1   **Paleoindians, paleolakes and paleoplayas:**
2   **Landscape geoarchaeology of the Tularosa Basin, New Mexico**

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Abstract

Karl Butzer was one of the first prehistorians to think about and write about people, ancient and modern, on the landscape. Moreover, as a geomorphologist he knew that past landscapes were as dynamic and varied as they are today — not static entities that formed the backdrop for human activity. That viewpoint is critical in understanding the physical environment faced by humans during the early peopling of the Americas (~13,500 to ~10,000 cal YBP). North America was undergoing rapid environmental changes as the continent was coming out of the last Ice Age. In the southwestern part of the continent large paleolake levels were falling and smaller playa basins were aggrading as the area was occupied by Paleoindian groups such as Clovis, Folsom, and later groups of First Americans. The paleolakes would have provided some resources, but modern gypsum deposits indicate that lake waters were unpotable. Numerous small depressions (playas) scattered around the floor of the Tularosa Basin contain muddy fills that span the Holocene and terminal Pleistocene, indicative of fresher water at least seasonally. Paleoindian sites tend to be clustered around these small basins and along drainages off of the mountains that flank the basin, as well as settings with good viewsheds rather than the main paleolake margins. Paleolakes were dramatic components of the late Pleistocene landscape in the Southwest, but likely were not the primary attractions to the First Americans.

Keywords: Tularosa Basin; Paleoindian; playa; paleolake

1. Introduction

Karl Butzer was one of the first prehistorians to think about and write about people in the archaeological past as they related to the physical landscape of the past (e.g., Butzer, 1971, 1982). Moreover, as a geomorphologist he knew that past landscapes were as dynamic and varied as they are today — not static entities that formed the backdrop for human activity. Those ancient landscapes were actively used by and modified by the people of the past.

This basic concept can be applied to understanding the physical environment faced by and used by humans during the initial peopling of the New World (~15,000 to ~10,000 cal YBP), the so-called *Paleoindian* period in archaeological parlance. At that time, North America was undergoing rapid environmental changes as the continent was coming out of the last Ice Age (e.g., Dawson, 1992; Orme, 2002; Gillespie et al., 2004; Holliday and Miller, 2013)¹. The glaciers were rapidly melting, sea level was quickly rising, and rivers were undergoing significant metamorphosis in discharge, sediment load, and channel form. In the southwestern part of the continent large paleolakes were shrinking and smaller wetland playa basins were aggrading. At the same time the area was occupied by Paleoindian groups such as Clovis, then Folsom, and later groups of First Americans (Judge, 1973; Huckell and Judge, 2006; Holliday, 2015) (see Table 1 for the basic Paleoindian chronology).

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¹ The late Pleistocene began with the start of the last Interglacial (MIS 5), ~130,000 years ago (Head and Gibbard, 2015). The Terminal Pleistocene is defined here as ~16,000 to 10,000 ¹⁴C YBP (~19,100 to ~11,700 cal years), based on the beginning of substantial retreat of the southern margin of the Laurentide ice sheet (after Dyke, 2004, and Mickelson and Colgan, 2004). The Pleistocene/ Holocene boundary is 11,700 cal years (Rasmussen et al., 2006; Walker et al., 2009).

This paper presents the initial results of geoarchaeological research in the Tularosa Basin of south-central New Mexico (Figs. 1, 2), aimed at understanding the distribution of Paleoindian sites across the basin floor as a function of the evolving paleohydrology and related geomorphic processes. Many Paleoindian sites have been recorded in the basin (e.g., Amick, 1994a,b, 1996; Holliday, 2015; Amick and Stanford, 2016), particularly during the course of archaeological surveys on military lands (e.g., Wessell et al., 1997; Holliday, 2015). Geoarchaeological research linking archaeological sites to the paleo-landscape is scarce, however. This paper is a first step toward placing Paleoindian foragers on the paleo-landscape of the basin.

2. Setting and Background

The Tularosa Basin is a topographic and structural basin; one of a series of such basins along the Rio Grande Rift (the Rift, hereafter). The Rift is essentially the far eastern component of the Basin and Range region of far western and southwestern North America. For this paper *Southwest* refers to the Basin and Range landscape, including the Rift, of New Mexico and Arizona. The rift runs from the San Luis Valley in south-central Colorado south into far western Texas and northeastern Chihuahua, Mexico (Fig. 1) (Hawley, 2005). The Tularosa Basin is on the east flank of the rift and is east of the Rio Grande itself. Most of the basins of the Rift are flanked by mountain ranges. The west side of the Tularosa Basin is defined, south to north, by the Organ, San Andres, and Oscura mountains. The east side of the basin is flanked, south to north, by the Hueco Mountains, Otero Mesa, the Sacramento Mountains, and Sierra Blanca (Fig. 2). The basin becomes progressively constricted to the north-northeast. The Rio Grande defines the southern limit of the basin. Most of the research presented in this paper is from the area between the San Andres and Sacramento mountains, roughly in the northern half of the basin

(Fig. 2).

The Tularosa Basin is the setting of the famous White Sands dunes, the largest gypsum dune field in the world (Fig. 2). Those dunes represent only the most recent (Holocene) and only a part of the landscape evolution of the basin, however. A significant component of this paper is devoted to highlighting unrecognized components of the landscape evolution of a region that in general is little known in the academic literature on the geomorphology and evolution of the landscape of the Southwest.

The floor of the basin is covered by a complex of lacustrine, eolian, and alluvial deposits. In the study area, Pleistocene gypsiferous lake deposits dominate the substrate. The best known gypsum beds are those associated with paleolake Otero (a remnant of which is modern Lake Lucero) on the west-central side of the basin (Fig. 2) (Allen et al., 2009). Limited dating indicates that paludal conditions were extant on the basin floor by ~41,000 ¹⁴C YBP and that a lake precipitating gypsum evolved by ~30,000 ¹⁴C YBP (Allen et al., 2009). A lake with fluctuating water levels persisted until at least ~15,500 ¹⁴C YBP. These data are confirmed by dating of a stratigraphic sequence of gypsum beds reported by Bustos et al. (2018). The maximum lake level (undated) reached an estimated elevation of 1204 m according to Allen et al. (2009), approximated by the area of the lake in Fig. 2. Shorelines are very poorly preserved, however, resulting from wind erosion on the east side of the old lake basin and wave and wind erosion on the west side. Deflation of gypsum from paleolake Otero produced the White Sands dunes. The oldest date from the gypsum dunes is ~7300 cal years (Kocurek et al., 2007), but few dates are reported.

Outside of the area of the paleolake and the gypsum dunes most of the work on geomorphology, soils, and Quaternary stratigraphy prior to the research reported in this paper

was at the southern end of our study area on the southern end of the White Sands Missile Range (Blair et al., 1990; Hall et al., 2010; Monger 2011) and farther south on the Ft. Bliss maneuvering range (Monger 1993; Johnson 1997; Hall et al., 2010). The basin floor is composed of older (pre-Otero?) gypsum deposits and gypsum lunettes, quartz sand dunes, quartz sand sheets, and (along the basin margins) alluvium from fan/bajada systems. Canyon systems in the flanking mountain ranges feed intermittent flows of water and alluvium into the basin. A few flow into the Lake Lucero/Paleolake Otero system. These drainages built fan/bajada systems along the mountain fronts on the east and west sides of the basin.

The quartz sand dunes are equivalent to units Q3 and Q4 of Blair et al. (1990) and the ‘dune sheets and dune piles’ of Johnson (1997, p. 43) and parts of mapping units 1 and 2 of Monger (1993). The dunes are mostly Holocene in age, based on very minimal development of surface and buried soils (A-C horizonation) in these eolian deposits, limited numerical age control, and presence of older archaeological materials below (Gile et al., 1981; Monger 1993; Johnson 1997; Hall et al., 2008; Holliday et al., 2009).

