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EOLIAN STRATIGRAPHY OF INTRABASINAL FAULT DEPRESSIONS IN THE NORTHERN HUECO AND SOUTHERN TULAROSA BASINS: EVIDENCE FOR NEOTECTONIC ACTIVITY

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Abstract—North-south-trending depressions, which parallel the major boundary faults between the northern Hueco and southern Tularosa Basins and the Franklin, Organ, and San Andres Mountains, have been interpreted as small intrabasinal normal faults (Seager, 1980, Seager et al., 1987; Machette, 1987; Collins and Raney, 1990, 1991a, b, 1994). However, because these areas lie within the Fort Bliss Military Reservation and White Sands Missile Range, little work has been done on them. This project excavated and described approximately 140 profiles, including 81 within eight intrabasinal fault complexes as part of an archaeological study to determine the late Quaternary stratigraphy within the basin. Our results show five major stratigraphic units within the Hueco Basin: La Mesa, eolian analogs of the Jornada (I and II), Isaacks' Ranch, and Organ deposits, and lastly, the Historic Blowsand deposit. These sediments contain the same morphologic features and have similar radiocarbon ages as sediments along adjacent alluvial fans, indicating that these eolian sediments are time correlative to the extensively-studied deposits along the alluvial fans in the adjacent Desert Project (Buck, 1996; Buck et al., 1997; Buck and Monger, in press). Morphologic features, isotopic and pollen studies, as well as radiocarbon dates, suggest that the stratigraphy of both types of sediments are controlled by alternating periods of erosion and deposition, which are primarily driven by climatic fluctuations. However, stratigraphic differences along intrabasinal faults suggest some additional local tectonic controls. Understanding the late Quaternary stratigraphy within these basins is crucial for future neotectonic studies. Evidence for seismic activity possibly as recently as the late Pleistocene or early Holocene was found in the form of seismic-induced liquefaction features and fault-related offset of units.

INTRODUCTION

The Hueco and the Tularosa basins form one of the eastern-most extensions of the southern Rio Grande rift. These basins are bounded by the Sacramento and Hueco Mountains to the east, and the San Andres, Organ, and Franklin Mountains to the west. A system of high-angle normal faults bound the San Andres, Organ and Franklin mountain ranges and show considerable Quaternary movement (Gile, 1987; Machette, 1987). This fault system is over 180 km long and has been described as "the most impressive Quaternary fault zone in the interior of the United States" (Machette, 1987, p. A17). In addition to these boundary faults, an intricate system of en echelon intrabasinal fault complexes are present in the Tularosa and Hueco Basins. Access to the majority of these basins is controlled by the Fort Bliss Military Reservation or White Sands Missile Range.

While many of the intrabasinal faults may be from shallow tectonic downwarping of the basin-fill sediments (Seager, 1980), a seismic profile across the northern end of the Hueco Basin indicated that three out of five intrabasinal faults reached bedrock (Collins and Raney, 1991a, b, 1994). The height of these scarps ranges from 3 to 28 m, but is obscured by coppice dunes of the Historic Blowsand deposit (Seager, 1980; Machette, 1987; Collins and Raney, 1994; Buck, 1996). Determining the late Quaternary stratigraphy within the southern Tularosa and northern Hueco Basins is a necessary first step for future neotectonic, geomorphic, and archaeologic studies. In this paper, we present evidence for seismic-induced liquefaction features and fault-related offset of units, which indicate seismic activity possibly as recently as the late Pleistocene or early Holocene. In addition, our results show that the stratigraphy along these faults differs somewhat from that in the rest of the basin. In some cases, the hangingwall depressions have experienced a higher rate of sedimentation, and may contain playa deposits (Buck, 1996). Therefore, these fault depressions have the potential to be an important source of information for not only neotectonic and earthquake hazard studies, but also for archaeological and paleontological studies of the region because of increased potential for preservation and as a possible important source of water for late Pleistocene populations.

Regional soil-geomorphology

A model based on soil-geomorphology, stratigraphy, pollen, isotopic, and radiometric analyses has been developed to explain the late Quaternary stratigraphy in and around the Organ Mountains (Ruhe, 1967; Hawley, 1975; Gile et al., 1981; Monger, 1995). This model suggests that alluvial erosion and deposition along the alluvial fans is primarily controlled by climatic fluctuations in which decreased precipitation results in decreased vegetative cover, increased erosion and concurrent deposition and progradation of younger fan surfaces. 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 occurs (Gile, 1975; Gile et al., 1981; Monger 1995). These climatic fluctuations had similar effects within the northern Hueco Basin (Buck, 1996). The morphologic characteristics, stratigraphic position, and radiocarbon dates within geomorphic surfaces in both the adjacent alluvial fans, and the basin floor, indicate that the late Quaternary eolian sediments within the Hueco Basin are time correlative to the alluvial sediments on adjacent alluvial fans. The only major difference is that the primary control on erosion and deposition in the basin floor are eolian processes (Buck, 1996). Wind is currently the dominant control on erosion in the neighboring Jornada Basin (Gibbens et al., 1983; Hennessy et al., 1986) and similar geomorphic responses to climatic shifts in eolian systems have been documented in other areas (Gaylord, 1982; Gile, 1994).

