REPORTS

ALTITHERMAL ARCHAEOLOGY AND PALEOECOLOGY AT MUSTANG SPRINGS, ON THE SOUTHERN HIGH PLAINS OF TEXAS

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Excavations at Mustang Springs on the southern High Plains of Texas have yielded a relatively fine-grained record of late Pleistocene to middle Holocene environments and climate. The site contains over 60 Altithermal age water wells, direct evidence of the human adaptive response to this locally severe drought and of a drop in the water table of nearly 3 m. New radiocarbon dates from the wellfield are substantially earlier than previously published age estimates, putting the age of well digging in a brief period at the onset of the Altithermal. Human adaptive strategies during this period are yet undetermined, but the evidence points to generalized and highly mobile strategies and to the conclusion that this wellfield is surely not unique. The geology of Mustang Springs helps explain the scarcity of other Altithermal age sites on the southern High Plains.

Las excavaciones de "Mustang Springs" en el Sur de las Planicies Altas de Texas, han producido un registro arqueológico relativamente preciso sobre los medio-ambientes y climas del Pleistoceno tardío y Holoceno medio. El sitio contiene más de 60 pozos acuíferos de edad Altitermal que representan evidencia directa de las respuestas de adaptación humana a una sequía severa, y al descenso de casi tres metros en el nivel freático. Las nuevas fechas de radiocarbono del campo de pozos acuíferos son substancialmente más tempranas que las estimadas en publicaciones anteriores, poniendo la edad de construcción de los pozos durante un corto período en el principio del Altitermal. Las estrategias humanas de adaptación en este período continúan siendo indeterminadas, pero la evidencia señala una estrategia generalizada y móvil, y la conclusión de que este campo de pozos acuíferos seguramente no es el único. La geología de Mustang Springs ayuda a explicar la escasez de otros sitios de edad Altitermal en el Sur de las Planicies Altas.

The last half century of paleoecological and paleoclimatic studies have painted a detailed picture of the Altithermal in the American west. Although when first defined by Antevs (1948:178) the Altithermal was envisioned as a widespread "long [7000 to 4500 B.P.] warm age," it is now known that this episode was far more variable across space and through time than Antevs ever imagined (e.g., Barnosky 1989:71; Barnosky, Anderson, and Bartlein 1987:315; Barnosky, Grimm, and Wright 1987:265–266; Clague and Mathewes 1989:277; COHMAP members 1988; Davis 1984; Davis et al. 1986; Holliday 1989a; McKinnon and Stuart 1987; Van Devender et al. 1987:347–348). Nevertheless, Antevs's judgement was sound. He thought that in places the Altithermal was severe, and he was correct. Nowhere is that clearer than on parts of the High Plains, where paleoenvironmental indicators bear witness to a parched, wind-scoured landscape (e.g., Barnosky, Grimm, and Wright 1987; Holliday 1989a).

Antevs wondered about the people who lived under such conditions, but all he learned from archaeologists was that the Altithermal was "a blank page in the history of man in North America" (Antevs 1948:183). Forty years after Antevs, the page is no longer blank, at least in certain areas (e.g., Bender and Wright 1988; papers in McKinnon and Stuart 1987). In other areas, the southern High Plains, for example, less in known; here, barely half a dozen sites date to this period, though earlier and later sites occur in abundance (Collins 1971).

Does the scarcity of Altithermal archaeological evidence here (or elsewhere) bespeak evidence of

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scarce Altithermal occupations? Certainly, Altithermal groups may have abandoned drought-stricken areas entirely and—like prehistoric Joads heading to Bakersfield—sought refuge in distant, well-watered mountains or river valleys (Benedict 1979; Husted 1974). Yet, there is also reason to believe that in many areas we lack Altithermal human traces for more mundane reasons: either because such were long since destroyed by harsh environmental conditions, or because we have looked in the wrong places for Altithermal age sites, or missed them while focusing on the more spectacular and visible bison kill sites of earlier and later periods (Antevs 1948:183; Frison 1975:294–295, 1983:112; Mulloy 1958:208–209; Reeves 1973:1243; Walker 1987:119–121; Wedel 1983a:221–222, 1986:80). Thus, before concluding that the absence of Altithermal-age archaeological sites in a region is evidence of the exodus of Altithermal groups, there must be sufficient geoarchaeological study to preclude the possibility of sampling error or preservation bias.

Similarly, before concluding that the presence of Altithermal-age sites is evidence of an adaptation to drought, one must determine, on a local and regional scale, the degree (if any) of ecological and climatic stress (Bender and Wright 1988:620; Davis 1987:119; Dillehay 1974; Frison 1975:295; Graham 1987:41; Holliday 1989a:74). Then, those selective factors must be linked *directly* to the human adaptive responses detected archaeologically. Too often efforts to link Altithermal climates with a human response do not go beyond showing that certain cultural patterns are roughly "compatible" with a model of severe drought (Meltzer 1989:193; Schweger 1987:374).

The details of Altithermal *adaptations* surely varied by area, as did the severity of Altithermal climates (e.g., Frison 1975:296; Nance 1972; Wedel 1983b:101). But consider, in broad terms, just three possible adaptive responses to Altithermal conditions. At one extreme, of course, is the *Grapes of Wrath* response—complete abandonment of a region. At the other extreme is the *hardscrabble forager* response, wherein Altithermal foragers stayed to cope with scarce water and drought-stricken plant and animal communities (Buchner 1980; Johnson and Holliday 1986:46–47; Reeves 1973; Root and Ahler 1987; Walker 1987). Between these is a third alternative, the *collector* response: abandonment of the region but not certain of its resources, which are exploited intermittently or seasonally (conditions permitting) by collectors inhabiting nearby, more-favorable areas.

In this paper I shall discuss the Altithermal paleoecological and archaeological record from Mustang Springs, on the southern High Plains of Texas. Previous works (Hill and Meltzer 1987; Meltzer and Collins 1987), reported on the discovery of half a dozen Altithermal age water wells at this site, and summarized evidence of apparently similar-age wells from Blackwater Locality No. 1 and Rattlesnake Draw (Figure 1). Wells provide a tidy causal link between severe climates and a human response, but these initial reports left unanswered questions about the severity and timing of Altithermal climates and the details of the human adaptive response. To address those questions, and further strengthen the links between middle Holocene climates and human adaptation, subsequent fieldwork at Mustang Springs was undertaken. This new evidence is reported here, and insofar as it allows, I consider the implications of this record for the Altithermal adaptive response in this region.

THE MUSTANG SPRINGS SITE

Mustang Springs is 32 km northeast of Midland, Texas, located at an unusually wide and deep portion of Mustang Draw, one of the northwest–southeast-trending dry valleys that crosscuts the otherwise flat and featureless southern High Plains (Figure 1). Today Mustang Draw carries water only seasonally as surface runoff, but before mid-twentieth-century irrigation irreparably lowered the local (Ogallala) water table, freshwater emerged from the sidewalls and floor of the draw to form a relatively permanent and reliable spring and associated pond, named in 1849 by U.S. Army Captain Randolph B. Marcy (Marcy 1850:63).

At Mustang Springs artifacts are rare on the floor of the draw, but occur in great numbers on the adjacent plains surface to the east and west of the springs. Diagnostic artifacts range in age from Paleoindian through Historic (Meltzer and Collins 1987:13), showing long and regular use of the springs.

There is unmistakable evidence, however, that the springs failed during the Altithermal. Despite

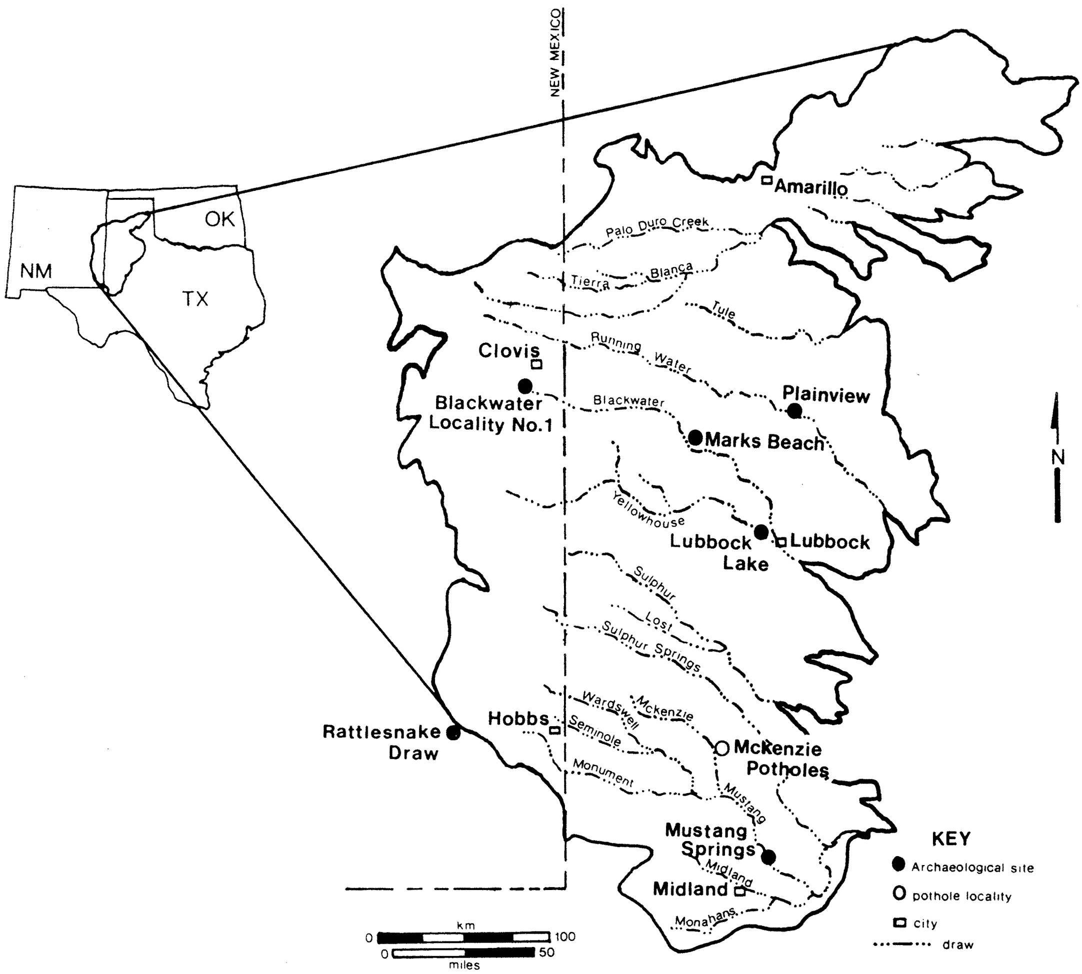

Figure 1. The southern High Plains, showing the location of Mustang Springs along Mustang Draw, and other sites and draws mentioned in the text.

this, human groups continued to use the site as a water source by digging wells. That the wells are preserved deeply buried in the valley fill of the draw is a result of a set of geological circumstances that are surely not unique to Mustang Springs. Understanding them has implications for Altithermal archaeology here and well beyond this particular locality.

Mustang Draw, like other draws and salina basins on the southern High Plains, cuts through the Caprock Caliche (the upper calichified zone of the Miocene–Pliocene age Ogallala Formation) and occasionally into underlying Cretaceous and Triassic units (Gustavson and Finley 1985:4). In some places Caprock outcrops on the surface, though for the most part it lies unconformably beneath the Blackwater Draw Formation (Holliday 1989b; Reeves 1976).