Throughout the southern end of much of our study area, to the south and southeast of the main area of the White Sands (and south of U.S.70; Fig. 2) are at least two sand sheets, one atop the other, beneath the Holocene dunes. The sand sheets and most of the fan/bajada alluvium have well-expressed soils (A-Bt-Bk horizonation with 7.5YR to 5YR hues), indicative of stability since the Terminal Pleistocene (Gile et al., 1981; Monger 1993; Johnson 1997; Holliday et al., 2006, 2009; Hall et al., 2008). Unit Q2 has an estimated maximum age of ~15,000 cal years (Blair et al., 1990), supported by our unpublished dating. Optically stimulated luminescence dating provides age estimates of up to ~22,000 years (Hall et al., 2010), although the dating and stratigraphy in that study is debated (Hall et al., 2012a; Monger et al., 2012). In a few exposures,

an older layer with a well-expressed soil is present. This is unit Q1 of Blair et al (1990) and a component of mapping unit 2 of Monger (1993, figure IV-1). It is likely the ‘La Mesa Surface and Doña Ana Soils’ of Johnson (1997), but in our field area this soil is associated with older (buried) gypsiferous lake beds. In proximity to Lone Butte are extensive exposures of lacustrine gypsum and associated lunette dunes (Figs. 2, 3). Around the margins of this area of gypsum, the older quartzose sheet sands are locally apparent on top of the lake beds. These gypsum deposits and associated landforms are discussed below.

Paleoindian sites are common on the floors of many of the intermontane basins of the region. Some of these basins are closed and provide evidence for paleolakes or paleoplayas (e.g., Roosa 1968; Lyons 1970; Judge 1973; Hill and Holliday 2011; Holliday 2015), and other basins are open and have through-flowing drainages (e.g., Jodry 1999). For example, in the Albuquerque Basin, the distribution of Paleoindian artifacts is hypothesized to be linked to the evolution of playa basins (Judge, 1973). In the C-N subbasin of the Plains of San Agustin, the presence of Folsom sites is linked to paleo-wetlands that formed on the floor of the basin after the lake drained from that basin (Hill and Holliday 2011). Only very limited data are available for non-Folsom Paleoindian occupations. Similarly, in the Basin and Range landscape just west of the Rift, along the upper San Pedro River Valley of southeastern Arizona (Fig. 1), are a series of Clovis mammoth kills, one of the densest concentrations of mammoth kills in the world (Haynes and Huckell 2007; Ballenger 2015). The sites are located in proximity to springs or drainages or both, although some of the kills may simply be from opportunistic hunting (Ballenger 2015). Camp sites are probably a better indication of how people used a landscape (kills by foragers more likely indicate how animals used the landscape), but Clovis camps are exceedingly rare and subsequent Paleoindian occupations are unknown in the San Pedro Valley.

The settlement by early foragers of western basins with water resources is not unique to the Rio Grande Rift, but dense concentrations of Paleoindian sites are generally unknown elsewhere in southwestern North America. They are reported, however, from some of the basins in parts of the western Basin and Range in the Great Basin (e.g., Beck and Jones, 1997; Adams et al., 2008; Grayson 2011; Madsen 2007, 2016; Madsen et al., 2015). Similar to the Rio Grande Rift, these basins with high concentrations of early archaeological assemblages also contained paleolakes. Also similar to the Rift, the early settlement of the Great Basin was underway as paleolakes were declining.

Several general models propose changes in land use and settlement over time by the earliest foragers in the Southwest and the Great Basin. All link settlement to the evolving wetlands and lakes on the basin floors. The first systematic attempt based on a sizeable archaeological record is that of Judge (Judge and Dawson 1972; Judge, 1973) working with collections of Paleoindian artifacts from the Albuquerque Basin. He proposed that Folsom occupations are found closer to small playa depressions because of the resources they offered, but subsequent late Paleoindian sites are more widely dispersed because the playa basins were drying and resources were being sought over larger territories. At the time, however, no data were available from the playa basins. Further, Amick (1994a) noted that the Albuquerque Basin is an area of little environmental diversity, and therefore the full range of potential diversity of land use was unknown. The artifact assemblages collected from archaeological sites in the Albuquerque Basin also was generated by collectors who focused on areas with high artifact density (which happened to be near playa basins) thus limiting the full picture of Paleoindian land use.

In the Tularosa Basin a predictive model for Paleoindian sites was developed by Wessel

et al. (1997) for the White Sands Missile Range, which occupies roughly the northwest quadrant of the Tularosa Basin. The study incorporated a broad range of landscape settings but was based on a limited (1%) pedestrian survey and literature review. They noted that recorded Clovis sites are rare to absent in the basin, although a few may be in the adjacent uplands, but also indicated that recognition of Clovis artifact assemblages is problematic. They did not observe Paleoindian sites on the basin floor east of paleolake Otero, but hypothesize that Folsom sites may be found around playas southeast of the paleolake. Very limited data suggested that late Paleoindian occupations shifted to the uplands, perhaps as the basin floor dried.

In the southern Tularosa Basin, largely south of the area reported in this study, Condon et al. (2013) examined the distribution of >100 Paleoindian projectile points (based on site files). They noted that a number of artifact finds were in proximity to paleolake basins identified by Johnson (1997). The history of those lakes has not been established, however. Other artifacts are scattered, apparently randomly, across the basin floor. Like Wessel et al. (1997), Condon et al. (2013) plotted very few Paleoindian projectile points east, northeast, or north of paleolake Otero.

Farther afield, several models have been proposed for the evolution of Paleoindian land use in the Great Basin. Beck and Jones (1997) provided one of the first, based on a sizeable database of artifacts from across the region. Fluted points (which they assume are contemporaneous with Clovis and Folsom farther east) are commonly found along the margins of paleolakes (though where the water was at the time of occupation is unclear) or elsewhere on the basin floors. Subsequent occupations (based on artifact styles, which were poorly dated at the time of writing) are more widely scattered, suggesting broader use of lowlands and uplands.

Focusing more on the central and eastern Great Basin and working with more data on site locations and paleo-diet, Madsen (2007) provided more nuance, proposing that the transition

from Paleoindian foragers (referred to as *Paleoarchaic* in the Great Basin) to Archaic foragers was a shift from broad-spectrum foraging to *very broad-spectrum* foraging; i.e., movement to unoccupied areas with lower-ranked resources, but with the addition of ground-stone tools (p. 15). But in terms of land use, regional variation is suggested. In the east-central Great Basin, where wetlands dating to the Terminal Pleistocene/early Holocene (TP/EH) transition were relatively small, isolated, and scattered, the human occupations were widely scattered short-term residential camps. Farther east, however, where the huge paleolake Bonneville system was declining, but was still quite sizeable, high concentrations of sites exhibit less mobility where wetland resources remained abundant (e.g., Madsen et al., 2015).

Several difficulties arise in testing these models across the Southwest and the Great Basin, and in particular in the Tularosa Basin. Data on the paleoecology of the basins and the geochronology of lakes and wetlands is spotty at best. The Great Basin has a long history of systematic research into late Quaternary history, including archaeology and environmental evolution (e.g., Hershler et al., 2002; Enzel et al., 2003; Graf and Schmitt 2007; Orme 2008; Grayson 2011; Oviatt and Shroder, 2015), compared to the Southwest, although only a few basins have been well studied. In the Rio Grande Rift such data are much more variable and comparatively scarce. None of the basins have been subjected to a comprehensive and systematic study of their late Quaternary history (i.e., stratigraphy, vegetation history, lake-level chronology, and archaeology). Lake level and vegetation histories are poorly known in most basins. The history of paleolake Otero is known from only a handful of radiocarbon dates (Allen et al., 2009; Taylor-Montoya et al., 2015). Shorelines are very poorly expressed and in any case undated. Considerable paleobotanical research has been conducted on packrat middens from the mountains surrounding the Tularosa Basin (e.g., Betancourt et al., 2001, and references therein),

providing important indicators of vegetation conditions in the late Pleistocene and Holocene and broad trends in climate that likely can be extrapolated to the basin floor. Packrat middens and the data they provide have two important limitations, however. They are from the uplands and only provide snapshots of vegetation in their immediate area. Therefore they do not provide information on the vegetation available on the basin floor.