Five major stratigraphic units are present within the Hueco Basin: La Mesa, eolian Jornada (I and II), eolian Isaacks' Ranch,

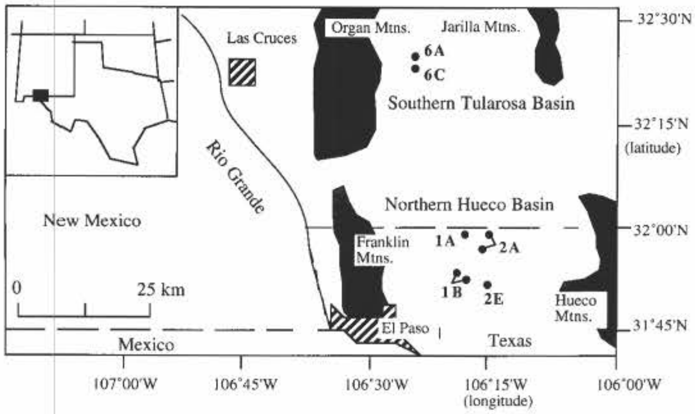

FIGURE 1. Location of trenches (black dots) along intrabasinal fault complexes, northern Hueco and southern Tularosa Basins. All are located on Fort Bliss Military Reservation and labeled according to their corresponding maneuver areas.

eolian Organ, and Historic Blowsand (Monger, 1995; Buck, 1996; Monger et al., in press). However, because of the non-uniform nature of eolian processes, specific locations within the basin may lack one or more of these units due to either non-deposition or erosion. In addition, overgrazing within the last 150 yrs. has resulted in basin-wide destabilization of the desert grassland and resulted in massive, but non-uniform erosion (Buffington and Herbal, 1965; Blair et al., 1990). Locally, topographic differences associated with the north-south trending intrabasinal faults within the Hueco Basin have also affected the stratigraphy. Excavation of soil-profile trenches originally for geomorphic and archaeological purposes allowed us an opportunity for a preliminary investigation of the stratigraphy associated with eight of these intrabasinal fault complexes (Fig. 1).

Methods

Approximately 140 profiles were excavated and described throughout the Hueco Basin to determine the stratigraphy and eolian evolution of the basin. Eighty-one of these profiles occur within eight fault complexes and were described to determine the history and stratigraphy of the fault complex. Texture on specific profiles was determined by feel according to the flow chart by Thein (1979). Soil color was determined using the Munsell soil color chart. Inorganic radiocarbon dating of specific samples were 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 OF THE NORTHERN HUECO AND SOUTHERN TULAROSA BASINS

Based on soil morphology, profile development, stratigraphic position (with associated unconformities), and radiocarbon dates, the stratigraphy of Quaternary eolian sediments within the northern Hueco and southern Tularosa Basins has been determined to be an eolian analog to that in surrounding alluvial fans (Buck, 1996). Listed below are the major stratigraphic units found within these basins.

La Mesa

The La Mesa surface in the southern Tularosa and northern Hueco Basins overlies the fluvial facies of the Camp Rice Formation, which contains well-rounded pebbles derived from the Rio Grande (Seager, 1981; Seager et al., 1987). The La Mesa geomorphic surface extends across the entire basin floor except for areas in which normal faulting has resulted in uplift and erosion. In many instances it contains stage III, but more commonly contains stage IV or V carbonate morphology, which is characterized by a massive, plugged horizon of calcium carbonate, with or without a laminar cap or pisolites (Gile et al., 1966; Machette, 1985). However, this massive, plugged horizon is not a planar, continuous unit across the entire basin. Instead, it is often characterized by dissolution pipes, in which large sections of the petrocalcic horizon are missing. In addition, because the depth to the top of the petrocalcic horizon has had localized differences through time, the petrocalcic horizon has precipitated and dissolved at different rates and depths. Therefore, the La Mesa petrocalcic horizon varies extensively across the entire basin in both its degree of development and character.

Eolian Jornada I and II

Eolian Jornada I and II sediments within the Hueco Basin are very rare and difficult to identify. In most places within the basin, the Jornada age deposits are: (1) welded onto the La Mesa petrocalcic horizon, (2) have been eroded, or (3) were never deposited. This makes the interpretation of Jornada I or II classification within the basin floor very difficult. However, within some of the fault complexes, the subsidence rate was high enough to preserve distinct Jornada-equivalent deposits. In these cases, the Jornada I unit is usually characterized by a well-developed argillic horizon overlying a thin or incipient stage III petrocalcic horizon overlying the La Mesa petrocalcic horizon. The Jornada II unit can be identified by a well-developed argillic horizon with stage II nodules underlying an Isaacks' Ranch deposit.

Playa deposits: Petts Tank and Lake Tank

Playa deposits are rare within the northern Hueco Basin, but are characterized by sandy clays with or without gypsum, and are present in closed depressions and/or fault complexes (Monger, 1995; Buck, 1996). 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 is usually correlative with Jornada II deposits on the alluvial fans, but in places it contains well-developed stage

TABLE 1. Soil-stratigraphy in the northern Hueco and southern Tularosa Basins (Gile et al., 1981; Monger, 1995; Buck, 1996). Asterisk (*) indicates uncommon occurrence.

Deposit	Carbonate Morphology	Age
Historic Blowsand	no carbonate	100-150 yr. (Historical)
Organ III	no carbonate	100? - 1100 yrs. B.P.
Organ II*	faint stage I	1100 - 2100 yrs. B.P.
Organ I	stage I	2200 - 7000 yrs. B.P.
Isaacks' Ranch	stage II	8 - 15 ka (early Holocene to late Pleistocene)
Jornada I and II*	stage II-III	25 - 400 ka (middle-late Pleistocene)
La Mesa	stage III- IV	> 400 ka (middle-early Pleistocene)

Playa Deposit	Age
Lake Tank*	Present to Late Pleistocene
Petts Tank*	Late Pleistocene (25 - 75 ka)

III carbonate morphology, which suggests an older age. Lake Tank deposits are similar in lithology to Petts Tank, but are younger, usually early Holocene in age (Table 1).