The Blackwater Draw Formation usually occurs as a thick (ca. 5–7 m) blanket of sandy to clayey aeolian sediment (Holliday 1989b:1598; Reeves 1976:222); at Mustang Springs it is only 60–70 cm thick. It occurs on the Plains surface adjacent to the draw, but not within the valley fill. It is covered by an even thinner (ca. 10–30 cm) mantle of loose, deflating sandy loam. Holliday (1989b) has refined the definition of the formation and argues it was deposited episodically over the Quaternary, beginning around 1.6 million years ago, with its uppermost layer deposited between 120,000 and 30,000 years B.P. (Holliday 1989b:1605).

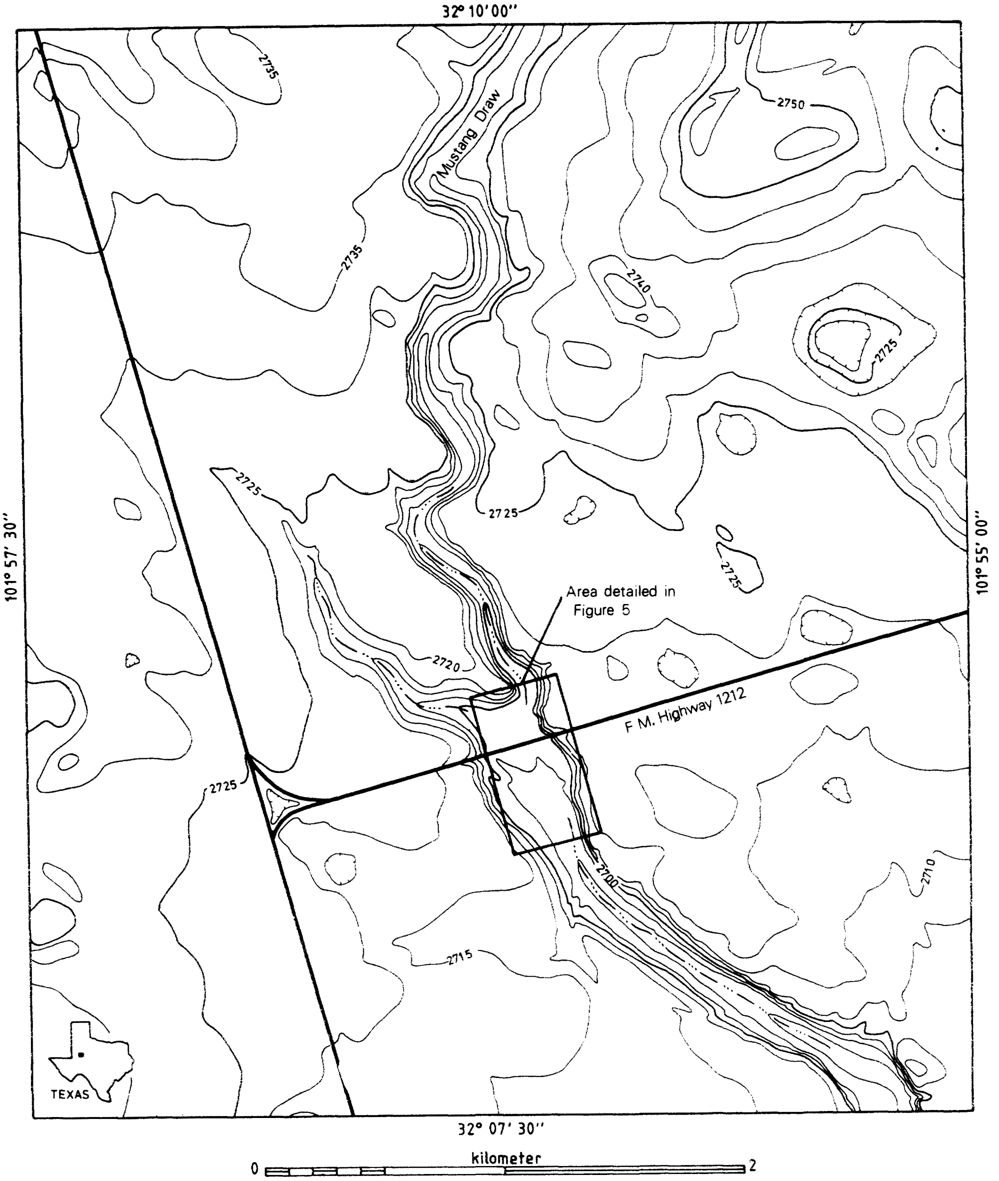

Figure 2. The configuration of Mustang Draw near Mustang Springs.

No artifacts have been found in primary context in the Blackwater Draw Formation; instead, artifacts are mixed together in the uppermost unconsolidated sandy loam (this is common in the region [Collins 1971]). It is not known whether these artifacts were once in stratigraphic position and became mixed owing to erosion and deflation (accelerated in recent decades by agricultural and oil-related activities), or whether this upper zone has simply not seen significant deposition in the last 11,000 years.

Over much of its reach Mustang Draw forms a narrow (ca. 100 m) and shallow valley. At Mustang Springs the draw opens considerably into a wide (ca. 300 m), flat valley. Approximately 1 km downstream the valley curves gently to the southeast and again narrows (Figure 2). Augering and trenching along the draw axis just north of Mustang Springs revealed that Caprock Caliche lies within 1.25 m of the present valley floor. Yet, in the site area itself, and for a distance downstream (perhaps 5 km), consolidated bedrock is beyond the reach of an auger (> 4 m) and, based on evidence from resistivity surveys, perhaps as much as 20 m below the present valley floor.

That and other evidence suggests the Mustang Springs site lies within a structural basin or bowl—resistivity surveys indicate local bedrock faulting (Hill and Meltzer 1987:127). That one of the few major springs on Mustang Draw emerged here, within this broad and deep bedrock basin, seems not to be a coincidence. Perhaps the dissolution of underlying Permian halite beds led to collapse of the upper rock units, created the basin, and fractured the overlying Ogallala and created spring flow (Hill and Meltzer 1987:127, after Gustavson and Finley 1985). Gustavson observes that Mustang Draw, which overlies and parallels the axis of Triassic paleovalleys, was created during post-Triassic dissolution of Permian bedded salt (halite); these and other site features would be expected if regional collapse and localized subsidence had occurred (T. C. Gustavson, personal communication 1989). Such inferences await geological testing.

However produced, the geology of Mustang Springs would have profound consequences, for created here was a permanent freshwater spring and pond, used by human groups throughout prehistory. Even during episodes of severe drought, when other sources of surface water on the High Plains either evaporated or became concentrated with solutes or carbonates, freshwater would have been available at this spot, emerging from a groundwater source—the Ogallala aquifer. Across much of the southern High Plains, the aquifer is inaccessible from the ground surface, for it lies beneath meters of solid rock. In the basin at Mustang Springs, where the overlying rock apparently has been removed, groundwater from the aquifer would have been accessible with relative ease. And the porous and permeable sediments that filled the basin would have provided an excellent rechargeable storage medium that would not readily evaporate or accumulate salts (T. C. Gustavson, personal communication 1989).

The consequences for the paleoecology and archaeology of the Altithermal are important as well. Over at least the last 12,000 years this basin has sporadically trapped sediment (the maximum age of the draw fill is not known). The result is a now deeply buried late Pleistocene through Holocene stratigraphic sequence that provides a detailed paleoecological record and clear-cut evidence of Altithermal human occupations. Each of these records will be discussed in turn.

LATE PLEISTOCENE TO MIDDLE HOLOCENE STRATIGRAPHY AND PALEOECOLOGY

The depositional and erosional sequence at Mustang Springs is much like the sequence at other spring-fed archaeological sites on the southern High Plains, including Blackwater Locality No. 1 (Clovis), Lubbock Lake, and Marks Beach (Hill and Meltzer 1987:Figure 1; Holliday 1989a:Figure 2). This indicates similar paleoclimatic controls (Holliday 1989a:79), though the chronologies differ some between these sites, and these spring fed sequences are not generally representative of draw stratigraphy throughout the region (Holliday 1990).

The base of the mapped section of valley fill at Mustang Springs is an extensive spring and/or fluvially deposited sand sheet (Figure 3). This unit is within 1 m of the surface in the western half of the draw, but on the eastern side plunges to 3.5 m below surface. The bottom of this deposit has not been mapped, and its overall thickness is unknown; it is at least 4 m thick in some areas (the western side of the draw).

Designated as Stratum 1 (previously treated as two separate units, Stratum 1 and 2, in Meltzer and Collins [1987:14]), this deposit is a light gray to light brownish gray, fine to very fine sand to sandy loam (Figure 4; the percentage of sand ranges from 50 to 90 percent sand, and increases toward the valley edges). The sands grade upward from a zone of underlying gravels, which range in size from pebbles to boulders that are subangular to rounded and subprismoidal to spherical (Hill and Meltzer 1987:127). Secondary $CaCO_3$ is present only as traces in this unit (no travertines are evident), and those traces may be the product of reworking from the caliche gravels.

Radiocarbon ages from the overlying unit shows that the deposition of Stratum 1 predates 10,200 B.P. (Table 1). The diatom population of Stratum 1 (Winsborough 1988) is dominated by alkali-

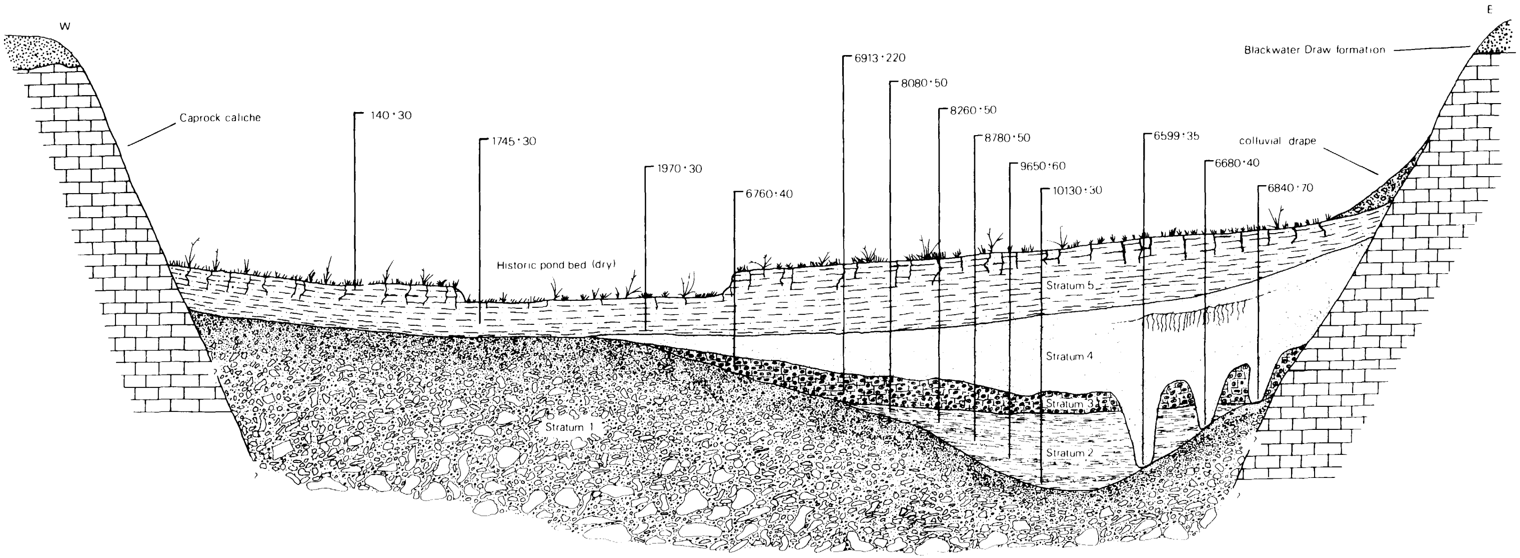

Figure 3. Schematic cross section of Mustang Draw at Mustang Springs. No scale is implied, save that the horizontal and vertical scales are different.