A key component of paleolakes and paleoplays of direct significance to human occupation, but one that is poorly studied, is that of water quality. This is particularly critical for the paleolakes of the Rio Grande Rift where some lakes (Estancia, Trinity, and Otero) produced thick and extensive layers of gypsum. An important but as yet unanswered question is: what was the water quality in terms of potability when Paleoindian foragers arrived?

Archaeological information along the Rio Grande Rift is more plentiful than paleolake data but is still spotty. The large population center in the Albuquerque Basin, including artifact collectors and academics, resulted in a reasonable understanding of the Paleoindian archaeological and geoarchaeological record (e.g., Judge, 1973; Huckell and Kilby 2002; Huckell and Ruth 2004; Holliday et al., 2006). In contrast, the Plains of San Agustin are remote and the archaeological record is poorly understood (but see Hill and Holliday, 2011). In the Tularosa Basin, federal military and park lands have been well protected from collecting and subjected to numerous systematic archaeological surveys, providing, for example, data sets useful in regional studies of Paleoindian archaeology (e.g., Amick, 1994a,b, 1995, 1996, 2000, 2002; Wessel et al., 1997; Condon et al., 2013; Holliday, 2015; Holliday et al., 2017a).

Data from artifact collectors have been useful in some research studies in the area. The work of Judge (Judge and Dawson, 1972; Judge, 1973) noted above was based on extensive private collections from the Albuquerque Basin. In the San Luis Valley of Colorado at the far

northern end of the Rift, collectors discovered key in situ Folsom sites and provided surface assemblages for study (Jodry, 1999). Research on Folsom technology and mobility in the Tularosa Basin (Amick, 1994a,b, 1996, 2000, 2002) and Plainview archaeology throughout and adjacent to the Rio Grande Rift (Holliday et al., 2017a; Huckell and Merriman, 2017) relied heavily on private collections. However collecting often destroys important data such as artifact context and site setting. In some situations sites are obliterated wholesale. This is particularly apparent on Bureau of Land Management (BLM) land in the Tularosa Basin. For example, collections from the Lone Butte and Moody Tank Folsom sites were key to the work of Amick (1994a,b, 1996); the Lone Butte site alone produced over 6000 pieces of Folsom tools and manufacturing debris (Amick and Stanford, 2016). Today essentially nothing is on the ground at either site. Collectors who are open to working with professional archaeologists provide valuable data. The problem is with the collectors who remain unknown. We do not know what we are missing.

3. Methods

A particular focus of this project is on sites in proximity to small playas and other paleo-wetlands on the floor of the Tularosa Basin and, to a lesser extent, along drainages. Almost all of the archaeological sites are surface scatters, usually exposed by wind erosion of Holocene dunes or sand sheets. The sites were visited to assess the geomorphic settings and the archaeological assemblages. Data on the archaeology were also gathered from sites files and, if available, from publications (usually archaeological survey reports). The adjacent paleoplayas or paleo-wetlands were recognized on the basis of shallow topographic depressions with gray mud or clay, similar to paleoplayas in the Albuquerque Basin (Holliday et al., 2006).

The initial aim of this project was to determine if the paleoplayas and paleo-wetlands were attractions to Paleoindian foragers. To determine if the playa fill is stratified and dateable, they were probed with a Giddings hydraulic soil coring rig using a 2.5-inch (6.4 cm) diameter barrel. Cores were described using standard nomenclature (e.g., Table 2) and sampled for radiocarbon dating. All investigated potential playa basins are filled almost exclusively with the gray mud or clay and are dateable by the radiocarbon method (based on the gray to dark gray hues, which are indicative of organic matter). Samples were pretreated with an acid wash and dated on a carbonate-free basis at the University of Arizona AMS Radiocarbon facility (Table 3). All samples reported here are from massive (i.e., unstratified) palustrine mud. Dating reversals are apparent in some cores, likely resulting from bioturbation that mixed both the mud and secondary mobile humic acids. Disparities between the humic acid and humate fractions in playa muds (Holliday et al., 1996, 2006, 2008), not differentiated here, might also create apparent reversals. Nevertheless, the dating reversals provide approximate age estimates.

4. Paleoindian geoarchaeology in the Tularosa Basin

The work presented in this study deals with Paleoindian sites and Terminal Pleistocene landscapes in the northern half of the Tularosa Basin. The focus is the basin floor, with a lesser focus at this point on drainages emerging from the mountains. Essentially this study is the first stage of a test of the model offered by Wessel et al. (1997). As noted, they observed that few Paleoindian sites are recorded on the basin floor east and northeast of paleolake Otero and proposed that sites, especially Folsom, may be more likely near small playa basins southeast of the paleolake rather than adjacent to the paleolake itself. Those playa basins appear to be the ones in the area of Lone Butte, toward the eastern side of the basin (Fig. 2) (Johnson, 1997,

figure 28; Allen et al., 2009, fig 2). Those basins are all somewhat elongate and generally >400 m at their minimum width, and some much larger (Fig. 3). They also appear to be deflation basins inset into older gypsum lake beds and fringed by lunettes on the eastern (downwind) margins. In the course of field work for this project, a number of smaller more circular basins (<400 m diameter) inset into siliciclastic sheet sands were found scattered across the landscape southeast and south of the paleolake (Fig. 4). No previous investigations distinguished between these two types of basins (larger and elongate vs. smaller and more circular), but, as argued below, such differentiation is critical.

4.1. *Basin margin drainages*

The lowest part of the Tularosa Basin is on the west side, site of present-day Lake Lucero and ancient paleolake Otero. As a result, drainage development includes deeply incised canyons in the San Andres Mountains and formation of short steep alluvial fans. Some of the fans were subsequently incised and exhibit terraces along the incised drainages. On the east side of the basin alluvial fans are much broader, some coalesced into bajadas. Numerous drainages are incised into these fans and extend far out onto the basin floor (Fig. 2). Most appear to form distributaries on the basin floor, but their full geomorphic extent has not been established on the ground.

Two Paleoindian sites, both multicomponent, are located along drainages coming out of the San Andres Mountains. The San Nicholas site is on a fan-terrace along Little San Nicholas Canyon, which flows north-northeast out of the mountains down to Lake Lucero (Fig. 2). It must have fed paleolake Otero. The stone tool assemblage is a dense lithic scatter that produced end scrapers, a Folsom point, and a possible unfluted Paleoindian projectile point (Wessel et al.,

1997). To the north is the extensive Rhodes Canyon site (Eidenbach, 1983) (Fig. 2). It is on the upper end of an alluvial fan that formed at the mouth of Rhodes Canyon. The drainage likely fed paleolake Otero, to the south but a clear drainage connection is not apparent. The site appears to be a complex of a number of individual artifact loci. Artifacts recovered include Folsom, unfluted Paleoindian, and possibly Clovis. Between those two large sites, on a bajada surface near the western escarpment of the modern Lake Lucero basin, a small lithic scatter with a Folsom artifact is reported by Purcell and Greenwald (2002) (Fig. 2). Along the mountain front northeast of Rhodes Canyon is a dense multicomponent lithic scatter including late Paleoindian artifacts (Wessel et al., 1997) (Fig. 2).

Farther northeast along the western mountain fronts of the basin, seven Paleoindian sites were recorded on the east side of the Oscura Mountains at the north end of the Tularosa Basin (Fig. 2). Six are on alluvial fans, and one is on a bedrock ridge. Most of the sites are lithic scatters exposed in deflated alluvium. Paleoindian artifacts include Folsom, possible Midland, other unfluted projectile points, and end scrapers.