Eolian Isaacks' Ranch

Isaacks' Ranch deposits within the basin are characterized by stage II nodules of calcium carbonate (Table 1) and were deposited between 15,000 and 8000 yrs. before present (yrs. B. P.) (Gile et al., 1981; Gile 1995). These sediments usually contain slightly higher percentages of clay (sandy loam) as compared to the younger Organ and Historic Blowsand deposits (loamy sand) (Buck, 1996). However, in many areas within the Hueco Basin, the Isaacks' Ranch deposit is missing entirely, and often only its stage II nodules remain. These nodules of carbonate are present either in a paleolag deposit, or as part of a modern deflational lag between coppice dunes.

Eolian Organ

On the piedmont slope of the adjacent alluvial fans, Organ deposits have been divided into three distinct units: Organ I, II, and III (Gile et al., 1981). Organ I deposits have been dated between 7500 and 2200 yrs. B. P., Organ II between 2200 and 1100 yrs. B. P., and Organ III between 1100 yrs. B. P. and approximately 150 yrs. ago (Table 1) (Gile, 1975; Gile et al., 1981). Within the Hueco Basin, the three Organ units are distinguished upon their carbonate morphology, texture, and relationship to the other stratigraphic units within a profile. Generally, Organ I sediments contain readily visible, strong stage I carbonate filaments. Organ II sediments contain weakly developed, faint stage I filaments that are not always present. Organ III deposits within these basins often overlie Organ I sediments. Organ III sediments are characterized by the absence of carbonate filaments and either no or very faint stratification. All Organ deposits within these basins have a loamy sand texture, but generally vary in color from strong brown (7.5YR5/6; 5/8), light brown (7.5YR6/4) or reddish yellow (7.5YR6/6) (Buck, 1996).

Historic Blowsand

The Historic 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 has formed within approximately the last 150 yrs. (Table 1) as a result of overgrazing and/or a possible recent increase in aridity (Buffington and Herbal, 1965; Gile, 1975; Blair et al., 1990). This resulted in decreased vegetative cover and erosion of underlying deposits. 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 a Jornada I deposit, and stage II nodules from the Isaacks' Ranch, or possibly a Jornada II deposit. This lag also contains artifacts which may have originated from any of the underlying units within the basin.

Discussion on stratigraphy

As described above, soils formed in sediments above the La Mesa petrocalcic horizon are interpreted as distinct deposits of either eolian Jornada I, Jornada II, Isaacks' Ranch, or Organ units based upon their morphologic characteristics. However, in many cases there are no distinct disconformities, stone or carbonate lag deposits, or other features to prove separate periods of deposition occurred. Therefore, the possibility exists that the original parent materials of these interpreted younger deposits are actually the upper horizons of the La Mesa solum. The lesser carbonate morphologic stages (I and II) of these sediments may be the result of a decrease in the depth of wetting which occurred after the last glaciation. The lack of a distinct argillic horizon cannot always be used to interpret distinct periods of deposition and re-working of the upper horizons of the La Mesa soil because other physical disturbances such as burrowing and carbonate precipitation can also destroy clay coats (Gile and Grossman, 1968). However, where the lack of an argillic horizon is coupled with an unconformity, distinct younger eolian deposits can be identified. The interpreted designations contained within this study are based upon the morphologic characteristics, stratigraphic position, and radiocarbon dates of archaeological features within each unit.

Although the eolian stratigraphy within the northern Hueco and southern Tularosa Basins can be correlated to surrounding alluvial fans, some differences can be discerned. Two major differences include: (1) The Jornada I and II units, which bury the La Mesa surface, are not as easily discerned as they are on the piedmont. These deposits may be present along and near bedrock at the edges of the basin, or within fault complexes. However, within the basin itself, these deposits are not readily identifiable (Table 1). Either these sediments were never deposited within the lowlands of the basin, or successive desertification events have since eroded and/or welded these sediments onto the La Mesa surface. (2) A paleolag deposit composed of stage II nodules from the Isaacks' Ranch deposit is fairly common within the basin. Isotopic evidence suggests that a major desertification event at approximately 8000 yrs. B. P. caused the erosion of the Isaacks' Ranch soil and subsequent vertical collapse of the nodules (Monger, 1995; Buck, 1996). (3) A distinct eolian Organ II deposit is commonly not present, or often cannot be distinguished from the Organ I or III unit (Table 1) (Buck, 1996). In contrast, on the alluvial fans, Organ I and II deposits are separated by an abrupt contact, characterized by a period of soil formation between approximately 4000 to 2200 yrs. B. P. (Gile, 1975). At approximately 2200 yrs. B. P., deposition of the Organ II unit on the alluvial fans is believed to have been initiated by an arid event (the Fairbanks Drought of Gile, 1975). Because distinct eolian Organ II deposits appear only locally throughout the basin, this arid event (Fairbanks Drought) may not have been severe enough to affect the entire basin. (4) A laterally continuous A horizon, which does not contain carbonate filaments, is present beneath the Historic Blowsand deposit. This horizon by definition is usually interpreted to be Organ III, however the lack of carbonate filaments could also be indicative of the upper horizons of an Organ I deposit if no distinct break or disconformity is present. Where a distinct Organ III unit with an A horizon is interpreted to be present, the contact between the overlying Historic Blowsand deposit and the A horizon is always smooth, abrupt and laterally continuous. This indicates a relatively planar surface existed across most areas in the basin floor before the development of the Historic Blowsand coppice dunes and interdunal deflational areas.