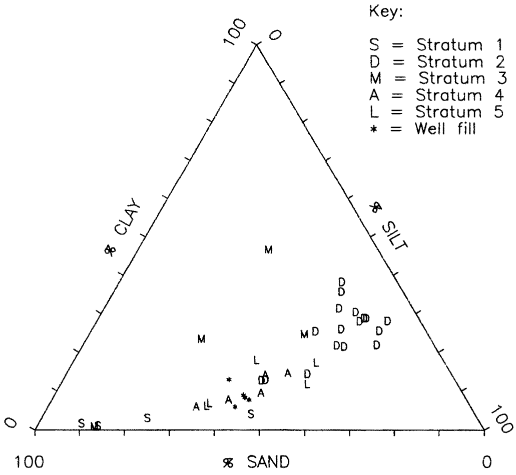

Figure 4. Textural triangle of sediments from Mustang Springs. Key: S = Stratum 1; D = Stratum 2; M = Stratum 3; A = Stratum 4; L = Stratum 5; * = Well fill. The high sand content of the marls reflects, in part, the resistance of carbonate sediments to disaggregation, where small bits of carbonate "act" as various particle sizes.

philous, cool-water spring or stream forms common in sand and mud (e.g., *Fragilaria brevistriata* var. *inflata*, *Denticula elegans*, and *Nitzschia denticula*). This unit was deposited during a period of net aggradation and high-energy spring discharge and/or surface runoff, likely related to higher precipitation and cooler temperatures.

There is a disconformity along the upper surface of Stratum 1. Stratum 2 is a lacustrine and marsh deposit, comprised of alternately gray and black diatomite and cienaga sediments. Stratum 2 accumulated slowly (roughly .048 cm/yr) between ca. 10,200 and 8000 B.P. (Table 1). The sediments from this early Holocene lake/marsh, possibly inset in Stratum 1, occur in an oval area on the east side of the draw (just north of the historical-period pond), roughly 100 m wide (east to west) and some 275 m north to south (ca. 2.75 ha). Testing further down draw has revealed the presence of additional, apparently noncontiguous, pond sediments.

Stratum 2 (previously designated as Stratum 3A through 3G in Meltzer and Collins [1987]) ranges to just over a meter in thickness. This unit is loamy at the base, but fines upward to silt loam and silty clay loams (Figure 4). Stratum 2 is essentially noncalcareous; traces of $CaCO_3$ occur only in the uppermost and lowermost substrata of this unit, and are likely secondary deposits.

Diatoms (but no pollen) have been recovered and studied (Winsborough 1988) from two of the trenches (Trenches 2 and 6).[1] The lowest levels of Stratum 2 (the latest Pleistocene and earliest Holocene) are dominated by diatoms that inhabit cool, deep and clear-standing water (*Cymbella cesatii*, *Achnanthes minutissima*, *Denticula elegans*, and *Nitzschia denticula*). In the first millennia of the Holocene, the pond became a very shallow, alkaline marsh, with fluctuating water tables, higher organics and abundant soil diatoms (dominant species include *Epithemia argus*, *Nitzschia tropica*, *Nitzschia amphibia*, *Rhopalodia gibba*, and later *Denticula elegans*). Later still (ca. 8500 B.P.), there was a return to deep water conditions, with little evidence of organic material, and a diatom community similar to that in the earliest Holocene (with a spike of *Denticula elegans*). Beginning around 8000 B.P., the pond becomes shallower, briefly deepens, then becomes shallow, slightly alkaline, and nutrient rich (dominant taxa are *Epithemia argus*, *Nitzschia amphibia*, and *Rhopalodia gibberula*).

Overlying Stratum 2 is a paludal marl, Stratum 3 (this unit previously was designated Stratum 3H in Meltzer and Collins [1987]). This is a pinkish gray, highly calcareous marl ($CaCO_3$ values from 39 to 68 percent), which varies texturally from a clay to a loamy sand (the latter occurs closest to the valley wall, hence the disproportionately high sand content). The marl is on average 40–50

Table 1. Radiocarbon Dates for Deposits at Mustang Springs

Stratum/ Area	Years B.P.	$\delta^{13}C$	Lab Number	Comments
6/Trench 2	140 ± 30	−13.7	SMU-1589	organic-rich near surface sediment lens (prairie fire?)
5/Trench 9	1,745 ± 30	−17.0	SMU-1785	recent pond and fluvial sediments from bone bed with *Bison bison*
5/Trench 2	1,970 ± 30	−14.8	SMU-1588	recent pond and fluvial sediments
4/Area A	6,599 ± 35	−16.3	SMU-1971	aeolian sediments comprising the fill in the base of Well 32 (Sample 1987-1)
4/Trench 5	6,680 ± 40	−16.1	SMU-1800	aeolian sediments on the Altithermal surface above and adjacent to Well 84
4/Trench 4	6,840 ± 70	−16.8	SMU-1786	aeolian sediments on the Altithermal surface above and adjacent to Well 83
3/Trench 6	6,760 ± 40	−20.4	SMU-1783	calcareous marl, pre-Altithermal deposit
3/Area A	6,913 ± 220	−18.3	SMU-2173	calcareous marl, with small inclusions of underlying diatomaceous sediments, from Pit 32 below Stratum 4 fill; intact marl or redeposited marl and diatomite from well digging; pre-Altithermal deposit (Sample 1987-2)
2F/Trench 6	8,080 ± 50	−22.2	SMU-1784	diatomaceous sediment, penultimate Stratum 2 deposit in Trench 6
2G/Trench 2	8,260 ± 50	−22.1	SMU-1587	diatomaceous sediment, penultimate Stratum 2 deposit in Trench 2
2F/Trench 11	8,780 ± 50	−21.1	SMU-1799	diatomaceous sediment, from *Bison* spp. bone bed, Stratum 2
2E/Trench 2	9,650 ± 60	−22.1	SMU-1586	diatomaceous sediment, Stratum 2
2A/Trench 2	10,130 ± 30	−21.8	SMU-1585	lowest cienaga sediments, Stratum 2
4A/Trench 2[a]	7,620 ± 50	−18.95	SMU-1664	aeolian sediments base Well 81, humic acid; high fulvic acid and presence of snails indicates contamination from depositional units beneath Stratum 4, thus making the date too old (see Meltzer and Collins 1987:16–17)

Note: Ages are based on a radiocarbon half-life of 5,568 years and are corrected for $\delta^{13}C$ fractionation. Dates on this list have *not* been calibrated.

[a] This date was rejected.[2]

cm thick; it thickens toward the edges of the marsh and downstream (in the main 1987 excavation areas, see Figure 5).

Radiocarbon determinations on sediments from uppermost Stratum 2 and on Stratum 3 show that deposition of the marl began after 8000 B.P. and lasted as late as 6900 to 6800 B.P. (Table 1). The latter ages provide a more precise measure of the chronology of drying than previously available (cf. Meltzer and Collins 1987:16). However, the upper surface of Stratum 3 was wind scoured and younger deposits may have been removed (Meltzer and Collins 1987:16).

Stratum 3 represents the first stage of the Altithermal. The dominant diatoms in this unit (*Fragilaria virescens*, *Gomphonema angustatum*, and *Epithemia argus*) indicate shallow marly or slightly saline marsh conditions and increased turbidity. Overall, the changes in diatom species from Stratum 2 mark a decline in the water table, with an attendant loss of freshwater forms (*Achnanthes minutissima*, *Nitzschia denticula*, and *Fragilaria brevistriata* var. *inflata*), and an increase in salt-tolerant taxa (Winsborough 1988:19–20). Similarly, the change in mode of sediment deposition from underlying lake sediments to a paludal marl is possibly indicative of higher temperatures (Holliday 1989a:78), as are, perhaps, carbon-isotope values ($\delta\ ^{13}C$) (Table 1) suggestive of more C4 plants.

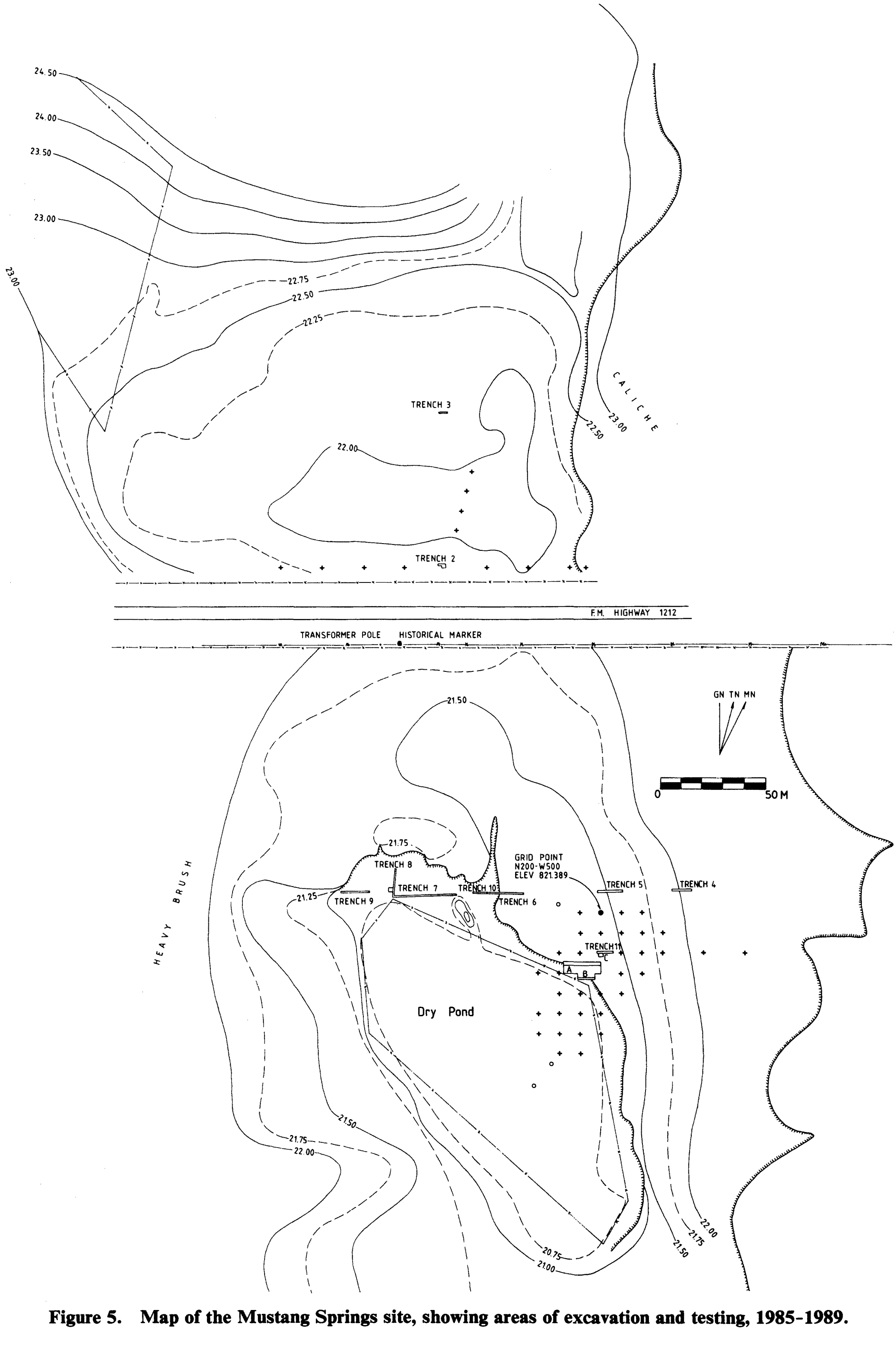

Figure 5. Map of the Mustang Springs site, showing areas of excavation and testing, 1985-1989.

