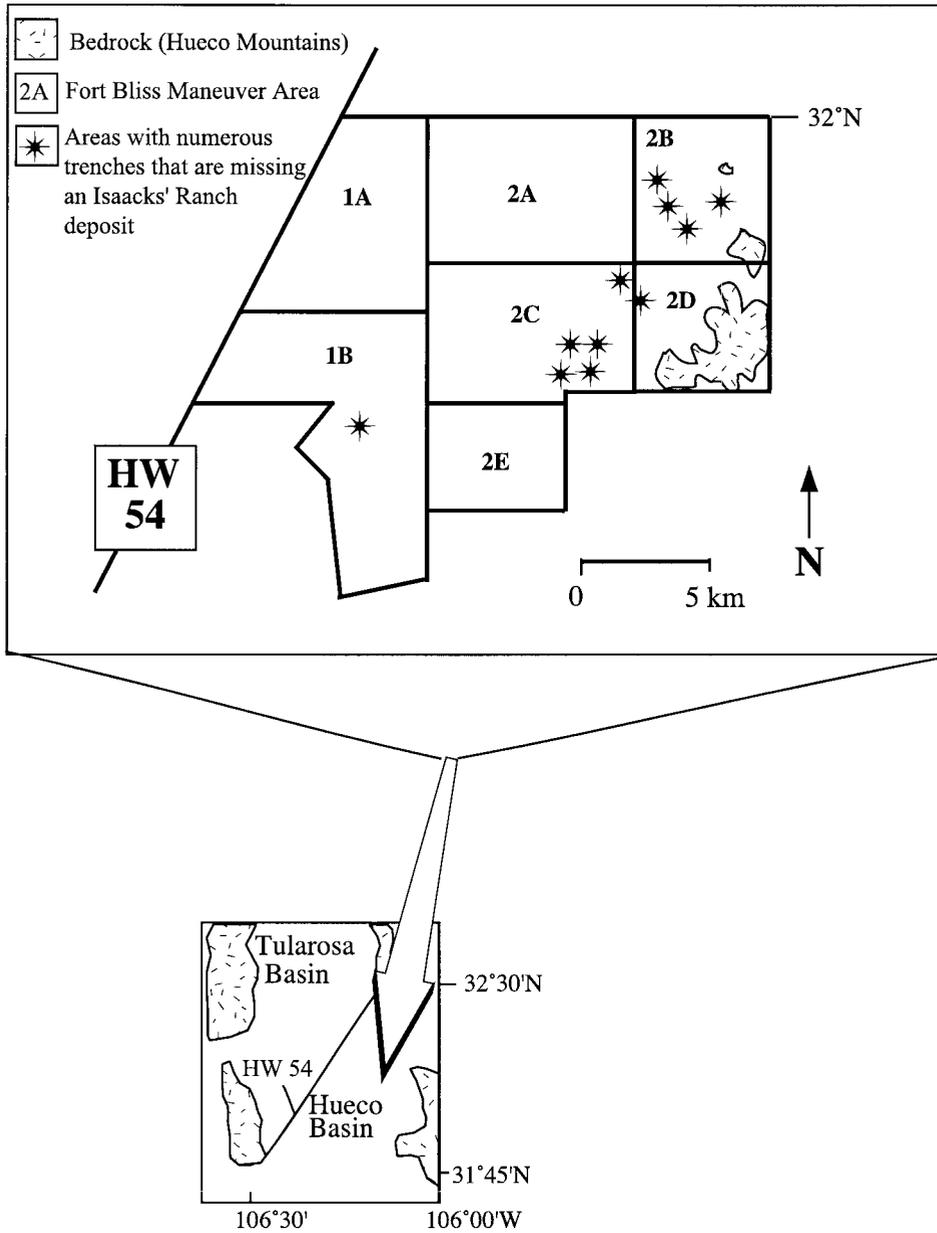
Figure 7. Map showing the distribution of trenches that are missing an Isaacks' Ranch deposit, but do have numerous stage II carbonate nodules remaining at the surface.