Each of these stratigraphic differences can be explained as a result of the non-uniform nature of eolian processes and the degree of each successive climatic fluctuation, which initiated both the deposition of each new deposit, and the erosion of the previous deposit. In addition, these differences only apply to those areas in the basin that are unaffected by fault movement. The areas surrounding fault complexes have a more complicated stratigraphy in which not only climate, but also tectonic activity affects erosion and deposition of sediments. Lastly, overgrazing during the last 150 yrs. has resulted in the destabilization of the desert grasslands and massive eolian erosion. This added factor has resulted in localized and varying degrees of erosion and deposition throughout the Hueco Basin and further complicates the stratigraphy.

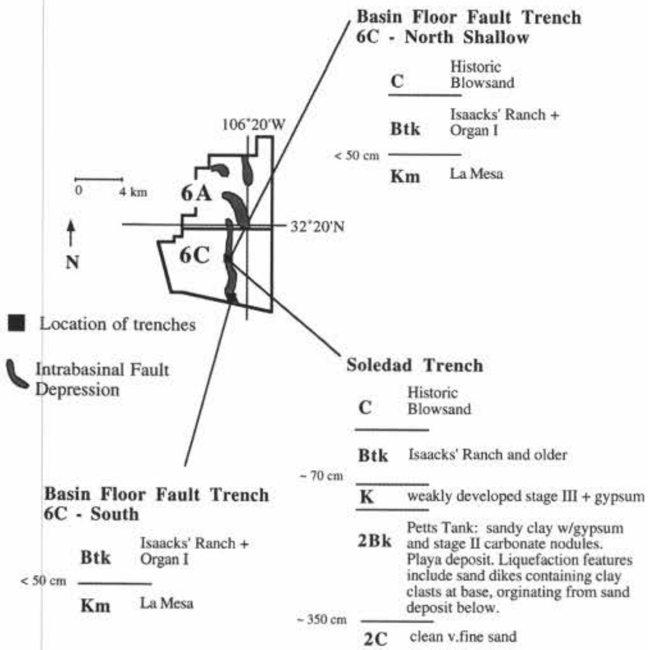

FIGURE 2. Location of intrabasinal faults and associated stratigraphy in maneuver area 6C. Sand dikes interpreted as seismically induced liquefaction features are present in playa deposits in Soledad Trench.

SOIL STRATIGRAPHY IN INTRABASINAL FAULT DEPRESSIONS

The intrabasinal fault scarps included in this study are located in maneuver areas 6C, 6A, 2A, 2E, 1A and 1B on Fort Bliss Military Reservation (Fig. 1). Because these intrabasinal faults form depressions, the stratigraphy is often more complete and thicker than in the rest of the basin. General trends include: (1) thicker Isaacks' Ranch, Organ, and Historic Blowsand deposits with very diffuse boundaries, (2) higher occurrence of Isaacks' Ranch deposits, which are often missing in other parts of the basin, and (3) presence of fine-grained playa deposits correlating to the Petts Tank and Lake Tank deposits of the Desert Project (Gile et al., 1981). These trends indicate that the majority of offset on most, if not all, of the intrabasinal faults occurred prior to the latest Pleistocene, to create a topographic depression in which thicker and better preserved deposits accumulated as compared to the rest of the basin. Additionally, during periods of greater effective precipitation, these depressions often contained playas with associated high or perched water tables. Therefore, because these areas may have been an important source of water for late Pleistocene populations, these fault depressions have the potential to be an important source of information for not only neotectonic and earthquake hazard studies, but also for archaeological and paleontological studies of the region.

Other individual stratigraphic anomalies associated with intrabasinal fault complexes are more difficult to distinguish from basin-wide climatic controls. However, detailed descriptions of the soil-stratigraphy and associated radiocarbon dates within intrabasinal faults are listed below according to maneuver area. Implications of this data for timing of fault activity are discussed.

Maneuver area 6C

Approximately ten exploratory trenches were dug in two locations within the fault depression in maneuver area 6C (Fig. 2). In nine of the ten trenches, the La Mesa surface (stage IV carbonate morphology) was encountered at shallow depths (Fig. 2). This indicates that although this fault scarp has considerable topographic relief today (minimum 3–6 m), it has not experienced a high rate of sedimentation since probably the middle to late Pleistocene, or these deposits have been extensively eroded since then. However, the landscape surface must have remained relatively stable for some hundreds of thousands of years in order for the stage IV carbonate morphology to have formed (Gile et al. 1981; Machette, 1985). This suggests a slow sedimentation rate possibly coupled by small episodes of minor erosional events in most areas of this fault complex. The soil above the La Mesa petrocalcic horizon is well developed with strong stage I and incipient stage II carbonate morphology as well as an argillic horizon. In addition, the early to middle Holocene paleodeflational lag that is found in other parts of the basin was not present in this fault complex. This suggests that a distinct Isaacks' Ranch or older unit was never deposited at this location. Possibly, the depth to the La Mesa petrocalcic horizon was maintained at relatively shallow depths such that carbonate from Isaacks' Ranch time was welded onto the La Mesa petrocalcic horizon. Younger carbonate was deposited at progressively shallower depths after the last glaciation in the argillic horizon.