Stratum 3 contains abundant snails. They are not as habitat-specific as diatoms. Nonetheless, the aquatic forms (*Fossaria dalli, Stagnicola caperata, Stagnicola bulimoides techella, Physa virgata, Gyraulus parvus*)—indicative of marshy, generally slow water conditions (Cheatum and Fullington 1973)—do not conflict with the diatom or sediment evidence. I was previously unable to determine whether the snail fauna in Well 81 had been redeposited from older sediments or were living in the well when it was open (Well 1 in Meltzer and Collins [1987:15]). It is now known that snail faunas are common in Stratum 3, but are exceedingly rare in the fill of all other wells excavated. It is reasonable to conclude the snails reported previously were redeposited from the marl.

The upper surface of Stratum 3 is highly irregular and sculpted, displaying unmistakable evidence of erosion. There are no bedforms on that surface (e.g., no gravel bars, ripple marks, or gullying), that would point to water as the agency of erosion. Rather, it appears the surface was deflated (overlying this Stratum are wind-blown sediments), though weathering as a result of wetting and drying and occasional runoff would have served to mobilize sediment. While the upper surface of Stratum 3 was exposed to erosion and deflation, it does not appear to have been exposed for a long period of time (see discussion below). Rather, it was buried quickly under aeolian deposits, designated Stratum 4.

Stratum 4 is an aeolian deposit that is a reddish-brown sandy loam to a loam (the sands are well sorted and mostly fine to very fine), which ranges up to 1 m in thickness. This unit is finer in the valley axis and coarser on valley margins. It also appears to thicken against the eastern margin (on the southern High Plains, dunes from the deflation of playa basins typically accumulate on the eastern edge of the basin, see Evans and Meade [1945:499]).

Although there is a slight colluvial component (on the valley margins), Stratum 4 is dominantly aeolian in origin. The unit lacks cross bedding; there are no sedimentary structures whatsoever. Stratum 4 is relatively homogeneous from bottom to top, with neither gravel lenses nor well sorted layers of sands, silts and clay. The sedimentary source is likely the Blackwater Draw Formation (V. T. Holliday, personal communication 1989).

Radiocarbon determinations on sediments from the base of Stratum 4 suggest deposition began between 6800 and 6700 B.P. (Table 1:SMU-1786, SMU-1800). These dates are not statistically equivalent (using the statistical procedures developed by Hietala and Haas [H. Hietala, personal communication 1989]), but this is not surprising. The older of the two samples (SMU-1786) comes from the eastern valley margin, where aeolian deposits are deeper and presumably would have begun earlier.

Stratum 4 results from widespread, long-term wind erosion. Such deflation and dust accumulation indicates low rainfall, a surface considerably thinned of vegetation, and a loss of soil moisture (Holliday 1989a:78; Schlesinger et al. 1990; Wigner and Peterson 1987). Those conditions ameliorated sometime later, as the uppermost zone of Stratum 4 contains a weakly developed buried soil, marked by a slightly darker A horizon of higher organic carbon content. Carbonates present in this unit may have been derived during pedogenesis (an analog to this buried soil may be the Lubbock Lake soil [Holliday 1985:1489]).

The upper surface of Stratum 4 is slightly wavy, and a disconformity separates it from Stratum 5. This last unit, texturally a silt loam, began to accumulate around 2000 B.P. (Table 1). Stratum 5 is a pond deposit, and presumably marks the onset of climatic conditions not unlike those of the present, and the recharge of Mustang Springs, which produced the pond recorded by Marcy.

NATURAL POTHOLES OR ARTIFICIAL PITS?

The first Altithermal-age water wells reported from Mustang Springs, dug from the deflated surface of Stratum 3, were discovered quite unintentionally, during geoarchaeological testing of the draw (Meltzer and Collins 1987:13). The wells from Blackwater Locality No. 1 (Evans 1951; Hester 1972), Marks Beach (Honea 1980), and Rattlesnake Draw (Smith et al. 1966) also had been fortuitous discoveries. As a result, the Altithermal was being viewed through the narrow window of the sidewalls of backhoe trenches or, worse, gravel pits and natural exposures. There had been few opportunities to examine these wells or the surfaces from which they were dug.

A large, horizontal exposure of the "Altithermal surface" (the top of Stratum 3), obviously would provide a better measure of the magnitude of well digging; that six wells had been found at Mustang Springs in as many backhoe trenches indicated either remarkable luck, or that such features were abundant. It also potentially would reveal spatial/temporal variation in the morphology or depth of the wells themselves and, possibly uncover associated artifacts and subsistence remains. Therefore, in 1987, a ca. 100-m^2-area excavation was opened at Mustang Springs, of which 80 m^2 were taken down to the Altithermal surface (Figure 5:Area A). Subsequent (and shorter term) fieldwork at the site in 1988 and 1989 involved additional geoarchaeological and geochronological studies, but no further exposures of the Altithermal surface.

The Altithermal surface at Mustang Springs is uneven, sculpted, and pockmarked by numerous small pits (< 15–20 cm in diameter) and 63 large (≥ 50cm in diameter) pits (Figure 6). The small pits are extremely irregular in shape—some bear a faint resemblance to animal tracks, though trackways were not detected. Others are clearly the result of rodent activity. Still others may have been erosional remnants of physical processes. None appear artificial and hereafter are ignored.

In general, with regard to the 63 larger pits (Figure 7):

1. The pits are similar in shape (Table 2, shape in plan). The majority of them are circular, oval, or double lobed (this last group are not two pits that intrude into each other)(Figure 8). All were symmetrical in cross section with nearly vertical walls.

2. The pits are similar in size. At the top they ranged from .50 to 1.35 m in diameter, but most clustered tightly around a mean diameter of .70 m (note the high kurtosis values for top length and top width in Table 3).

3. All pits begin at the same surface (the eroded top of Stratum 3), but varied in depth from .10 to 1.65 m (Table 2, maximum and minimum depth). They bottomed out in different stratigraphic units. Some extended into Stratum 1 sands; others only as far as Stratum 2; most others bottomed out in the lowest levels of Stratum 3 (the abundance of pits bottoming out in Stratum 3 likely reflects the fact that the excavation was atop the thickest sections of marl on the site. Had the excavation been a few tens of meters north, where the marl is thinner, more of the pits would have bottomed out in Stratum 1 or 2).

4. All of the pits were filled with Stratum 4 sediments (making the pits readily visible and easily excavated, since there were obvious differences in soil color, texture, and structure between the fill and the units through which the pits extended).

5. All of the pits through Stratum 2 display on their side walls pockmarks that are triangular in plan and angled in section.

6. The majority (62 percent) of the pits contain small holes (on average 14 cm in diameter, and 15 cm in depth, Table 3), labeled "boreholes" (Meltzer and Collins 1987:24). These always are located centrally on the floor of the pit and are uniform in size and shape (Figure 9). Where the boreholes were dug through harder, more resistant sediment, vertical (and not spiral) flutes are present around the inner wall. This feature is unreported in wells from other sites.

Even though excavations were begun in anticipation of finding a large number of wells, the discovery of one pit for every 1.27 m^2 of the exposed Altithermal surface went beyond expectations. It also prompted some uneasiness about their origin. That many seemed to imply a natural rather than cultural origin. Before concluding all are artificial, or even that all are wells, it seems advisable to consider alternative possibilities.

Resolving Equifinality

The topographic, sedimentary, and geochemical settings of the pits at Mustang Springs suggest three natural processes that might have pitted the Altithermal surface: solution of carbonates, fluvial erosion, and animal burrowing. Obviously, if these pits resulted from fluvial erosion or carbonate solution, that suggests greater moisture during the middle Holocene than is indicated in the stratigraphic record at Mustang Springs.

Carbonate Solution by Groundwater or Rainfall Etching. The highly calcareous Stratum 3 sediments (that range from 39 to 68 percent $CaCO_3$), where all of the pits begin would be readily

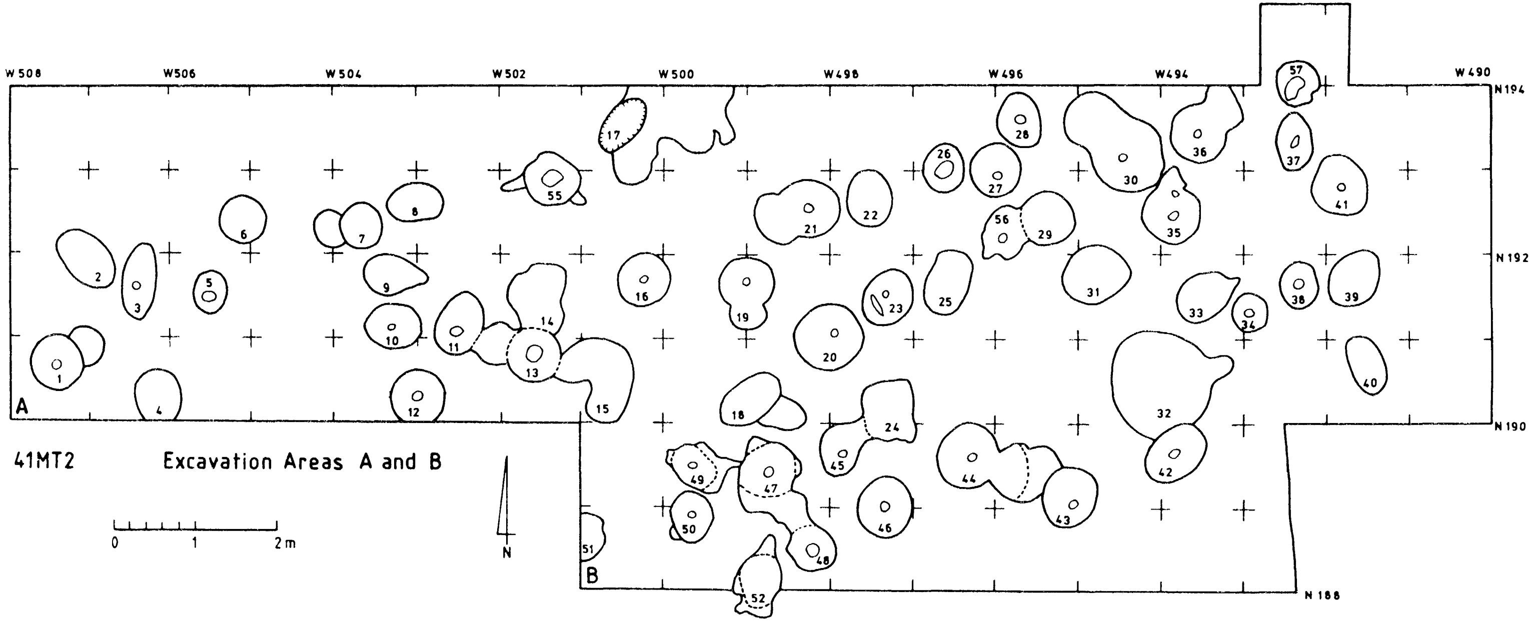

Figure 6. Plan map of 1987 excavation of the Altithermal surface; the numbers in each pit correspond to those numbers in Table 2. Wells 53 and 54, located in an adjacent excavation (Figure 5, Area C), are not shown here.