On the east side of the Tularosa Basin several Paleoindian sites are reported in association with either drainages or fan deposits or both. East of the White Sands dunes and west and northwest of Alamogordo, on an old fan surface and along or near incised draws are a series of Paleoindian sites consisting of lithic scatters with Paleoindian artifacts (Fig. 2). All are exposed via erosion of Holocene cover sand. Another series of Paleoindian sites were recorded south of Alamogordo, just west of the mountain front. Most are surface scatters on alluvial fans. However, the Boles Wells site and another just downstream (Fig. 2) are buried in alluvial fines along distributary drainages coming off of a fan from Alamo Canyon to the northeast (Mauldin and O'Leary, 1994). This drainage system also feeds the playa complex around Lone Butte,

discussed below. Among Paleoindian sites in New Mexico west of the Pecos, the Boles Wells complex is rare in that it is buried and probably once intact. It is now mixed from bioturbation. To the southeast of the Boles Wells complex are four more lithics scatters with Paleoindian artifacts on alluvial fan surfaces.

Farther out on the basin floor is a shallow, almost imperceptible drainage informally called Garton Draw. A Plainview site was found about 100 meters from the old drainage (Fig. 2). Along the draw is a dark gray mud, similar to playa deposits (Table 2A). A series of cores were recovered to determine if the drainage might have been the attraction for the Paleoindian occupants. The base of the mud is dated to ~12,300 cal years (~10,400 ¹⁴C YBP) (Table 3; Fig. 5), indicating that a wetland was present during the Paleoindian occupation. A small Folsom site is also reported along the draw ~25 km upstream (Fig. 2).

4.2. Basin floor and paleolake Otero

The floor of the Tularosa Basin has very few Paleoindian sites east, northeast, and north of the modern Lake Lucero and White Sands dune system. This was the case documented by Wessel et al. (1997) and remains so, more or less, in spite of decades of archaeological survey in the area. Sand generated by erosion of the gypsum lake beds from paleolake Otero covers large areas downwind of the paleolake, forming the White Sands dune field. This sand likely covers some archaeological sites. A few late Paleoindian parallel-oblique projectile points are known from archaeological sites located in blowouts within the dunes, according to National Park Service records. Further, the massive erosion in the Holocene on the east side of the paleolake that produced the dunes would have destroyed the Paleoindian landscape and any associated sites in that area. Surveys along the intact lake margins along the west side and southern end of the

paleolake produced very few Paleoindian artifacts, although local deposition of Holocene alluvial-fan sediments buried the Paleoindian landscape (Love et al., 2014; Rachal et al., 2016). The only reported exception from the main area of paleolake Otero is the small Folsom locality west of the lake margin on a bajada surface, noted above. Apparently the area surrounding the main paleolake was not an attraction. Other Paleoindian sites include one from the area of Davies Playa, which is a remnant lake basin south of and aligned with the main paleolake (Fig. 2), and another site among several large gypsum playa basins on the northwest margin of the basin west of a Holocene basalt flow (Fig. 2) (Wessel et al., 1997).

To the south and southeast of paleolake Otero are a number of Paleoindian sites exposed by wind erosion of Holocene sands (Fig. 2). Many are associated with small playa basins. Several previous investigators note a relationship between Paleoindian sites and playas (Carmichael, 1986, p. 209; Wessel et al., 1997, pp. 258-265; Amick and Stanford, 1996) but provide few specifics regarding individual sites or playas other than the Lone Butte site (discussed below).

For this project, five playas or playa complexes, four with immediately adjacent Paleoindian sites, were investigated, including coring and dating. The Lone Butte site is on the flank of a prominent isolated butte in the east-central Tularosa Basin (Figs. 2) (Broilo, 1973; Amick and Stanford, 2016). Two Folsom sites are noted in the area by Wessel et al. (1997, figure 8.4); but only one, the Lone Butte site itself, is in the literature. As noted, the site was essentially completely destroyed by artifact collectors. The large collection from the site (over 6000 Folsom artifacts, including 29 Folsom points and 43 Folsom preforms) suggests a long-term occupation (Amick and Stanford, 1996). The archaeological assemblage rested on or above a well-developed

soil (Bt-Btky profile with 5YR hues) formed in fan alluvium and was buried by or within eolian sand. Amick and Stanford (2016) proposed that a key attraction, in addition to the viewshed provided by the elevation, was the series of paleolake basins around the butte (Figs. 2, 3) (Johnson, 1997, figure 28; Allen et al., 2009, figure 2). In particular, Amick and Stanford noted a large (~16 km²) 'locally enhanced catchment basin' (p. 102) immediately west and northwest of the site. The basin is formed in gypsum and the 'local enhancement' apparently refers to deflation of the basin along with formation of lunettes (Fig. 3).

Notably, north of Lone Butte is a large area popular with local artifact collectors and called Tres Hermanos. The artifacts (including 88 Folsom points and 21 preforms) came from among the dunes and playas of the area, but no specifics are available for individual sites and their settings (Amick, 1994a,b). This is also the general area of termination of the distributary system from Alamo Canyon, which runs through the area of Boles Wells (Figs. 2, 3).

Limited coring of the basin floor and associated lunettes west and north of Lone Butte yielded no evidence for standing water or wetlands dating to Paleoindian time. Extensive wind deflation, as illustrated by the large lunettes (Fig. 3), could have destroyed evidence for Folsom-age lakes or wetlands. However, a core in the basin floor north of Lone Butte yielded minimally weathered eolian sand resting on lake beds ~21,605 cal years old (Table 3; Fig. 6). Lunettes commonly stabilized when adjacent lake basins hold water because the basin no longer deflates (Holliday, 1997a), but a core through one lunette west of Lone Butte provided no evidence of significant stability during Paleoindian time (Fig. 6). A core through eolian sand and silt upslope from the Lone Butte site (i.e., farther up on the fan) produced evidence for a well-expressed buried soil with a Btk horizon formed in ~1 m of dark gray mud (Table 2B), similar to playa

sediments (Fig. 6). The base of these deposits dated ~11,240 cal years (Table 3). This deposit may represent some sort of wetland available on the fan surface, perhaps spring-fed.

The other playas investigated for this study are the smaller variety. They appear in clusters, particularly south of Lone Butte (Fig. 4). They are inset into likely eolian sheet sand with a well-expressed surface soil (Bt-Btk horizonation with 5YR hues; Q2 of Blair et al., 1990?). Gypsum underlies this sheet sand. The distinct clustering of these basins suggest that they may represent some sort of subsidence features resulting from dissolution of gypsum, creating a karstic landscape. The Paleoindian archaeology associated with three of these four study playas of this type rested on the well-developed red soil that comprises the local upland adjacent to the basins. In most cases the archaeological materials were covered by Holocene sand and then exposed by local wind erosion.

The Moody Tank site is south of Lone Butte within a relatively dense cluster of playas and sand dunes (Figs. 2, 7). The dunes appear to be derived from the playa basins. The Moody Tank playa basin was once surrounded by scattered Paleoindian occupations that included Folsom and Plainview projectile points (Russell, 1968). The site was heavily collected for artifacts. A core from the playa produced ~360 cm of homogeneous, organic-rich mud (Table 2C, Fig. 5). The basal 10 cm is Last Glacial Maximum (LGM) age (~23,030 cal years); 350 to 310 cm is early Holocene with a radiocarbon reversal (Table 3) probably from bioturbation in a wetland. A disconformity is present, but clearly the basin was a wetland during the LGM and in the early Holocene. The basin may have been deflated at the onset of the Holocene and/or in the Younger Dryas.