Soledad Trench in the central portion of this fault complex contains a strikingly different stratigraphy. This trench was dug to a depth of approximately 3.5 m (Fig. 2). The base of the trench contains a Vertisol with a sandy clay texture, gypsum crystals, and strong stage II carbonate development, indicating the presence of a playa. Above the clay deposit is a sandy loam with very strong stage II development, which based upon carbonate morphology, is probably older than Isaacks' Ranch. The age and clayey texture of the playa deposit suggests that it may correlate to the Petts Tank deposit of the Desert Project (Gile et al., 1981). However, there is a thin stage III carbonate and gypsum deposit directly overlying the clay. This may be partially of groundwater origin and texture dependent, but it may also indicate that this playa deposit represents the uppermost Camp Rice Formation. Uranium-series dating of the carbonate or other radiometric analysis is necessary to determine a more precise age of this deposit.

Sand dikes

A deposit of fine-grained sand underlies the playa deposit and in places has been injected up into the playa deposit in the form of sand dikes. We interpret these sand dikes to be seismically induced liquefaction features because: (1) they contain angular clasts of the surrounding clay deposits within them, (2) the underlying sand source is clearly exposed, showing the sand dikes intruding upward into the overlying clay deposits, (3) underlying sand (silty, very fine-grained sand, 7.5YR7/4 pink) differs from sand overlying the playa deposit (sandy loam, 7.5YR6/6 reddish yellow), indicating the source of sand for the dikes is from below, and (4) the sand dikes are generally less than 30 cm in diameter, narrow upward, and have angular, sharp and broken boundaries with the surrounding clay deposit. In addition, these sand dikes have only been found in playa deposits (Petts Tank or Lake Tank), which would have the saturated conditions necessary for liquefaction to occur. None of the sand dikes appear to resemble burrows: they lack any consistency in size or shape, do not have smooth or unbroken contacts with the surrounding clay deposits, the source of sand is beneath the clay deposits, and the dikes narrow upward to very fine (<0.5 cm) fissures of sand. In this trench and in the other exposed profiles where Petts Tank or Lake Tank deposits were found, none of the sand dikes penetrate through the entire thicknesses of the clay deposits. In this trench, these clay deposits are over 2 m thick. Although there is the possibility that these sand dikes may be pseudoliquefaction features that may have resulted from processes other than tectonic, their presence along intrabasinal faults and the proximity to numerous faults throughout this area together with their physical character suggest that they are seismically induced liquefaction features. These liquefaction features indicate tectonic activity along this or other nearby faults at the time at which the clay was deposited, therefore determining a more precise age of the playa deposit would be useful for future neotectonic studies.

Maneuver area 6A

In maneuver area 6A, three trenches were dug in the southernmost fault complex (Fig. 3). All three contained similar stratigraphy. The stratigraphy of this fault complex consists of playa deposits (young Petts Tank and Lake Tank) overlain by Organ I eolian sands with Historic Blowsand coppice dunes at the surface (Fig. 3). The playa deposits contain well-developed stage II nodules composed of homogeneous 1–2 μm euhedral micrite crystals. Radiocarbon dates of inorganic pedogenic carbonate near the top of this deposit in Rattlesnake Trench suggest a late Pleistocene to early Holocene age (17,370 ± 110 and 7010 ± 160 yrs. B.P.), which is consistent with stratigraphic position and soil morphology (Fig. 3). Sand dikes similar to those described for maneuver area 6C are found at the base of this trench (Fig. 3). The source for the sand was not exposed in this trench, but the sand dikes only occur at depths greater than 230 cm suggesting a source of sand below. In addition, they contain clasts from the surrounding playa deposit and have the other characteristics as described in maneuver area 6C. Therefore, these are also interpreted to be seismically induced liquefaction features resulting from movement on this or other nearby faults.

The presence of the playa deposits in this area suggest tectonic movement along this fault either prior to or during the late Pleistocene and early Holocene to create and possibly maintain the topographic low in which the playa developed. The playa was filled in with eolian sands corresponding to the Organ I deposit at some time between 4450 ± 150 and 7010 ± 160 yrs. B. P. (Fig. 3).

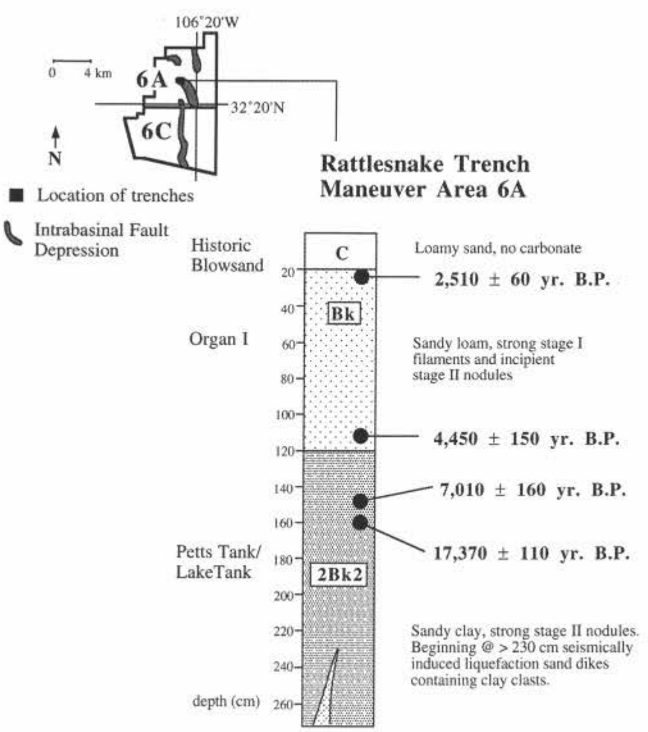

FIGURE 3. Rattlesnake Trench in maneuver area 6A. Radiocarbon dates from inorganic pedogenic carbonate. Sand dikes interpreted as seismically induced liquefaction features present in playa deposits at base of trench.