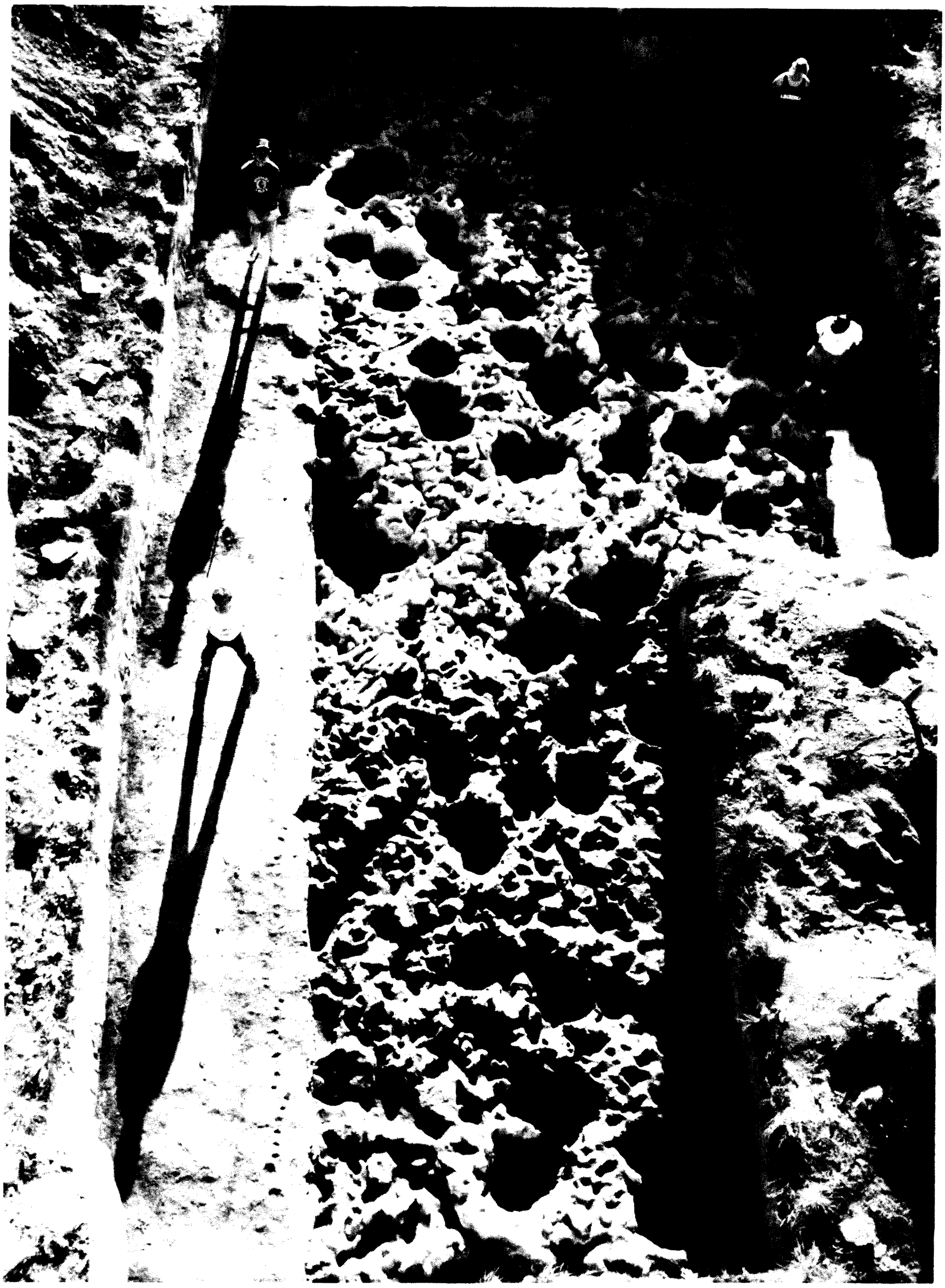

Figure 7. Wellfield on Altithermal surface, looking east from a height of approximately 10.7 m. Individuals included for scale.

modified by solution—either by groundwater or rainfall. Yet, solution seems an unlikely cause for the features seen at Mustang Springs.

A number of the pits extend through Stratum 3 and through the underlying and *non*-calcareous Stratum 2 and Stratum 1. However, solution (groundwater or rainfall) should have removed only

Figure 8. Well 32 (larger, with water) and Well 42 (intrusive). Dimensions are given in Table 2.

calcareous sediments, producing pits that bottom out when the water reached the upper boundary of impermeable, noncalcareous beds.

Solution pits are usually irregular in shape (though they become oblong when several coalesce) and size (ranging from 15 to 45cm in diameter), and may or may not be especially vertical (though rainfall etched potholes tend to have rough vertical walls and very flat and level to slightly concave bottoms [Bretz and Horberg 1949:504–505; Udden 1925:5–6]). When etched in rock, the pits are generally shallow (ca. 12.5 cm deep) (Udden 1925:7). None of the pits reported to have been produced by the etching process has yielded fluted boreholes. Obviously, the pits at Mustang Springs are quite different.

Solution pits also should be filled with the residue left by carbonate dissolution (even in the case of rainfall solution, much of the residue left behind by the etching process might have deflated, but surely traces would remain in the bottom of some pits). No pit was filled with just marl residue. Instead the fill in these pits is identical to Stratum 4 sediments in color and texture (Figure 4); there is no stratigraphic separation between the pit fills and Stratum 4. Moreover, the fill is not carbonate free or noncalcareous: $CaCO_3$ is present in the fills in higher percentages (mean = 34 percent) than occur in Stratum 4 (mean = 21.5 percent), but less than average values for the marl (mean = 56.8 percent). What this suggests is that marl in these pits was physically removed (not dissolved), but not totally, and then the pits subsequently were filled with aeolian material mixed in with bits of the marl.

Most telling, marl deposits occur in many sites and draws on the southern High Plains. Some of these marls are the same age as those from Mustang Springs (as at Lubbock Lake, Plainview, and sites on lower Blackwater and Runningwater draws); others are more recent (mainly along middle and upper Blackwater Draw and lower Sulphur Draw). Yet, none of these marls has yielded any pit-like features (perhaps, as Holliday suggests [personal communication 1990], the Altithermal

Table 2. Size, Shape, Depth, and Elevation of Wells at Mustang Springs.

No	Sh	TL	TW	BL	BW	MxD	MiD	B	BL	BW	BD	BA-SELE	BOR-ELE	OR	BF	ST
1	3	.70	.70	.50	.50	.54	.36	1	.11	.11	.10	819.17	819.07		1	2?
2	2	.80		.60	.40	.60	.32	2				819.17		306		2?
3	2	.90	.50	.94	.40	.53	.22	1	.15	.10	.10	819.19	819.09	6	1	3
4	1	.60	.54	.50	.40	.48	.34	2				819.21				3
5	2			.51	.40	.20	.05	1	.14	.15	.32	819.45	819.13	11	2	3
6	1	.56	.56	.60	.60	.59	.36	2				819.13				3
7	3	.60	.50	.54	.48	.51	.26	2				819.15		339		3
8	2	.75	.47	.64	.45	.27	.07	2				819.48		72		3
9	5	.70	.50	.50	.40	.33	.15	2				819.40		250		3
10	2	.70	.53	.46	.35	.55	.40	1	.11	.08	.13	819.22	819.09	258	2	3
11	2	.70		.61	.56	.60	.03	1	.13	.13	.12	819.18	819.06	16	1	3
12	1		.70	.46	.46	.58	.33	1	.13	.13	.07	819.15	819.08		1	3
13	1			.60	.60	.62	.03	1	.17	.17	.26	819.17	818.91		1	2
16	1	.66	.66	.60	.60	.60	.28	1	.13	.11	.10	819.22	819.12		1	3
17	5	.60	.36	.48	.30	.79	.23	2				819.02		39		2
18	2	.70	.46	.58	.40	.46	.30	2				819.23		42		3
19	3	.80	.80	.64	.64	.65	.41	1	.14	.14	.19	819.19	819.00	344	1	2
20	1	.80	.80	.80	.80	.65	.46	1	.14	.12	.14	819.20	819.06		1	3
21	3	.61	.61	.56	.56	.71	.48	1	.10	.10	.07	819.22	819.15	62	2	2
22	2	.60	.46	.31	.31	.69	.62	2				819.18		348		3
23	1	.63	.63	.60	.57	.56	.44	1	.14	.14	.12	819.31	819.19	30	2	3
24	4	.66	.66	.60	.60	.72	.59	1	.15	.15	.04	819.18	819.14	0	2	3
26	1	.61	.51	.53	.46	.26	.19	1	.20	.17	.36	819.61	819.25	348	2	3
27	1	.60	.60	.56	.56	.58	.47	1	.13	.12	.12	819.30	819.18		1	3
28	1	.70	.60	.60	.60	.60	.50	1	.12	.11	.08	819.30	819.27		1	3
29	1	.59	.59	.52	.52	.62	.53	2				819.30				3
30	3	.84	.84	.67	.67	.57	.52	1	.14	.11	.13	819.31	819.18	290	1	3
32	1	1.20	1.40	.70	.70	1.65		2				818.04				1
34	1	.54	.54	.46	.46	.26	.12	1	.15	.15	.18	819.64	819.46		2	3
35	1	.60	.60	.62	.62	.27	.12	1	.11	.13	.30	819.66	819.36		2	3
36	3	.70	.70	.55	.60	.60	.42	1	.12	.15	.12	819.31	819.19		1	2
37	2	.75	.50	.56	.44	.56	.33	1	.14	.10	.11	819.36	819.25	323	1	3
38	1		.54	.44	.42	.30	.11	1	.11	.11	.16	819.57	819.41	323	2	3
39	1	.76	.62	.63	.55	.31	.20	2				819.59		23		3
40	2	.70	.50	.65	.50	.55	.36	2				819.36		331		3
41	1	.70	.70	.66	.64	.55	.32	1	.17	.12	.09	819.34	819.25		1	3
42	2	.73	.55	.70	.53	.56	.45	1	.12	.12	.06	819.29	819.23	32	1	3
43	3	.75		.68	.62	.57	.33	1	.16	.13	.08	819.29	819.21	42	1	3
44	3	.71	.71	.65	.65	.65	.27	1	.14	.12	.11	819.26	819.15		1	3
45	2	.73		.64	.53	.60	.47	1	.16	.14	.12	819.28	819.16	14	1	3
46	1	.72	.65	.62	.61	.68	.60	1	.16	.16	.09	819.21	819.12	354	1	3
47	1			.60	.60	.63	.51	1	.12	.11	.12	819.21	819.09		1	2
48	1			.70	.60	.62	.40	1	.14	.15	.18	819.24	819.06		1	2
49	1			.52	.42	.25	.13	1	.17	.11	.14	819.51	819.37		1	3
50	1	.65	.52	.52	.48	.20	.16	1	.13	.12	.24	819.51	819.27		2	3
53	1	.70	.70	.46	.46	.74	.61	1	.12	.13	.20	819.00	818.80		1	1
54	1	.50	.50	.42	.42			1	.17	.18	.21	819.42	819.21		1	2
55	1	.65	.60	.60	.55	.10	.01	1	.25	.20	.42	819.70	819.28		2	3
56	2	.55	.55	.59	.59	.52	.42	1	.23	.15	.10	819.39	819.29		1	3
57	1		.60	.55	.52	.46	.28	1	.21	.15	.07	819.44	819.37		2	3
81	6	.70		.40		1.11		2				819.56				1
83	6	.50		.35		.73		2				820.21				3
84	6	.75		.45		.91		1				819.39	819.15		2	2
85	6	1.35		.65		.92		2				818.94				1
86	6			.25		.29		1				819.37	819.29		2	2

Note: All measurements are in meters. This table does not include Pits 14 and 15 (suspected rodent burrows), or Wells 25, 31, 33, 51, 52 and 82 (which were either unfinished or not fully excavated, and hence have insufficient data). Thus, of the 61 wells, only 55 are listed here and used in Table 3.

surface was exposed at most a few hundred years and the marl was being precipitated [was saturated] until shortly before burial with any dissolution, therefore, not leaving noticeable pits).