were either found on the 8 ka paleosurface or on the modern deflational surface (Figures 2, 3, and 4). In addition, evidence for bioturbation was also rare on the basin floor. The stage I filaments in the Organ I deposit were always intact, and usually a clear break distinguished the Organ I deposit from the Organ III. If bioturbation is or was a major process in these basin floor soils, these filaments should not be intact. In addition, no textural difference was seen within the Organ sediments as would be expected in a biomantle (Johnson, 1989, 1990). Floral and faunal activity within the basin floors appeared to be much lower than in nearby environments on alluvial fans. No clasts were ever found in burrows backfilled with sediment. Therefore, although the formation of biomantles can be a significant process in sorting fine from coarse materials and forming stone lines (Johnson, 1989, 1990; Paton et al., 1995), there is little to no evidence to support this as a significant process in the study area. Lastly, these sediments are all loamy sands with very small amounts of clay (Buck, 1996; Buck and Monger, 1999; Buck et al., 1999), so the potential for shrink/swell essentially nonexistent. Therefore, little to no evidence supports shrink/swell, freeze/thaw, or bioturbation processes to explain the presence of older clasts overlying younger sediments in this study.

Desert Pavement Mantle: Fines Accumulate Beneath Coarse Clasts

McFadden et al.'s (1987) study showed how younger silt could accumulate beneath older clasts on desert pavement surfaces. The desert pavements described in their study, however, differ from the surface lag deposit described herein. Their desert pavements are composed of a nearly continuous cover of surface clasts, whereas, in this study, the surficial lag can vary between only a few scattered clasts to a dense covering of clasts. In addition, McFadden et al. (1987) found that clay and silt-sized particles drive the processes of forming a vesicular A horizon and keep coarser clasts at the surface. In this study, the younger Organ deposits that lie underneath the older clasts are composed of much coarser loamy sands. Even then, the process would be ongoing since at least the Camp Rice period for the Rio Grande pebbles to have remained at the surface. Further, if this were the case, these pebbles should have acquired some degree of desert varnish within the last 2 million years (depending upon clast lithology). This, however, was not the case in these basins, leading one to suspect either a more recent exposure to the surface or removal of varnish via sand blasting. Therefore, it is less probable that the same processes that are responsible for younger fine materials accumulating beneath older surface clasts in a desert pavement environment could be responsible for the situation we see in this study.

Eolian Deflation Combined with Lateral Movement over Younger Intact Stratigraphy

Another hypothesis to test is the lateral movement of clasts from exposed older deposits across younger deposits. If the older sediments are exposed along the edges of the basin and are moved laterally out into the center of the basin, they

could have moved on top of the younger sediments. This scenario, however, can be ruled out as a viable hypothesis in this study. None of the units containing clasts, which include the Camp Rice, La Mesa, and Isaacks' Ranch, are exposed along the flanks of the basins. Therefore, the origin of the surficial clasts is not along the flanks of the basins.

However, there are windows of deflational areas within the basin where eolian erosion has cut down into the La Mesa petrocalcic horizon. The extent and size of these windows are not well known, but consistent with the known local variations in stratigraphy in this study, they probably vary greatly. Therefore, these areas of deflation could be the source of the surface clasts in this study. Once exposed at the surface, these clasts could be moved laterally onto younger, intact stratigraphy (Figure 8). The processes of lateral movement could be wind and/or sheet-flow during intense storm events.

Movement of these grains by water is probably not a significant process in this area because bedforms (i.e. sheet sands, ripple laminations, etc.) or other sedimentary features indicative of water flow are absent. The clasts are not sorted or grouped at the surface, which would be expected with sheetflow during storm events. Although bedforms could be reworked/erased through eolian processes, it is unlikely that water flow plays a significant role in moving sediment in this basin because no sedimentary features are present and no permanent or intermittent streambeds occupy the basin floors.

In contrast, the potential for lateral movement by wind could be significant. To determine the minimum threshold velocity of wind needed to initiate surface movement, the following equation can be used:

$$V_{*t} = A \sqrt{\rho_s - \rho_f \, gd/\rho_f}, \qquad \text{where A = 0.1 for air (Bagnold, 1954).}$$

This equation assumes that air flow is turbulent, air is flowing over a flat bed of loose grains, the grains are spherical, and we do not take into account any changes in soil texture, moisture status, or vegetation along the pathway of movement. In addition, this equation does not include any movement that will occur from impacts from other grains. Therefore, using this calculation gives a minimum wind velocity needed to initiate movement of clasts from direct wind action only. For the average clast of 0.8 cm diameter, the minimum threshold velocity is 29 mph. For the largest clast in this study, 3.8 cm diameter, the minimum threshold velocity is 64 mph. However, in these coppice dune fields, particle–particle collisions probably are more important in moving these small pebbles (Gillette, 1981). Bagnold (1954) has found that the impact of a saltating grain can move a surface grain 6 times its size. Thus, saltation of fine grains can move larger grains (surface creep) that direct wind action would not otherwise move.