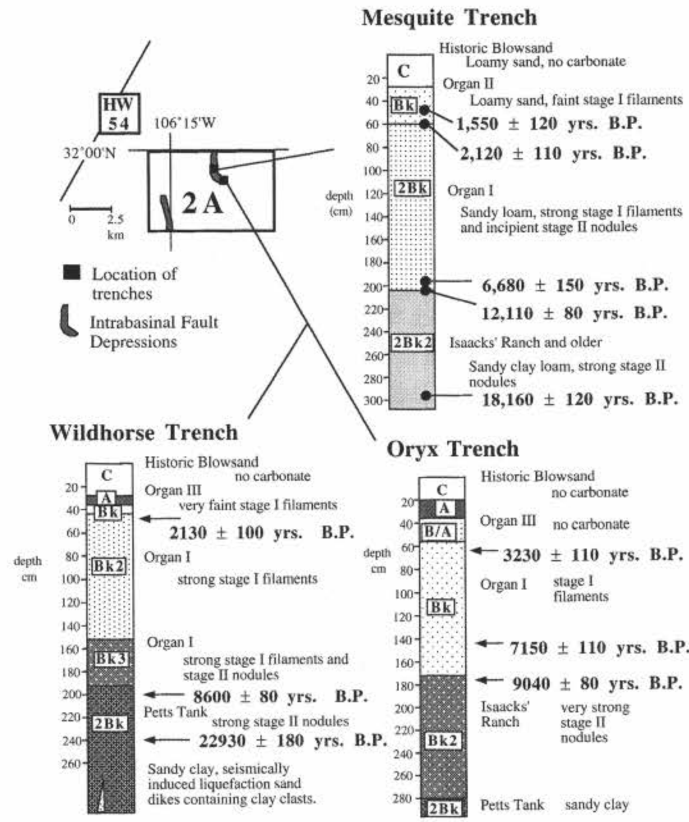

FIGURE 4. Location of intrabasinal faults and associated stratigraphy for maneuver area 2A. Radiocarbon dates from pedogenic inorganic carbonate. Sand dikes interpreted as seismically induced liquefaction features present in playa deposits.

Maneuver area 2A

Two fault complexes in maneuver area 2A were examined (Fig. 4). Numerous shallow and four deep trenches were dug in the northernmost fault complex to locate the areas with the highest Holocene sedimentation rates. While the exact location of this fault is obscured by coppice dunes of the Historic Blowsand deposit, the general trend is north-south. Four trenches indicate high sedimentation rates associated with fault offset, two contain playa deposits, and one trench shows offset of the La Mesa surface.

Thick deposits of Isaacks' Ranch, Organ and playa deposits are found along this fault (Fig. 4). These profiles indicate high sedimentation rates during the late Pleistocene and Holocene. The Organ and Isaacks' Ranch sediments are much thicker than in areas outside the fault depression. There is no stratigraphic indication of any severe erosion event during the late Pleistocene and Holocene. The paleodeflational lag is not present and each successive deposit in the profile gradually grades into the one above.

Two trenches contain playa deposits at their base: Wildhorse and Oryx trenches (Fig. 4). These playa deposits differ from those found in maneuver area 6C in that they do not contain gypsum, and based upon the morphology of the overlying sediments, are probably younger. However, these sandy clays contain prominent stage II carbonate nodules similar in morphology to those in Soledad and Rattlesnake Trenches in maneuver areas 6A and 6C (Figs. 2 and 3). In Wildhorse Trench, vertical and near vertical sand dikes intrude into this playa deposit at its base and contain clasts of the playa deposits. These dikes are similar to those found in Rattlesnake Trench in that the probable underlying source for the sand is not exposed. However, the upward-narrowing character of the dikes in addition to their irregularity and presence of angular clay clasts

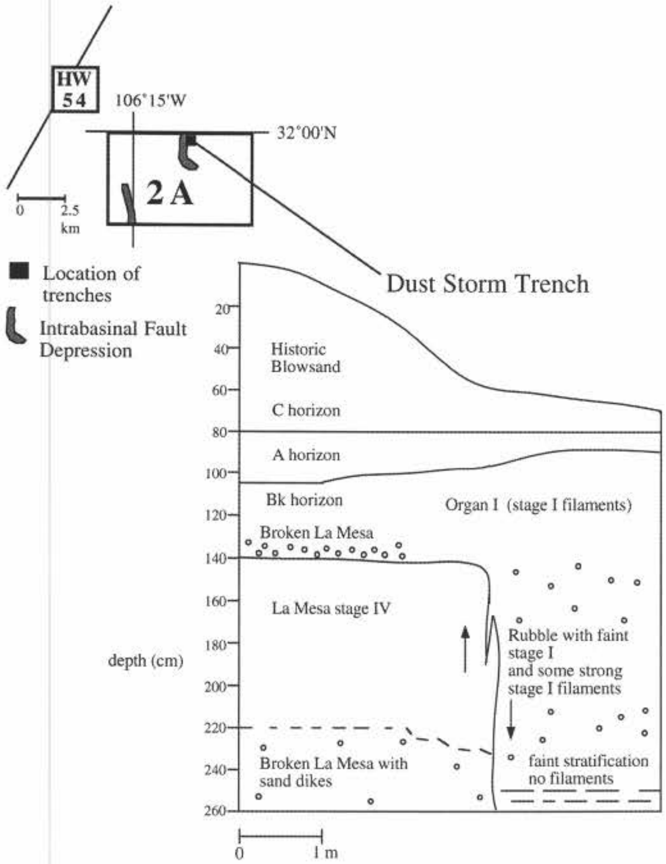

FIGURE 5. Dust Storm Trench in maneuver area 2A. Offset of the La Mesa petrocalcic horizon with overlying development of Organ I soil. Lack of development of an Isaacks' Ranch soil along the downthrown side suggests most recent offset occurred between the latest Pleistocene and earliest Holocene.