Fluvial Erosion. Water erosion of resistant bedrock or sediment, either by direct impact (gouge holes and plunge pools), or the scouring of a bed by sediment or rocks "whirled by stationary eddies, or ones that act intermittently or continuously at the same point" (eddy holes) produces potholes (see Alexander 1932:305; Allen 1971:183; Matthes 1947:255–256). Erosion requires rapid or precipitous water flow, often is associated with steep gradients, and occurs even with limited bedload (Alexander 1932:335; Butzer 1976:140). The sparse literature on the morphology of natural potholes was supplemented with an excavation of two potholes on the floor of McKenzie Draw in Gaines County, Texas, some 80 km northwest of Mustang Springs (Figure 1). These occur in the caliche floor of the draw and are filled with Blackwater Draw Formation sediment. I also have examined and photographed exposed potholes on other valley floors.

Potholes vary considerably in shape, depth, and the angle of the cylindrical axis, all of which depends on the rock or sediment being eroded (Alexander 1932:307). Eddy holes often are "fluted" or grooved spirally (Alexander 1932:308) and sometimes contain rounded stones (that may have bored the holes). Gouge holes, characteristic of steep rapids, tend to be oval in plan and have an inverted bell shape in cross section, with the long axis parallel to stream flow (Alexander 1932:330).

The McKenzie Draw potholes are roughly the same size and shape as the Mustang Springs pits. The potholes are circular and oval and plan and extended 80 cm into the bedrock; each is only slightly more than 1 m in diameter. One exhibited a "bench" (seen in seven of the Mustang Springs pits) and had rounded stones in the fill (as did a few of the Mustang Springs pits). The similarities, however, are not as significant as the differences.

Natural potholes are highly *irregular* in size and shape, and if they contain "boreholes," that fact is unreported. In addition, unlike the Mustang Springs pits, the McKenzie Draw potholes were asymmetrical in section along the down-draw axis. Their upstream wall was sloped gently to the base of the pit, while the downstream wall was nearly vertical. Carving potholes requires either free-falling water (plunge pools), fast-moving streams or rapids (gouge holes), or upward, strong, and swift vortex action (eddy holes). But there is no evidence of bedforms or downstream or linear erosional channels on the Stratum 3 surface. In fact, analysis of the axis orientation of 31 noncircular pits (data from Table 2) showed no significant difference from the pattern expected by chance ($\chi^2 = 11.38$, $df = 17$). This contrasts with the nonrandom (down-valley) orientation that would be expected were these features created by stream flow. Stratum 4, of course, is aeolian.

Bioturbation. Swift fox (*Vulpes velox*) and badger (*Taxidea taxus*) are native to the region, den underground, and may have produced the Mustang Springs pits. But unlike burrows, the majority

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Key to column headings:

No = number (numbers 81–86 were found in earlier field seasons than 1–55).
Sh = shape in plan (1 = circular; 2 = oval; 3 = bi-lobed; 4 = square; 5 = irregular; 6 = unknown).
TL = top length (top diameter in circular wells).
TW = top width (circular wells same as TL).
BL = bottom length (bottom diameter in circular wells).
BW = bottom width (in circular wells same as BL).
MxD = maximum depth.
MiD = minimum depth.
B = borehole (1 = borehole present; 2 = borehole absent).
BL = borehole length (borehole diameter in circular boreholes).
BW = borehole width (borehole diameter in circular boreholes).
BASELE = absolute elevation of basin floor.
BORELE = absolute elevation of borehole floor.
OR = orientation in degrees.
BF = borehole fluting (1 = borehole fluting present; 2 = borehole fluting absent).
ST = stratigraphic unit in which well bottoms out. Wells 1 and 2 appeared to have bottomed out in Stratum 2, but due to an oversight in the field this was not confirmed by a reaction test with HCl, hence the question mark on these entries.

Table 3. Descriptive Statistics on Wells at Mustang Springs

	Mean	Standard Deviation	Skewness	Kurtosis	Minimum	Maximum	n
Top length	.703	.151	2.484	8.700	.50	1.35	46
Top width	.611	.162	2.959	13.403	.36	1.40	41
Bottom length	.566	.115	.043	1.970	.25	.94	55
Bottom width	.522	.105	.020	−.189	.30	.80	50
Maximum depth	.564	.245	1.540	6.492	.10	1.65	54
Minimum depth	.324	.167	−.157	−.834	.01	.62	48
Bore length	.146	.033	1.408	2.184	.10	.25	37
Bore width	.132	.025	.545	.309	.08	.20	37
Bore depth	.150	.087	1.512	1.983	.04	.42	37
Base elevation	819.304	.269	−1.129	10.029	818.04	820.21	55
Bore elevation	819.178	.132	−.325	.978	818.80	819.46	39
Bottom elevation	819.198	.258	−.523	10.637	818.04	820.21	55

Note: Data are taken from Table 2. Bottom elevation is the lowest point any well reached and corresponds to either base or borehole elevation for a particular well, as appropriate.

of the pits at Mustang Springs have open tops, conform to standardized size and shape classes (that might occur in burrows of the same animal species), are symmetrical in section with vertical walls, and possess centrally located boreholes.

Two of the pits (14 and 15) and the upper part of Pit 17 are irregularly shaped, lack vertical walls, and in the case of Pit 14, severely undercut the Altithermal surface. Neither possessed a central bore hole. There was no evidence in either of animal activity, but by their shape and size they appeared to be animal burrows or dens. Pits 14 and 15 are thus excluded from subsequent discussion, and only the lower part of Pit 17 is used in the analysis.

Argument by Exclusion: The Case for Artificial Origins. The large pits on the Altithermal surface at Mustang Springs cannot be explained by any obvious natural agencies, or at least any of which I presently am aware. Until additional alternatives appear, it seems reasonable to conclude these pits are artificial. Doing so helps account for other features, such as the pockmarks on the side walls of certain pits (that seem to result from the use of picks or digging sticks) and the backdirt piles of diatomite adjacent to a few of the pits that were dug through Stratum 2.

STORAGE PITS, CISTERNS, OR WATER WELLS?

While there is a priori reason to suspect these pits were water wells, there are alternative possibilities: notably, that these are storage or processing pits, or cisterns to capture surface runoff or rainfall. In order to test the possibility the pits were used to acquire, process, or store food or other resources, all sediment filling the pits was fine screened and in some cases further examined by flotation. If organic or inorganic materials were used with these pits, the evidence has so far eluded all efforts at detection. The fill was virtually clean, save for the odd snail and bison-bone fragments redeposited from units through which the pits extended. The lack of organic materials might be attributable to harsh conditions when the pits were open.

The possibility that the pits were cisterns or retention basins to catch and store surface water from rainfall or sheet wash, as opposed to wells, is something of a moot point in terms of their adaptive role. Both would serve the same purpose. Nonetheless, the possibility that these were features to capture surface water has quite different *paleoclimatic* implications than if they were wells (the former implies the presence of surface water; the latter does not).

Water-capture features are found in a number of southwestern sites, but so far none occur earlier than A.D. 700 (Crown 1987:217). These features take the form of holes located on rock surfaces, or simple depressions on slopes. Often these are found on the tops or sides of mesas or terraces, "situations generally not amenable to other types of water collection" (Crown 1987:217).

The possibility that the Mustang Springs pits served to capture surface water can be rejected.

Figure 9. Example of well (46) with borehole. Dimensions are given in Table 2.

First, these pits are located only on the floor of the Draw, and not on its nearby slopes or on the adjacent Plains surface. Documented cisterns are not so restricted in their placement. Second, capturing rainfall and sheet wash involves broader retention basins spread over a much larger area than the closely packed and relatively smaller pits at Mustang Springs. Finally, the Mustang Springs pits lack associated features for capturing and channeling water into the pits, and have vertical, as opposed to gently sloping walls.

A Wellfield at Mustang Springs

In the absence of compelling support for the alternative explanations, and given that the fact that the pits were dug from a barren, wind-scoured surface following the evaporation of the local pond; that they are located on the floor of Mustang Draw where the subsurface water table could be reached with relative ease; and, that they show subtle evidence within their fills of water settling (the deeper borehole fill is coarser than the basin fill), it is reasonable to conclude the large pits at Mustang Springs are water wells. The group, more properly, is a prehistoric water wellfield.

The Mustang Springs wells resemble water wells documented archaeologically (Evans 1951; Hester 1972), and among hunter–gatherers in arid environments (e.g., Gould 1977:28–29; J. O'Connell, personal communication 1987). This observation, however, is not itself taken as proof that the Mustang Springs pits are wells.

Concluding these pits are wells does not conflict with the observations made of their regularity in size and shape, or variation in depth. It helps explain the three large caliche boulders (weighing a total of 13.7 kg) found at the base of the deepest pit (boulders are not a usual part of an aeolian deposit, no matter how hard the wind blows). They would seem to be placed there as a platform for standing in this deep well.

Viewing these pits as wells possibly explains the presence and purpose of the boreholes. It was earlier suggested that boreholes served to lift water by hydrostatic pressure into the main well basin (Meltzer and Collins 1987:24), assuming the hydrological head was at a slightly higher elevation than the well floor. Other alternatives come to mind. Boreholes may have acted to increase well recharge rate by increasing the surface area for seepage. Or, digging out a large basin, then a smaller, deeper borehole to tap the water table, may have been done to save labor. Although the technologies are vastly different, such a procedure is used routinely by modern well drillers (Gene Wheeler, personal communication 1987). Lee (1979:122) records that when !Kung San collect water from surface depressions "a shallow pit in the center is often hollowed out to collect the remaining water and reduce evaporation as the pan dries out." Regardless of their purpose, I would not infer that the 36 percent (22/61) of the wells without boreholes are unfinished (that seems an excessively high number).

WATER TABLES, WATER WELLS, AND ALTITHERMAL CLIMATES

The wellfield at Mustang Springs graphically illustrates the severity of Altithermal climates on the southern High Plains, and corroborates the fact that the springs dried, or at least no longer supported surface water. Wells would have been superfluous in a pond (Meltzer and Collins 1987: 19). It also puts archaeology in the unusual position of providing (not merely consuming) fine-grained paleoclimatic data, in the form of precise measures of the rate and magnitude of changes in prehistoric water tables.

The deepest of the Mustang Springs wells (Well 32, Figure 8 and Table 2) bottoms out an elevation of 818.04 m, 1.65 m below the Altithermal surface at that point in the site. But 1.65 m is only a *minimum* figure for the drop in the water table. The Altithermal surface was eroded and deflated, and is only the upper *preserved* limit of the marl (which here is at an elevation of 819.69 m).