Typical wind speeds in this area vary greatly, but the average wind speed measured in El Paso between 1961 and 1990 is 8.9 mph, and peak gusts up to 84 mph have been recorded (National Weather Service). Wind speeds of more than 40 mph can occur every month (National Weather Service). Therefore, even without the
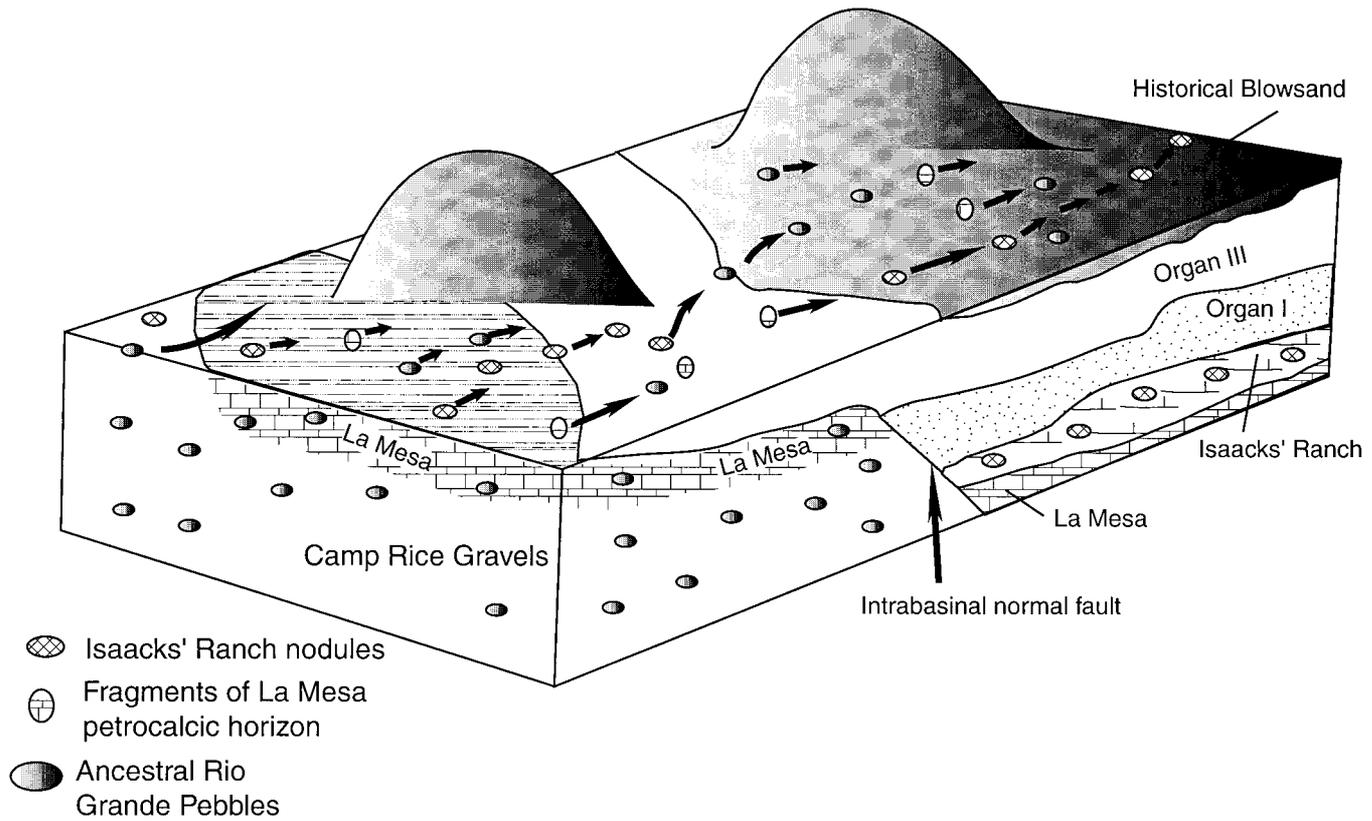
Figure 8. Conceptional model for formation of inverted clast stratigraphy in this study. Eolian "windows" of deflation expose older sediments and create a surficial lag deposit. Clasts within the surficial lag are moved laterally onto areas that are not deflated. (Note: clasts are not drawn to scale.)

added surface creep caused by the impacts of saltating smaller grains, the average-sized clast in this study could be easily moved during normal peak wind gusts experienced during most months. Additional support to suggest the plausibility of this mechanism can be found in a study of a wind storm in southern California. In December 1977, a wind storm with maximum velocities measured between approximately 30 and 140 mph, blew clasts as large as 5.5 by 3.6 by 3.0 cm at least as high as 1.6 m. Particles larger than the average size in this present study were found 2.4 m high and lodged into telephone poles (Wilshire et al., 1981).