contained within them, and their location along an intrabasinal fault, again suggest that they are seismically induced liquefaction features. The morphology of the overlying strata as well as radiocarbon analyses of inorganic carbonate indicate that the playa deposit may be early Holocene to late Pleistocene in age. Overlying these fine-grained deposits is a middle Holocene sandy loam deposit corresponding to the Organ I unit. This abrupt shift, in which the late Pleistocene playa was filled with sand and rubble, may be the result of the abrupt increase in aridity at approximately 8 ka indicated by stable isotopic analyses, pollen, and stratigraphy across this basin and in surrounding areas (Gile et al, 1981; Monger, 1995; Buck, 1996).

Faulting of La Mesa

Evidence for early Holocene fault activity is found in Dust Storm Trench, east of the fault depression along what appears to be the upthrown block (Fig. 5). The La Mesa petrocalcic horizon in this trench is abruptly missing, and the offset parallels the north-south trend of the fault depression. We interpret the missing petrocalcic horizon as a fault offset and not a dissolution pipe for five reasons: (1) The edge the petrocalcic horizon is very irregular, fractured, and contains rough splinters (<20 cm long) of carbonate extending from it (similar to the sketch in Figure 5). In contrast, dissolution pipes are usually characterized by smooth walls and often vertical laminae extending downward into the pipe. No evidence for dissolution of the petrocalcic horizon is present. (2) Often in dissolution pipes, carbonate gradually decreases away from the petrocalcic horizon, resulting probably from uneven distribution of dissolution throughout the pipe. In the Dust Storm Trench however, the break in the La Mesa petrocalcic horizon is very abrupt, and the downthrown side is filled in with rubble including broken fragments of the La Mesa petrocalcic horizon. (3) The entire exposed portion of the La Mesa petrocalcic horizon is greatly fractured and in places contains pockets of sand and broken stage IV fragments. The fracturing increases toward the offset. (4) The lowermost fine-grained sediments on the downthrown side contain faint stratification with no filaments. These features suggest deposition without major pedogenic alteration. If the lack of the La Mesa petrocalcic horizon was the result of dissolution, we should expect that any original stratigraphic structures would have been obliterated by the dissolution fluids. However, increased pedogenic features are observed with decreasing depth: strong stage I filaments gradually grade upward to faint stage I filaments. (5) The offset parallels the north-south trend of the fault depression and occurs on what appears to be the footwall portion of the main fault complex (the exact location of the fault is greatly obscured by coppice dunes of the Historic Blowsand). Therefore, we interpret the missing petrocalcic horizon to be the result of fault-related offset, followed by sedimentation and deposition of broken La Mesa stage IV clasts, and then probably regional Organ deposition and soil development. Timing of the offset must be constrained between latest Pleistocene and early Holocene because nowhere along the hanging wall did an Isaacks' Ranch soil develop, but an intact Organ I soil is present across both sides of the offset (Fig. 5). Future studies involving larger and deeper excavations of this fault scarp would be useful to provide more information about prior tectonic activity along this fault.

The southernmost intrabasinal graben in maneuver area 2A was also trenched. This fault scarp still retains a significant topographical expression (minimum 3–6 m). However, trenching revealed a stratigraphy similar to unfaulted areas within the basin. The timing of the most recent movement along this fault cannot be determined from the present data, but could be as great as middle Pleistocene.

Maneuver area 2E

Ten profiles were excavated and described in the southwestern corner of maneuver area 2E (Fig. 1). Seven of the ten trenches contained Isaacks' Ranch deposits and the modern surficial lag contains numerous stage II nodules. This indicates that Isaacks' Ranch sediments were probably ubiquitous in this area and that deflation in either or both of the two major deflational events at 8000 yrs. B. P. and during the past 150 yrs. have resulted in localized and non-uniform erosion of the Isaacks' Ranch deposit. Organ sediments are present in all ten profiles. The thinnest Organ deposits are found on the upthrown block of the fault to the west, and they increase in thickness into the hangingwall to the east (Buck, 1996). The overlying Historic Blowsand unit also is thickest along the fault scarp. The sediment for this deposit appears to originate from the west (upthrown block) and is accumulating at the break in slope of the fault scarp (Buck, 1996). Because all of the Holocene sediments increase in thickness into the fault depression, tectonic activity and creation of the fault depression must have occurred prior to their deposition. The lack of older deposits such as Jornada I or II suggest that tectonic activity along this fault complex either postdates them, or geomorphic conditions during that time resulted in their non-deposition, erosion, or incorporation into the La Mesa petrocalcic horizon.