Well 81, 200 m to the north of Well 32, started from the same surface, but at an elevation of 820.67 m. At Well 83, along the valley margin some 30 m to the north and 50 m east of Well 32, the Altithermal surface is at an elevation of 820.94 m (these values can be derived from Table 2, by adding maximum depth to base [or borehole, whichever is lower] elevation). On the northern and eastern edges of the site the Altithermal surface is 1.25 m higher than it is in the valley center, reflecting either differential deflation or accumulation of the marl.

Regardless, because this is the same lacustrine deposit, the water levels in the early Altithermal lake must have been at least as high as the highest preserved upper limits of the marl *on the site*.

Therefore, a *minimum* figure for the overall drop in the water table is the difference between the highest preserved elevation of the Altithermal surface (820.94 m) and the elevation in the deepest well, taken to mark the lowest level of the water table (818.04 m), or 2.90 m. At Blackwater Locality No. 1, the water table drop is estimated at 2.5 to 3 m (Evans 1951:7).

At Mustang Springs the 3 m drop in the water table was relatively rapid. The fill from the wells has been radiocarbon dated between 6800 and 6600 B.P. (SMU-1971, SMU-1786, SMU-1800), soon after the marl was deposited. These dates form a series, with the earliest obtained in association with the shallowest well on the valley margin, and with the latest on the deepest well in the valley center. This time-transgressive pattern may represent well digging moving toward the deeper center of the dry pond as the water table dropped.

The water table dropped at the rate of 1.5 cm/yr. That rate is approximate at best, since both the upper and lower measuring points and dates are not secure. The early Altithermal water levels may have been higher, *but not lower*, and the deep well may have been dug below the level of the water table.

The landscape of the southern High Plains is flat, undissected and feebly drained, with few permanent lakes and no permanent rivers. The only stable sources of freshwater are groundwater-fed springs and ponds (mostly located along the draws). Fluctuations in the water level of these springs and ponds are "reasonably attributable to recharge variation in response to precipitation" (Haynes 1975:76). Precipitation in this area is low (today about 40 cm/year), evaporation is high, and infiltration is hampered by the poorly permeable caprock caliche (Knowles et al. 1984:26). On average, Ogallala aquifer recharge rates are extremely slow, less than 5 mm of water per year reach the water table (Knowles et al. 1984:24; studies in recent heavy rainfall years show, however, that shallow aquifers may recharge faster).

The magnitude of the drop in the water table at Mustang Springs and at Blackwater Locality No. 1 some 280 km northwest, indicates an uninterrupted period of either lower precipitation, higher temperatures (and thus reduced effective moisture) or some combination of these (Evans 1951:7; also COHMAP 1988:1050; Kutzbach and Guetter 1986:1755). Warm and/or dry as it must have been, rainfall-fed ephemeral or seasonal ponds on the Plains surfaces would have become rare and unpredictable. Lubbock Lake, 160 km north of Mustang Springs, is an exception. Surface water was present there through the Altithermal (Johnson and Holliday 1986:44). Not surprisingly, no Altithermal age wells have been found at this site. This difference, and a lack of synchronism between depositional events at Lubbock Lake and Mustang Springs (despite nearly identical lithostratigraphy) likely reflects differences in the hydrology of the respective springs and in response time to changes in precipitation.

Radiocarbon dates put well digging at the Altithermal maximum, rather than the end of the Altithermal, as previously argued (Meltzer and Collins 1987:17). This earlier conclusion, however, was based on fewer dates, two of which were thermoluminescence (TL), and there were obvious incongruities.[2]

By the currently available radiocarbon evidence, well digging took place over a 200-year period. But judging by the fact that the same aeolian fill is in *all* the wells, regardless of depth, and that the Altithermal surface remained at the same position when all the wells were dug (none were dug through Stratum 4 deposits), well digging likely did not last that much longer.

In order to derive a more precise *relative* chronology of well digging, the wells were ordered by various attributes, including their maximum depth, presence or absence of boreholes by depth, and shape classes by depth. To test whether any of these orders represented a chronology, each was checked against the six pairs of overlapping wells whose relative age was known (the six pairs are *7*:8, *20*:23, 24:*45*, 29:*56*, *32*:42, *43*:44; the well dug first is italicized). None of these attributes would seem to have chronological significance, as each produced order violated the known chronology.

Given these results, the only relative chronology possible is of the six pairs of original:intrusive wells (Figure 10), though since none of these pairs overlaps with any other, the relative sequence is speculative. It represents a chronology only insofar as one can assume a uniform and nonreversible fall and rise in the water table between these wells. This order also indicates that over the period

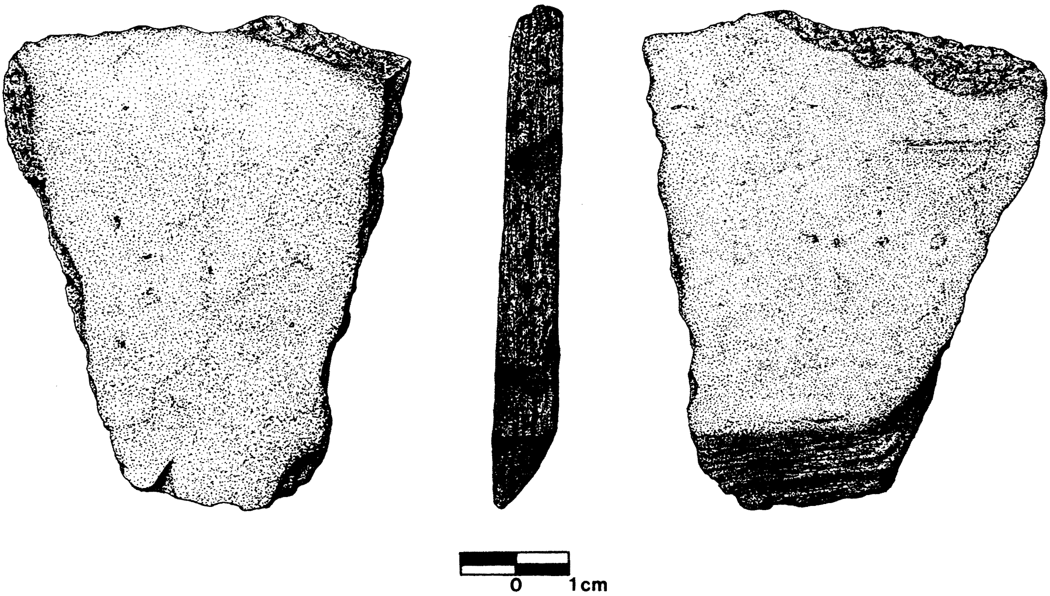

Figure 11. Metate fragment of Dockum sandstone, a possible well-digging tool found in Well 4.

sticks, the well in which this artifact was found was dug in the softer marls that do not preserve any digging marks.

Overall, this assemblage of tools had reached the end of its use life, and was discarded (though not necessarily used) on the Altithermal surface. Hence, it is not demonstrably a representative sample of Altithermal human activities, though taken at face value it indicates processing (grinding) of plant materials and scraping activities.

Thoughts on the Altithermal Adaptive Response

Although additional archaeological evidence is required, the available data, along with paleoenvironmental evidence, make it possible to suggest the *kinds* of adaptations one might expect to see under these circumstances. It appears that the Altithermal fauna and flora were similar in structure to the modern mixed to short grass prairie (Johnson 1987:94). Most of the animals that now inhabit the southern High Plains can survive drought conditions (by minimizing heat load and water expenditure, and/or by deriving moisture from plants), though some aestivate when faced with water loss (e.g., the western harvest mouse), while others have their reproductive cycles slowed or disrupted (e.g., Hispid cotton rat and eastern cottontail). A few key economic resources, however, almost certainly were rare or absent. These include the bird species that inhabit deeper surface lakes and marshes (such as herons, geese, and swans), and bison.

Bison were abundant on the southern High Plains in the late Pleistocene and early Holocene, but were scarce during the Altithermal (Dillehay 1974:185; MacDonald 1981:250; Meltzer and Collins 1987:21–22). No doubt a scarcity of surface water drove them from the region (bison must drink regularly), though that was probably not the only factor. While I tread very carefully in using the decade-long Dust Bowl as an analog for the 2,500-year Altithermal, during that recent drought, when rainfall deficits were highest during the summer months, the plant taxa hardest hit were the warm season (C4) grasses that dominate the region, notably Buffalo grass and Blue grama grass. During the Dust Bowl, the loss of these species was almost total (Tomanek and Hulett 1970:208; Weaver and Albertson 1956:79, 93).

A large proportion (80 to 90 percent) of modern bison diet is Buffalo grass and Blue grama grass was subsequent abandonment is unknown. The current evidence from Mustang Springs might suggest so. No wells were found that begin within Stratum 4, and the subsequent sign of activity is a small burned rock hearth and a few artifacts high in Stratum 4, associated with that weakly developed buried soil. What prompted groups to apparently cease well digging at Mustang Springs must be a matter of speculation, but it is clearly not attributable to a rise in the water table, for that would not occur until ca. 2000 B.P. The possibility is open that the climates worsened and the water table dropped beyond reach.

In a strict sense, the Mustang Springs record is also silent on the subject of whether other parts of the Southern High Plains were abandoned. Even so if, as it appears from archaeological and paleoecological evidence that surface water became rare or altogether disappeared, human foraging groups would have selectively abandoned or, better, repositioned themselves on the landscape. Perhaps like early Spanish explorers, they aimed their movements where the "watering places are known" (Hammond and Rey 1940:282).

The Artifacts from the Altithermal of Mustang Springs

It is difficult to determine whether the groups who dug the wells at Mustang Springs were *hard-scrabble foragers*, or *collectors*. Aside from well digging, there was only a scant archaeological record on the Altithermal surface (true at Blackwater Locality No. 1, as well [Evans 1951:6]). That could be because of relatively poor preservation or a tendency for Altithermal groups to camp on the Plains above the draw, rather than atop their wells. Setting sites beyond the immediate vicinity of a water source is characteristic of modern hunter–gatherers in arid lands. Doing so prevents fouling of the water supply, and avoids frightening game animals that might be attracted to the source (J. F. O'Connell, personal communication 1987; Wedel 1963:12). Regardless of why this was done at Mustang Springs, the result is that any nondiagnostic Altithermal artifacts lying on the Plains above the Draw are not easily identified amongst the jumble of 10,000 years of prehistoric occupation of the site in less than 30 cm of loose, deflating sediment—a common problem in the area's archaeology.

Moreover, despite the large area excavated, no evidence of food remains were found. Burned rock (caliche), which is ubiquitous on virtually all post-Paleoindian sites in this region, was noticeably rare (a mere 1,068 g were recovered, and much of that came as one large (820 g) cobble. A single, small (.4 g) piece of red ochre was found. There were just over two dozen lithic artifacts recovered from the Altithermal surface.

The chert artifacts (n = 11), including two core remnants and a series of core and bifacial thinning flakes, are heavily worn, recycled, or broken. Nearly all exhibited scalar (or other forms) of retouch and/or unifacial usewear along the majority of useable edges. They are manufactured on Edwards Formation (Cretaceous) chert; the nearest known outcrop is off the southern High Plains, 70 km southeast of Mustang Springs. Some flaking stone was sought locally. A limestone cobble (likely reworked from underlying Cretaceous formations) was recovered in one of the wells. In an apparent prehistoric test of the material, flakes were struck from it, but in each case flaws (quartz threads) in the stone led to abrupt terminations. The piece was discarded unused.