Mosquito Net (Fig. 2) is a small playa in an area of relatively few playas along with

scattered sand dunes. A Folsom occupation along with dense post-Paleoindian occupations are adjacent to the playa. Coring revealed ~230 cm of dark gray, homogeneous playa mud (Table 2D; Fig. 5). The bottom of the core produced two radiocarbon samples dated ~23,660 and ~19,500 cal years (Table 3; Fig. 5). Although reversed, probably from mixing, the dating shows that the basin has acted as a wetland since full glacial times.

Eagle Nest playa (Fig. 2) is a small basin inset into an otherwise flat, open upland. No known Paleoindian artifacts or sites are known from the immediate area. It was cored in order to examine and date the basin fill. The basin has over 2 m of dark gray, homogeneous, organic-rich mud (Table 2E; Fig. 5). Two samples, each 10 cm thick, from the lower section of the core, bracket the likely age of the Paleoindian occupation of the area (Table 3).

The HELSTF playa (Fig. 2) is in a setting different from the rest. It appears to be along the far western margin of the siliciclastic sand sheet with the old red soil, where this quartzose layer thins over gypsum. The HELSTF playa is about 4 km east of the margin of the (presumed) youngest high stand of paleolake Otero. The basin is inset into gypsum apparently linked to an earlier cycle of the paleolake. The basin is ~500 m from the HELSTF Paleoindian site. Although originally identified as a likely Clovis site (Laumbach, 1985), recent investigations (Lee, 2015) demonstrated that it is probably a Folsom and Plainview locality. A core from the playa revealed >2 m of gray, homogeneous playa mud (Table 2F; Fig. 5). The lower section produced reversed dates (Table 3), again probably a result of mixing, but they nevertheless document a long-term wetland.

5. Discussion and conclusions

The data presented here build on and also test the settlement hypotheses provided by Wessel et al. (1997). Paleoindian sites are widely scattered across the Tularosa Basin, from the surrounding mountains (Wessell et al., 1997), not discussed here, to basin-margin settings such as fans, bajadas, and associated drainages, to some areas of the basin floor. Paleoindian sites are known from the east and west basin margins. Two multicomponent sites are recorded along the eastern mountain of the San Andres Mountains. In contrast, a number of smaller, single-component Paleoindian sites are documented from fan/bajada surfaces on the east flank of the Oscura Mountains and along the west flank of the Sacramento Mountains. Some of these sites are adjacent to drainages cut into the fan/bajada surfaces, and other sites are along drainages beyond the fan/bajada landscapes. Additional sites are located on the basin floor, but most are concentrated near small playa basins.

The locations of the basin-margin sites likely reflect the variety of resources that should have been available. The fans would provide wide views of the basin floor, access to water flowing from mountain valleys, and ready access to biological resources and raw material for stone tools on the basin floor as well as in the mountains. Runoff in the area, particularly in the mountains, was likely significantly higher during the Paleoindian occupation of the region. This is indicated by the presence of paleolake Otero, although the lake chronology is very poorly dated. Other stratigraphic and paleoecological data are also indicative of wetter conditions and higher runoff (Holliday et al., 2009; Hall et al., 2012b; Hall and Penner, 2013). This runoff would provide at least seasonal if not perennial flows onto the basin floors. The two sites on the west side, San Nicholas and Rhodes Canyon, are on the mountain front, associated with fans and adjacent to drainages issuing from the mountains. This area is within White Sands Missile Range

and parts of it have been subjected to archaeological survey (e.g., Eidenbach, 1983; Wessel et al., 1997). The scope of those surveys was very limited but nevertheless suggest that Paleoindian occupations are rare on the western fans. The reason for this is far from clear, but few well-developed drainages are present on the western fans. The area may have been less attractive to foragers compared to the fans/bajadas on the eastern basin margin.

In contrast, the reported Paleoindian sites on the east basin margin are out on the fans. The areas with reported sites are on Holloman Air Force Base and their land holdings do not include the front of the Sacramento Mountains nor the fan heads. Thus, Paleoindian sites could be present farther up the fans on the east but are unknown or at least not reported.

The mountains also provide an array of raw materials for manufacture of stone tools. Systematic research and documentation on such resources have been limited, but some information is available. The Rhodes Canyon site is near an outcrop of Rancheria chert (Eidenbach, 1983). This distinct banded material is a high quality chert and common in Paleoindian, especially Folsom, lithic assemblages in the area (Carmichael, 1986; Amick, 1994a,b) such as that from Lone Butte (Amick and Stanford, 2016). Black chert similar to the better known Edwards Formation chert is also found in the San Andres and Sacramento mountains (summarized by LeTourneau, 1998, and observed by the third author).

Several studies of Paleoindian foragers in the western U.S. have linked settlement and the evolution of resources to changing lake levels and the distribution of wetlands (Beck and Jones 1997; Wessel et al., 1997; Madsen 2007; Madsen et al., 2015). In the Tularosa Basin, however, very few Paleoindian sites have been found in proximity to paleolake Otero. Although a few late Paleoindian artifacts and one site are reported along the eastern margin of the lake, the northeast

margin of the paleolake was subjected to severe wind erosion and the landscape beyond was buried beneath the gypsum dunes. Elsewhere, the near absence of sites from visible, intact surfaces in proximity to the paleolake is striking. Rachal et al. (2016) noted that some Paleoindian-age surfaces along the western margin may be buried by Holocene alluvial fans. Some fan surfaces are clearly older, however, as indicated by the presence of Paleoindian surface assemblages at the Rhodes Canyon and San Nicholas sites.

Most of the Paleoindian sites investigated for this study and most of the known Paleoindian sites in the Tularosa Basin are on the basin floor (Amick, 1994a,b, 2000; Wessel et al., 1997; Condon et al., 2013). Four localities reported here are in proximity to small playa basins (Moody Tank, Mosquito Net, HELSTF) or a drainage with a playa-like wetland (Garton Draw). Dating of the fill in these playa basins indicate that paleo-wetlands were present in the terminal Pleistocene and early Holocene. Further, very little gypsum was encountered in the fill, in contrast to sediment from the larger paleoplayas and paleolakes in the basin. Thus, the water quality was better and probably more attractive from a potability standpoint. In any case, these paleo-wetlands undoubtedly contained floral and faunal resources attractive to foragers. Indeed, one of the highest concentrations of Paleoindian artifacts was found around one of the small playas, Moody Tank.

Water potability is likely an important variable affecting settlement and land use. During most of the late Pleistocene history of paleolake Otero, gypsum was precipitated (Lucas and Hawley, 2002; Allen et al., 2009; Taylor-Montoya et al., 2015), meaning that the lake waters were saturated with calcium and sulfate. However, lakes with gypsum-saturated waters are known to be associated with a range of flora and fauna. Further, layers of low-gypsum organic-

rich muds and peats dated to the Terminal Pleistocene and intercalated with the gypsum document more abundant and subaerial plant growth. In exposures along the northwest margin of the paleolake, such layers are dated ~16,360, ~14,190, ~12,620, and ~11,890 cal years (Table 4). North of paleolake Otero and southwest of the Holocene basalt flow, an area of gypsum marsh deposits not linked to paleolake Otero, similarly contains layers of organic-rich muds dated ~12,765, ~12,595, and ~11,780 cal years (Fig. 2; Table 4). In our project we recorded and dated another exposure along the northwest margin of paleolake Otero, along Alkali Flat (Bustos et al., 2018) (Figs. 2, 8). A mud layer ~5 cm thick was dated ~15,300 cal years and an overlying and very thin (<1 cm) mud dated ~11,945 cal years (Fig. 8; Table 3). These layers are suggestive of fresher water persisting periodically on the basin floor before and during the Paleoindian occupation, which makes the paucity of Paleoindian sites around the paleolake all the more puzzling.