An additional factor in moving these surface clasts may be the hard-packed surface upon which they lie. In Figure 3, the surface under the clasts is hard-packed soil. This is common in the study area, although no data exist to determine its geographic or temporal extent (does it occur seasonally or is it more permanent?). This hard-packed layer underlying the surface clasts should increase lateral movement. It is also likely to decrease infiltration, leading to increased runoff during rare sheetflow events. It should also increase the ability of wind to move these clasts because less fine sand is available for suspension; increased suspension of particles causes increased drag and substantially slows wind velocities near the soil surface (Bagnold, 1954). This lack of available loose, finer sand (see Figure 3) could be expected to help increase the wind's capacity to move the larger surface clasts. Therefore, it is easily possible for wind in the Hueco Basin to laterally move (through rolling and saltation) the average (and even largest) clast in this study.

Therefore, in areas of severe deflation, clasts derived from the Camp Rice, La Mesa, and Isaacks' Ranch deposits would all be exposed on the surface and thus have the potential to be moved laterally by eolian saltation and surface creep into areas where deflation was not as severe and younger deposits remain intact (Figure 8). This lateral movement of clasts would have had to occur within the last 150 years, the most recent period of deflation. This is the event that converted an essentially planar, grassy basin into a series of interdunal deflation areas with small mesquite-capped coppice dunes and sandsheets. In areas of severe deflation, all the sediment down to the La Mesa surface has been removed. In some areas, there is evidence that the La Mesa petrocalcic horizon is missing, and thus deflation could have exposed the Camp Rice gravels. However, deflation down into the Camp Rice gravels is not necessary for the ancestral Rio Grande pebbles to accumulate at the surface. These gravels may also be present just above the La Mesa petrocalcic horizon because the La Mesa petrocalcic horizon (Bkm) formed in the uppermost sediments of the Camp Rice Formation.

This combination of vertical and horizontal processes is currently the most likely explanation for the inverted clast stratigraphy in the Hueco and Tularosa basins. Because deflation is a common process in eolian environments, and because lateral movement of clasts can occur at any time when the clast is at the surface, the destruction of stratigraphic and horizontal integrity of clasts in an eolian environment is highly probable. This is an important problem particularly for archaeologists working in eolian environments (deserts or coasts) because both the temporal and spatial distribution of artifacts could be disrupted. If other geologic or pedo-

logic clasts, or other temporally diagnostic artifacts are not present, it may be extremely difficult to recognize that artifacts have been significantly displaced from their original context.

CONCLUSIONS

The modern surface of the northern Hueco and southern Tularosa basins is substantially covered with a lag of clasts composed of pebbles from the ancestrial Rio Grande, fragments of the stage III–IV La Mesa petrocalcic horizon (Gile et al., 1966), and stage II nodules from the Isaacks' Ranch deposit (Buck and Monger, 1999; Buck et al., 1999). In all trenches where a surficial lag is present, younger intact stratigraphy lies beneath these older clasts. This inversion of clasts and the intact, younger sediment underlying them can be best explained through a combined process of deflation followed by lateral movement. The driving mechanism for this lateral movement is best explained by wind (with a minimum threshold velocity of 29 mph to move the average clast, not including the added effects of saltating grains). The minimum intensity for this process is within normal climatic parameters for the study area.

In light of this new geomorphic data, archaeological interpretations based on artifacts in these basins should be reexamined (e.g., Whalen, 1977, 1978, 1986; Doleman, 1992; Mauldin, 1994; Leach et al., 1998). Archaeological interpretations based upon the stratigraphic placement and association of surrounding artifacts may be highly misleading. More research is needed in several areas, including determining the rates and/or seasonality of lateral movement and the effect of the clast/artifact size and shape on movement. However, this initial work has shown that geologic and pedologic clasts in eolian environments can be useful in determining geomorphic processes that may also affect archaeological clasts. In addition, this paper shows how two geomorphic processes (eolian deflation and lateral movement) may act together to disrupt the original stratigraphic and horizontal relationship between clasts and eolian strata. This should be kept in mind when studying any eolian environment worldwide.

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