Maneuver area 1B South

Four trenches were excavated in the central portion of maneuver area 1B (Fig. 1). Only one of these profiles contain Isaacks'

Ranch sediments. No paleolag is present and the contact between this unit and the overlying Organ I deposit is diffuse suggesting no or very little erosion occurred at this site. However, the absence of any other Isaacks' Ranch deposits within any of the other profiles either indicates massive erosion at those locales or non-deposition. Some Isaacks' Ranch or older sediments must have been deposited and later eroded within this general location because stage II nodules are found in the modern lag at the surface today. In all of the trenches the Organ units are unusually thick and well preserved. The Historic Blowsand deposit varies between 2 and 50 cm within the four profiles studied, however, field observation suggests much thicker profiles are possible. The Historic Blowsand occurs in thick sheets and dunes draped over the fault scarp in a similar fashion to that in maneuver area 1B West and 2E. Again, the thickness and distribution of the Historic Blowsand and the Organ deposits suggests that pre-Holocene tectonic events created a topographic low in which thicker than normal accumulations were deposited. A significant offset still exists today (minimum 6 m).

Maneuver area 1B West

Eight profiles along this fault complex were trenched and described (Fig. 1). Four of the eight profiles contain Isaacks' Ranch sediments. Two profiles in the topographically lowest areas of this fault complex contain playa deposits (Petts Tank) of late Pleistocene age. These playa deposits are similar to those described in maneuver area 2A, however sand dikes are rare and not well enough exposed to make a confident interpretation on the processes surrounding their origin. A significant topographic relief is still present today (minimum 3–6 m), and appears to be affecting the distribution of the Historic Blowsand deposit, which varies between 0 and 58 cm. The greatest thickness occurs along the fault scarp, in which the sand appears to originate from the west (upthrown block) and is deposited at the edge of the scarp to the east, accumulating in large sandsheets and dunes (Buck, 1996).

Maneuver Area 1A

Ten trenches were excavated near the fault complex located in the northeastern corner of maneuver area 1A (Fig. 1). None of these trenches showed anything unusual in either the stratigraphy or thickness of units which could be used to infer about the tectonic history of this fault. However, unusually thick deposits of Isaacks' Ranch sediments as compared to the basin as a whole were found on the upthrown block of this fault. This suggests that the erosional event which occurred at approximately 8000 yrs. B. P. either did not occur or was minimal in this specific area (Buck, 1996). The reasons for this are probably not related to tectonic activity along this fault, but are more likely because of vegetation types and densities related to local soil-climatic conditions. More data is needed to determine late Quaternary tectonic activity along this fault complex.

CONCLUSIONS

North-south-trending intrabasinal normal faults occur throughout the northern Hueco and southern Tularosa basins. The stratigraphy of Quaternary eolian sediments within these basins is an eolian analog to that in surrounding alluvial fans based on soil morphology, profile development, stratigraphic position, and radiocarbon dates (Buck, 1996). Understanding the stratigraphy within these basins is important for future neotectonic studies and earthquake hazard analyses. The stratigraphy associated with the intrabasinal faults is often more complete and thicker than in the basin as a whole. Additionally, previously unknown playa deposits were found to occur in four of the eight fault depressions studied. Therefore, these intrabasinal depressions have the potential to contain important information for future geomorphic, archaeological and paleontological studies.

Sand dikes within at least three of the playa deposits are interpreted to be seismically induced liquefaction features because: (1) they contain angular clasts of the surrounding clay deposits within them, (2) in Soledad Trench, the underlying sand source is clearly exposed, showing the sand dikes intruding upward into the overlying clay deposits, and the underlying sand (silty, very fine-grained sand, 7.5YR7/4 pink) differs from sand overlying the playa deposit (sandy loam, 7.5YR6/6 reddish yellow), indicating the source of sand for the dikes is from below, and (3) the sand dikes are generally less than 30 cm in diameter, narrow upward, and have angular, sharp and broken boundaries with the surrounding clay deposit. The physical character of these sand dikes in addition to their location within fault depressions suggest that they are seismically induced liquefaction features associated with perched or high water tables consistent with the presence of the playas. The deposits in which these features occur are poorly dated and more data is necessary to determine the timing of tectonic activity.

Additional evidence for intrabasinal fault activity is found in Dust Storm Trench in maneuver area 2A. Within this trench, the La Mesa petrocalcic horizon is offset and is interpreted to be the result of fault movement and not a dissolution pipe because: (1) the edge of the petrocalcic horizon is irregular, fractured, and contains rough splinters (<20 cm long) of carbonate extending from it, (2) there is no evidence for dissolution, including smooth walls, vertical laminae, or a gradual decrease in carbonate away from the petrocalcic horizon, (3) the exposed portion of the La Mesa petrocalcic horizon is greatly fractured and in places contains pockets of sand and broken stage IV fragments, with fracturing increasing towards the offset, (4) the downthrown side is filled with rubble including broken fragments of the La Mesa petrocalcic horizon, (5) the lowermost fine-grained sediments on the downthrown side contain faint stratification with no filaments, and soil profile development of the Organ I deposit increases upward, and (6) the offset parallels the north-south trend of the fault depression. Therefore, we interpret the missing petrocalcic horizon to be the result of fault-related offset, followed by sedimentation and deposition of broken La Mesa stage IV clasts, and then probably regional Organ deposition and soil development. Timing of the offset must be constrained between latest Pleistocene and early Holocene because nowhere along the hanging wall did an Isaacks' Ranch soil develop, but an intact Organ I soil is present across both sides of the offset (Fig. 5). Additional data is necessary to determine the relationship between these intrabasinal faults and the major boundary faults bordering the Franklin, Organ and San Andres Mountains, and how they may affect earthquake hazard analyses for this region.

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