In contrast, among known and reported Paleoindian sites in the basin, the single highest concentration of artifacts comes from Lone Butte. Several paleolake basins are nearby (<1 km) (Figs. 2, 3), but the fills are dominated by gypsum and the basins are inset into more extensive late Pleistocene gypsum. Much of the area was subjected to considerable wind erosion, however, so evidence for freshwater lowlands may have been obliterated. No obvious freshwater basin is known in proximity to the site, although coring revealed evidence for a freshwater wetland on the fan upslope from the site. Further, the northeast margin of the paleolake complex is also where the drainage from Alamo Canyon reaches the basin floor. That area appears to be roughly where the extensive Tres Hermanos artifact-collecting locality was situated, which might explain the widespread distribution of Paleoindian artifacts.

In their study of the distribution of Paleoindian artifacts in the southern part of the basin, Condon et al. (2013) plotted artifacts in proximity to hypothesized paleolakes and large playas, but their study did not include field reconnaissance. Many artifacts they plotted are located on the basin floor in an area that appears to have numerous small playas based on remote sensing.

The Paleoindian sites reported for the northern Tularosa Basin, including those visited for this project, range from a scatter of a few stone artifacts to relatively dense concentrations of hundreds of lithic specimens (e.g., Lone Butte). What this means is difficult to ascertain, however, as a result of several significant variables. We may be seeing some land use trends in the distribution of Paleoindian sites, but the archaeological record has several biases. Site locations on alluvial fans or around freshwater wetlands and drainageways is logical and consistent with trends elsewhere. Absence of sites around sources of unpotable water is also logical. Lone Butte is surrounded by gypsum lake deposits and dunes, but fresh water may have been available, as noted. In addition it provides a spectacular viewshed. No Paleoindian sites are known for the Twin Buttes, to the west of Lone Butte. No obvious evidence is known for a freshwater playa basin around Twin Buttes, but our coring program has not progressed to that area. Localized wetlands, as indicated on the flank of Lone Butte, are unlikely around Twin Buttes because their fan surfaces have a much steeper gradient and because they are very rocky.

Issues of site access, site preservation, and site visibility likely play a significant role in our understanding of land use. The military lands (White Sands Missile Range and Holloman Air Force Base) and park land (White Sands National Monument) provided long-term protection of cultural resources. As a result, artifact collection has been minimal. A relatively small total percentage of these holdings has been formally surveyed for archaeological resources. To date,

no more than 20% of the Missile Range and 10% of White Sands National Monument lands have been subjected to a documented, systematic archaeological survey. The spottiness of the survey coverage is illustrated in Fig. 9. Perhaps the most striking aspects of those data are i) the many sites found in the south-southeast part of the Missile Range (south of U.S. 70), an area subjected to extensive survey, compared to ii) the rest of the Tularosa Basin (and parts of the Jornada del Muerto Basin to the north) where site discovery has been more rare, even in areas with extensive survey coverage. These data support the proposal that the higher concentration of reported sites in the south-southwest part of the study area reflects the actual distribution of sites. That area is also where most of the small playa basins are located. Those observations, in turn, support the proposal that the first foragers in the basin preferentially occupied the landscape in proximity to the small, fresher water playas.

Further, among the sites that are recorded, few have been visited and assessed more than once or twice. In contrast, the Paleoindian sites on BLM land were routinely and regularly collected over the course of decades. This is almost certainly why the sites and site areas with the largest known artifact assemblages (Lone Butte, Moody Tank, and Tres Hermanos) are on BLM land. Though protected by Federal law, the land is not monitored by BLM officials and therefore is open to artifact collectors. In particular, sites buried by sand dunes and sand sheets, including most of the sites on the floor of the Tularosa Basin, may yield only a handful of artifacts after a period of active wind erosion; but as is well documented in sites in similar settings in southeast New Mexico and neighboring western Texas, with persistent visits over the course of years or decades, large assemblages can be exposed (e.g., Hofman et al., 1990; Rose, 2011; Blaine et al., 2017).

577   This study of the Terminal Pleistocene landscape and Paleoindian land use in the
578 northern Tularosa Basin illustrates the many variables that come into play when undertaking
579 such research: changing depositional environments, landscape evolution, and modern land use.
580 Further, systematic archaeological research has been spotty. Nevertheless, several trends are
581 apparent. Paleoindian occupations do not seem to be tethered to paleolake Otero. Archaeological
582 sites from these early occupations are broadly scattered across other areas of the basin. The
583 reason why is not apparent, but water quality may have been an issue. Drainage systems and
584 alluvial fan/bajada systems, particularly on the east side of the basin, were attractions. These
585 settings provided access to fresh water, to biological resources in the basin and in the mountains,
586 and to raw material in the mountains for stone tools. On the basin floor, small playa basins that
587 likely contained fresh water, not previously recognized, were also attractions to the early
588 foragers. Lone Butte was a popular attraction, based on recovery of dense Folsom occupation
589 debris, probably because of nearby playas as well as providing a 360° viewshed of the northern
590 end of the basin. Curiously, nearby buttes provide no known evidence for comparable intensive
591 occupation.

592   How land use varied during the course of the Paleoindian occupation of the basin is
593 unclear. Clovis artifacts are essentially unknown from the basin. In contrast, artifacts from the
594 subsequent Folsom occupation comprise the most common Paleoindian artifact assemblage.
595 Folsom artifacts are known from all of the settings described above and represent most if not all
596 of the large Lone Butte assemblage. Late Paleoindian artifacts are common as well, but
597 recognizing specific artifact styles is difficult owing to recovery from camps, where points are
598 broken and often resharpened. Better understanding of the distribution of artifact styles across

the basin through space and time is the next stage of our research.

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- FIGURE CAPTIONS

Fig. 1. New Mexico and surrounding regions with the approximate boundaries of the Rio Grande Rift (based on Kluth and Schaftenaar, 1994, figure 1; Hawley, 2005, figure 1), locations of principal paleolakes, and the area of Clovis mammoth kills in the Upper San Pedro Valley in southeastern Arizona. SLV is the San Luis Valley.

Fig. 2. The northern Tularosa Basin illustrating key physiographic features (based on Wessel et al., 1997, figures 8.1, 8.4; Allen et al., 2009, figures 1, 2), archaeological sites, and exposures mentioned in the text. Archaeological and other coring site abbreviations: B = Boles Wells; D = Davies Lake; E = Eagle Nest; G = Garton Draw; H = HELSTF; LB = Lone Butte; MN = Mosquito Net; MT = Moody Tank; R = Rhodes Canyon; S = San Nicholas; T = Tres Hermanos.

Exposure abbreviations: A = Alkali Flats (this paper); TR = Field area reported by Taylor-Montoya et al., (2015) and Rachal et al. (2016); LA = field area reported by Love et al (2014).

Fig. 3. Playas in large deflation basins (P) and lunettes (L) around Lone Butte (LB). In the upper right are the distal ends of the distributaries that come from Alamo Canyon and across fans and past the Boles Wells site. In the lower left (above and right of the scale) are a few small playa basins inset into the red siliciclastic sand sheet. Other small playas are aligned along the floor of the large elongate playa basin that runs south-southeast from Lone Butte. Image is from Google Earth.

Fig. 4. The small playa basins (irregular dark gray shapes) with light tan areas of fresh quartz sand on their northeast sides (i.e., downwind). The main concentration on the right (east) is due north of the Jarilla Mountains (lower right). Another though more scattered concentration of playas is visible in the upper left. Image is from Google Earth.

Fig. 5. Cores from four small playas and from Garton Draw adjacent to a Paleoindian site (Fig. 2). All dates are the calibrated means (Table 2) in cal YBP and rounded to the nearest 5. Vertical scale is the same in all sections.

Fig. 6. Cores from the area of Lone Butte include the core upslope of the Lone Butte Folsom site (right), a core from the floor of one of the large deflated playas near the butte, and a core from a lunette adjacent to a deflated playa basin. All dates are the calibrated means (Table 2) in cal YBP and rounded to the nearest 5.

Fig. 7. Moody Tank playa (MT in Fig. 2), looking north, as an example of a playa basin inset into a siliciclastic sandsheet and filled with mud. The short grasses highlight the basin floor. The relief along the basin margin is indicated by the slope in the distance beyond the flowers.

Fig. 8. The upper stratigraphic section along the west margin of Alkali Flats (A in Fig. 2). The lower dark olive gray muds (~15,300 cal years) are convoluted, probably by soft sediment deformation. Above are finely laminated gypsum beds with intercalated dark gray muds; the youngest dated ~11,945 cal years. Details on dating are provided in Table 2 (see also Bustos et al., 2018, figure S1).

Fig. 9. Map of study area (including the Jornada del Muerto in the upper left) indicating coverage by archaeological surveys on Federal lands (White Sands Missile Range, Holloman Air Force Base, and White Sands National Monument, all within the dashed line exclusive of Ft. Bliss and Bureau of Land Management holdings) along with locations of reported Paleoindian sites (based on data from the New Mexico Cultural Resources Information System). Note that more sites are shown on this figure than on Fig. 2 because that map shows only sites visited.

Table 1. Paleoindian subdivisions and artifact chronology¹

Artifact Assemblage	Age Range ²	References
Parallel Oblique ³	~10,200 to ~8400 cal yrs (9000-7500 ¹⁴ C yrs)	Holliday 2000, Kornfeld et al. 2010 Thoms & Mandel 2007
Cody	~11,700 to ~8900 cal yrs (10,000-8000 ¹⁴ C yrs)	Holliday 2000, Kornfeld et al. 2010 Knell & Muniz 2013
Plainview	~12,100 to ~11,300 cal yrs (10,300-9900 ¹⁴ C yrs)	Holliday et al. 2017b
Folsom/Midland ⁴	~12,700 to ~12,100 cal yrs (10,900-10,300 ¹⁴ C yrs)	Holliday 2000, Kornfeld et al. 2010 Surovell et al. 2016
Clovis	~13,400 to ~12,700 cal yrs (11,500-10,900 ¹⁴ C yrs)	Waters & Stafford 2007, Miller et al. 2013 Sanchez et al 2014

¹ For better or worse, Paleoindian archaeology is heavily focused on projectile point morphology and technology. Subdivisions of Paleoindian archaeology are based specifically on projectile point typology, listed under “Artifact Assemblage.” Locally, where well dated, artifact types can be used as rough age indicators (e.g., the Southern Great Plains to the east of the Pecos River, Holliday, 1997b, 2000) but more broadly some artifact styles seem to vary in beginning and ending dates and duration (e.g., Miller et al 2013; Knell and Muniz, 2013; Holliday et al. 2017b). Midland, Plainview, Cody, parallel oblique and other “unfluted” artifact styles (e.g., Holliday, 1997b; Kornfeld et al. 2010) are often lumped as Late Paleoindian.

² Paleoindian assemblages have not been dated in the Rio Grande Rift. Age ranges are based largely on dating of sites on the Great Plains to the east and northeast and also, for Clovis, in southeast Arizona.

³ Frederick, Allen, and Angostura types.

⁴ Midland is usually linked to Folsom on the basis of technology and association in artifact assemblages, although this issue remains contentious. The only dated Midland site is Winkler-1 in southeast New Mexico, where calcined bone was dated ~10,470 to ~10,210 ¹⁴C yrs (Blaine et al 2017).

Table 2
Field description

(A) Garton Draw, core 14-3

Depth, cm	Soil ^a Horiz.	Description ^b
0-2		Gyp silt, 10YR 7/3d; loose, clear
2- ~100	A	SiC; 10YR 4/2sm; f sbk; v common gyp & carb bodies; str med sbk & v wk med pr; gradual (homogeneous wetland mud) <i>C14 samples: 60-70, 70-80, 80-90, 90-100cm</i>
~100-130		olive gray C, 2.5Y 4.5/2sm w OM mottles, 10YR 4/2sm; massive; clear
130-240		C, red 5YR 5.5/5sm

(B) Lone Butte site, core 15-2

Depth, cm	Soil ^a Horiz.	Description ^b
0-14	A	Sand, 7.5YR 6/4d; wk sbk/cr; calc; clear
14-44	Btw	SCL, 7.5YR 5.5/4d; wk med pr & str med sbk; thin, cont clay films; calc; clear
44-92	Btb?	SCL, 7.5YR 5/4d; wk med pr & str med sbk; thin, cont clay films; clear
92-128	Bwb1	SCL, 7.5YR 5/4d; wk med pr & mod med sbk; calc; abrupt
128-193	Btkb2	SCL, 10YR 5/4d; mod med pr & str med sbk; thin disc clay films; few carb bodies, but more common in lower 20 cm; calc (wetland muds?) <i>C14 sample: 185-190</i>

(C) Moody Tank playa, core 14-1

Depth, cm	Soil ^a Horiz.	Description ^b
0-35	A	V hard gray clay, 7.5 YR 5/3d, 4/3m; med str pr & med str abk; clear
35-110		Red-gray clay, 7.5 YR 5/3d, 4.5/3m; wk med pr & str med sbk; pressure faces on peds; clear <i>C14 sample: 100-110cm</i>
110-170		Red-gray clay, 7.5YR 5/3d, 4/4m; wk med pr & str med sbk; pressure faces on peds; rare carb nodules; clear (homogeneous wetland mud)
170-240		Red-gray clay, 7.5YR 5/3d, 4/4m; wk med pr & str med sbk; pressure faces on peds; few carb nodules & vertical thr; clear (homogeneous wetland mud) <i>C14 sample: 200-220cm</i>
240-295		Red-gray clay, 7.5YR 5/3d, 4/4m; wk med pr & str med sbk; pressure faces on peds; few carb nodules & vertical thr; few areas of gley color 5Y 5/3m& gley zones following root channels; clear (homogeneous wetland mud)
295-360		Red-gray clay, 7.5YR 5/3d, 4/4m; wk med pr & str med sbk; pressure faces on peds; few carb nodules & vertical thr; common areas of gley color 5Y 5/3m& gley zones following root channels; 3mm thick lens of sand or gyp at base; abrupt (homogeneous wetland mud) <i>C14 samples: 310-320, 320-330, 330-340, 340-350, 350-360cm</i>
360-425		LS, pervasive gley coloring 5Y 5/3m; few red areas 7.5YR 4/4 & 5/4m; massive; common carb bodies; 3mm thick zone of sand or gyp at ~412cm; abrupt
425-428		Tan fS w FeOx and green clay laminations; abrupt
428-450		SC with some red areas; colors as above; str med abk; common carb bodies;
450-480		Olive green clay, color as above; no carb bodies

(D) Mosquito Net playa, core 14-2

Depth, cm	Soil ^a Horiz.	Description ^b
0-10	A	SCL, 7.5YR 5/4d, 4.5/4m; cse str sbk; few faint carb &/or gyp films; clear
10-28	Bt	SC, 7.5YR 4/5sm; str med pr & str med sbk; thin cont clay films; clear
28-83	Bty	SC, 7.5YR 4/6sm; ; str med pr & str med sbk; thin cont clay films; common faint bodies of gyp; clear
83-93	Btkyb1	SC, 7.5YR 4/6sm; str med pr & str med sbk; thin cont clay films; common faint bodies of gyp; v common carb bodies in matirix; clear
93-212		C, 7.5YR 3.5/4m; mod med abk; common gyp xtals in upper 10cm; few distinct gyp bodies and dispersed carb thruout; common Mn patches; abrupt (homogeneous wetland mud) C14 samples: 216-228, 228-238cm
212-214		Dense gyp xtals; abrupt
214-238	Btb2	SC, 7.5YR 4.5/4sm; str med pr & str med sbk; thin cont clay films; common sand (or gyp?) coats on ped faces; clear
238-250		SC w pervasive gyp xtals & common carb; abrupt
250-270	Btb3	SCL, 7.5YR 5/4sm; massive

(E) Eagle Nest playa, core 14-1

Depth, cm	Soil ^a Horiz.	Description ^b
0-25	AB	Compacted, 7.5YR 5/4d; cse str sbk; clear
25-80	Bw or Btw	SCL, 7.5YR 6/4d; med str pr & med str abk; thin patchy clay films on ped faces; calcareous; clear (homogeneous wetland mud)
80-130	Bk	SCL, 7.5YR 6/4d; str cse sbk; carb bodies & thr, best expressed in upper 10cm; clear (homogeneous wetland mud)
130-197	Btb	SCL, 7.5YR 4.5/6sm; wk f pr & str med sbk; thin patchy clay films; few small carb bodies; clear (homogeneous wetland mud) C14 sample: 192-205cm
197-250		vfS & Si, 10YR (redder) 6/4d; loose; some muds from above mixed in; clear C14 sample: 205-215cm
250-280		cSi, 7.5YR 6/4d; loose

(F) HELSTF playa, core 14-1

Depth, Cm	Soil ^a Horiz.	Description ^b
0-15	A1	clay, 7.5YR 4.5/3sm; med str abk; clear
15-30	A2	clay, 7.5YR 5/3sm; med str abk; clear
30-110		Clay, 7.5YR 4/4sm; med str abk; clear (homogeneous wetland mud)
110-220		V hard clay, 7.5YR 6/3sm (200-210cm 2.5Y 6/3sm); med str abk to abk; probably has finely divided gyp; red loam 7.5YR 5/4sm, 175-185cm (homogeneous wetland mud) <i>C14 samples: 203-213, 213-220cm</i>

^a Empty cells are C horizons in various forms of unweathered sediment

^b Abbreviations for descriptions: Colors = Munsell d = dry; sm = slightly moist; m = moist
Textures: Si = Silt; SiL = Silty Loam; SiC = Silty Clay; S = Sand; SL = Sandy Loam; SCL =
Sandy Clay Loam; f = fine; c = coarse; Structure: sbk = subangular blocky; abk = angular
blocky; wk = weak; mod = moderate; str = strong; f = fine; med = medium; cse = coarse;
OM = organic matter; Bndy = boundary; irreg = irregular; Krots = krotovina, carb = carbonate;
calc = calcareous; gyp = gypsum; xtals = crystals; Wx'd = weathered.

Table 3. Radiocarbon dates from cores and sections reported in this paper.

¹⁴ C Age Years B.P.	Lab Number	Depth, cm	Calibrated Mean Probability Years B.P. ¹	Highest Probability Cal age range (1 sig)	Relative Area Under Probability Distribution ²	Material Dated
<i>Garton Draw</i>						
8520±41	AA105838	60-70	9513	9534-9496	1.000	Homogeneous wetland mud
8754±42	AA105839	70-80	9742	9820-9662	0.842	Homogeneous wetland mud
9028±43	AA105840	80-90	10,210	10,232-10,191	1.000	Homogeneous wetland mud
10,427±55	AA105089	90-100	12,306	12,532-12,092 ³	1.000	Homogeneous wetland mud
<i>Lone Butte Site</i>						
9843±30	AA107264	185-190 Core 15-2	11,240	11,253-11,221	1.000	Homogeneous wetland? mud
<i>Lone Butte/Tres Hermanos Area</i>						
16,060±88 (below lunette)	AA109083	383-395 Core 16-2	19,380	19,508-19,252	1.000	Bedded lake clay
17,831±74 (playa floor)	AA108626	214-226 Core 16-4	21,607	21,749-21,484	1.000	Bedded lake clay
<i>Moody Tank Playa</i>						
2130±40	AA105203	100-110	2111	2152-2046	1.000	Homogeneous playa mud
5455±52	AA105204	200-210	6251	6254-6209	0.522	Homogeneous playa mud

				6299-6260	0.478	
8714±44	AA105205	310-320	9665	9704-9560	0.979	Homogeneous playa mud
9781±85	AA105206	320-330	11,209	11,241-11,180	1.000	Homogeneous playa mud
9705±47	AA105207	330-340	11,147	11,204-11,103	1.000	Homogeneous playa mud
9523±52	AA105208	340-350	10,859	11,068-10,955 10,803-10,708	0.501 0.439	Homogeneous playa mud
19,120±110	AA105462	350-360	23,032	23,203-22,848	1.000	Homogeneous playa mud
<i>Mosquito Net Playa</i>						
19,790±160	AA105093	216-228	23,820	24,018-23,624	1.000	Homogeneous playa mud
16,413±72	AA105094	228-238	19,805	19,925-19,678	1.000	Homogeneous playa mud
<i>Eagle Nest Playa</i>						
9737±48	AA105092	192-205	11,181	11,223-11,146	1.000	Homogeneous playa mud
12,011±72	AA105091	205-215	13,872	13,955-13,766	1.000	Homogeneous playa mud
<i>HELSTF Playa</i>						
8803±31	AA106823	203-213	11,178	11,205-11,151	1.000	Homogeneous playa mud
9722±34	AA106824	213-220	9827	9902-9762	0.971	Homogeneous playa mud
<i>Alkali Flats Stratigraphic Section</i>						
10,223±29	AA109165	130-131	11,947	12,034-11,933	0.604	Laminated wetland mud

				11,889-11,830	0.396	
12,839±40	AA109166	142-145	15,298	15,373-15,199	1.000	Laminated & mixed wetland mud

¹ CALIB 7.1

² only >0.100 listed

Table 4. Previously reported Terminal Pleistocene radiocarbon dates for the northern Tularosa Basin.

¹⁴ C Age Years B.P.	Lab Number	Calibrated Mean Probability Years B.P. ¹	Highest Probability Cal age range (1 sig)	Relative Area Under Probability Distribution ²	Material Dated	References
<i>Northwestern Paleo-Lake Otero</i>						
10,190±40	Beta416437	11,891	11,985-11,804	1.000	Wetland mud	3
10,640±50	Beta319443	12,622	12,668-12,575	1.000	Wetland mud	4
12,280±40	Beta416438	14,192	14,260-14,099	1.000	Wetland mud	3
13,580±50	Beta386791	16,359	16,458-16,251	1.000	Wetland mud	5
<i>Gypsiferous Marsh Deposits of Paleo-lake Otero</i>						
10,130±40	Beta210309	11,780	11,832-11,700 11,941-11,880 11,671-11,641	0.672 0.222 0.106	Wetland mud	4
10,600±40	Beta204416	12,595	12,641-12,552	1.000	Wetland mud	4
10,900±50	Beta210310	12,764	12,794-12,720	1.000	Wetland mud	4

¹ CALIB 7.1

² only >0.100 listed

³ Rachal et al 2016

⁴ Love et al 2014

⁵ Taylor-Montoya et al. 2015

• Archaeological Site

✕ Exposures

○ Site Complex

— Margin of Wind Erosion

● Eolian Gypsum Sand

▨ Maximum Extent of Paleo-lake

⚙ Mountains

— Selected intermittent drainages

N

0 30 km
0 20 mi

↑
N

3 km

Lone Butte Playa Complex

Lunette

Playa Floor

Lone Butte Site

- Quartz Sand
- Gypsum Sand
- Lake Clay
- Playa Mud

A black and white photograph of a rock face showing distinct horizontal stratification. A knife is placed vertically on the left side of the rock face for scale. The rock surface is rough and textured. Two text labels with arrows point to specific layers: '~11,945 cal yrs' points to a light-colored layer in the upper half, and '~15,300 cal yrs' points to a darker layer near the bottom.

~11,945 cal yrs

~15,300 cal yrs

- Paleoindian Sites
- Surveyed Land
- ⋯ Study Area
- Roads

0 5 10 20 30
km

Sources: Esri, USGS, NOAA