The ground-stone artifacts (n = 15) were made of local material and showed evidence of heavy use. The majority of the pieces (n = 11, weighing a total of 58.2 g) appear to have come from a single artifact made of Antlers Formation (Lower Cretaceous) sandstone, the nearest outcrop of which is within 8 km of the site. My effort to refit the pieces was unsuccessful, but at least one face of the larger object had been ground smooth. There were two recognizable manos within the assemblage; the complete one was worn heavily.

One of the ground-stone tools was a metate fragment made of Dockum sandstone (Figure 11) found on the floor of Well 4 (Figure 6). Its context is suggestive, for Well 4 lacked a borehole and had a shallower-than-average depth relative to its diameter. The wide end of the artifact is bifaceted and steeply angled (ca. 75°), the narrow end is gently angled (ca. 35°), and terminates in a rounded and nibbled edge. Use wear suggests a pick-like or even scraping activity. This *might* indicate the piece served as a digging tool in excavating the pit or cleaning its sidewalls. Unfortunately, unlike those wells dug through the massive and resistant Stratum 2 that preserves the marks of digging

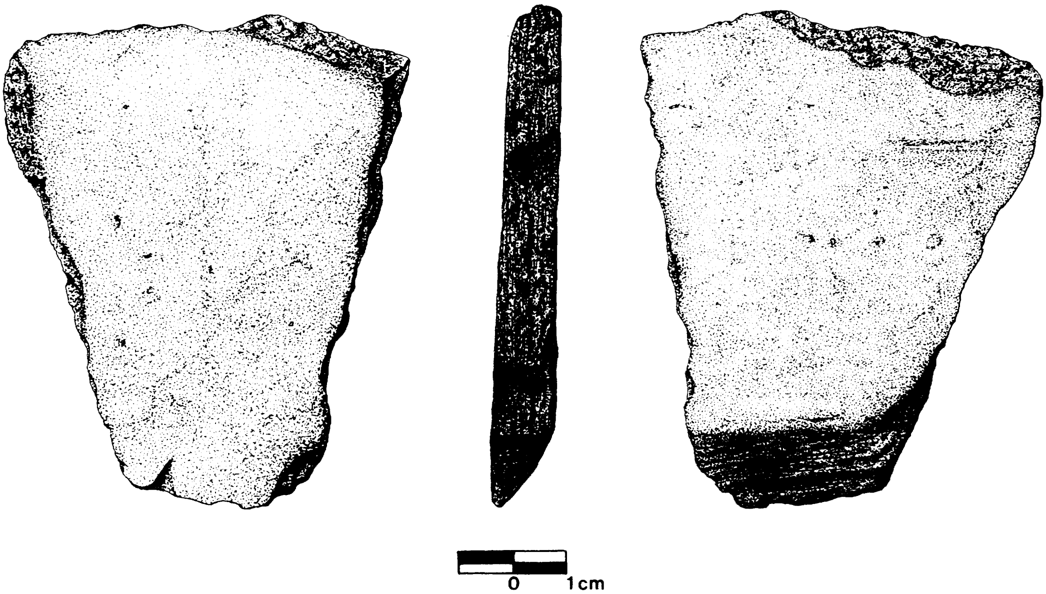

Figure 11. Metate fragment of Dockum sandstone, a possible well-digging tool found in Well 4.

sticks, the well in which this artifact was found was dug in the softer marls that do not preserve any digging marks.

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(Peden 1976:228). *If* the Altithermal was characterized by summer rainfall deficits (Kutzbach and Guetter 1986:1755; Meltzer and Collins 1987:23), and *if* bison diets were then as they are now, then clearly the preferred forage of these animals was reduced. Dental abnormalities indicative of poor range conditions have been observed in a sample of Altithermal age bison (Johnson 1987:94; Johnson and Holliday 1986:43). Coincidentally, the high plains grasshopper (*Dissosteira longipennis*) is an obligate feeder on buffalo and blue grama grass (Shelford 1963:346), and its numbers also may have been reduced during the Altithermal.

While it is not known how important grasshoppers were in earlier Paleoindian subsistence strategies, bison hunting clearly was very important, as numerous late Paleoindian bison kills attest. The reduction or disappearance of bison would have necessitated some alteration of subsistence.

It is difficult at present to say how those subsistence strategies changed. The foraging literature sends mixed signals on the expected responses to drought suggesting, for example, that groups either will expand the diet (O'Connell and Hawkes 1981:115); contract the diet (Belovsky 1987:Figure 5); concentrate on plants (Gould 1980:66; Pate 1986:110); or concentrate on animals (Belovsky 1988). All of these occur in certain settings, which suggests that changes in subsistence wrought by drought or ecological stress are dependent on the particular ecological conditions. In this case, unfortunately, there is little to go on. Perhaps all that reasonably can be argued about Altithermal subsistence strategies is that hardy plant species such as yucca, prickly pear, and thistle, along with drought-resistant ground- and brush-dwelling birds, turtles, snakes, lizards, rodents, jack rabbits, and pronghorn antelope likely figured in the resource base of foragers or collectors.

More might be said about settlement mobility. There is general agreement that a lack of water, and not food resources or foraging efficiency, is the limiting factor in arid settings (e.g., Gould 1989: 17; Kelly 1989:14; Lee 1979:120; Silberbauer 1981:221; Wedel 1963:9). As Gould (1989:17) put it, "drought stressed populations of arid land foragers characteristically seek to ensure and safeguard known or existing supplies of water."

Humans require substantial amounts of water on a daily basis (Larson 1977:184; Schmidt-Nielsen 1964) and are at greater or lesser risk on waterless landscapes, depending on the amount of transported water, the distance between water sources, and the availability, reliability, and predictability of those sources. Under drought conditions the number, timing, and distance of settlement moves is determined, perhaps in large part, by these factors (Kelly 1989:14; Lee 1976:84–90).

During the Altithermal, permanent and reliable surface water sources were rare, if not unpredictable, ephemeral, and not always potable. Obviously, under certain conditions Altithermal hunter–gatherers could and did enhance the water supply by well digging. Doing so required an ability to recognize near surface aquifers. There may have been surface clues. As Marcy (1859:46–47) later advised travelers crossing the southern High Plains during the dry season who needed to dig wells, "The lowest spots should be selected for this purpose where the grass is green and the surface earth moist."

Over the period the water table stayed within reach of hand-dug wells; these would have been predictable and relatively reliable water sources, and likely a focal point of settlement. The duration of occupation at a well site (or the number of settlement moves between sites) would, therefore, have been determined by the availability of water elsewhere and, secondarily, the density of food resources available locally (Kelly 1989:15). In ethnographic settings, where water is scarce overall, known water sources are occupied longer and there are fewer settlement moves (e.g., Lee 1979:355-360).

But an individual well has limited pool life, owing to infilling of sediment and debris, slow recharge, and organic contamination. Moreover, on a landscape where biomass was low, thinly scattered (drought-resistant taxa would not have to tether their movement to water holes), and difficult to predict, the food resources available around a water source would become exhausted rapidly under foraging pressure.

Human groups—whether foragers or collectors—would have a choice: either stay longer where water is known to occur, or not stay in any one locality for very long but move quickly from one to next. There are compromises to each. In the former, existing wells would have to be cleaned out or new ones dug nearby (itself not a significant limiting factor). But a longer stay in one place and the attendant pressure on the local resources might require an increase in the foraging radius surrounding the camp and possibly even an increase in the diet breadth (Kelly 1989:15). In the alternative case (move quickly and often), groups would have to gamble on well digging producing water elsewhere (or finding rare pools of surface water by following rainstorms [Gould 1980]), and on the presence of forage elsewhere. Obviously, if water is the critical resource, hunter-gatherers might select the former option, although if water sources (good places to dig wells) were known in the region the latter might be preferred.

A longer duration of occupation should produce evidence for cleaning out old wells (e.g., Gould 1977:76; Green 1962:232) or digging new ones. If a number of wells are dug during a single period of occupation, they should all bottom out at the same elevation—the piezometric surface.[3] Underground water, unless in a confined aquifer (absent in this unconsolidated valley fill), will lie on a horizontal plane (at least on a scale relative to humans), and wells dug to that relatively stable plane will have the same bottom elevations. In contrast, wells dug to different depths would imply groups cycling through the site repeatedly, but staying only briefly at any one time. Not knowing precisely the rate of water-table fluctuations, it is impossible to say whether the cycles were seasonal, annual, or longer.

The bottom elevation of the wells at Mustang Springs ranged over 2.17 m. But this figure is slightly misleading since most (47 wells) bottomed out in a relatively short vertical range (between elevation 819 and 819.5 m), producing a peaked distribution (kurtosis = 10.637, Table 3). Not all were dug to the same plane, even assuming a $\pm$ 10 cm margin in which the water table could be tapped.

None of the wells at Mustang Springs showed evidence of cleaning out and reuse. That absence might speak to the ease of digging new wells, the difficulty of relocating old wells filled in with sediment, or the fact that different groups were using the site and had no knowledge of the location of another groups wells.

The wells were dug to different stratigraphic units: 4 bottom out in Stratum 1 (basal sands); 10 in Stratum 2 (diatomite); and the remaining 39 in Stratum 3 (marl). Yet, this does not necessarily mean the wells were dug to different depths since the elevation of these units varies across the site (as earlier discussed). A well that bottomed out in Stratum 1 sands at the north end of the site would, at that same elevation 200 m south in the main excavation area, bottom out in marl.

Statistical analysis (ANOVA) comparing bottom elevation of wells dug into the various strata, however, shows there are significant differences in the bottom elevations of wells dug into Stratum 3 and those dug into Strata 1 and 2 ($F = 6.923$, $p = .002$). Altogether, there is variation in bottom elevations among all wells. Surprisingly, of the eight wells with bottom elevations significantly shallower or deeper than the mean bottom elevation (as measured by z scores), four were not from the main excavation area. Given the stratigraphy of the site, this is not unexpected.

In essence, the argument can be made that at Mustang Springs the wells do not bottom out at the same elevation, and one can thus infer the wellfield as a whole does not represent a single episode of occupation, but was repeatedly used over different times.[4] Given the clustered distribution of bottom elevations within the main excavation area, I would speculate that many of these particular wells were dug over a short period of time.

This situation is slightly different than that reported at Blackwater Locality No. 1, where "the wells all bottomed out in the same stratigraphic horizon and at nearly the same actual elevation indicat[ing] an essentially stable position in the water table throughout the period during which the wells were being dug" (Evans 1951:6). Evans (1951:6) concluded that the Blackwater wells had been "dug within a relatively short period of time." However, wells later recorded there bottomed out in several horizons (Hester 1972).

If the general pattern Evans reported holds, it may reflect differences in the hydrology of Blackwater and Mustang Springs (perhaps a confined aquifer at Blackwater), or differences in the duration of well use (with the Mustang Springs wellfield used repeatedly and over a longer period of time). It would be valuable to gain better data on the variation or lack thereof in well depth at Blackwater Locality No. 1, if possible, and at other sites, if found.

If artificial water wells were the main sources of water on the landscape, and if the groups who dug the wells at Mustang Springs were cycling through the site, traveling from water source to water source and not staying for significant lengths of time at any one, then one conclusion seems inescapable. *The Mustang Springs wellfield must not be unique.* There should be other wellfield sites in similar geological settings across the southern High Plains. There appears to have been one at Blackwater Locality No. 1, where a total of 19 wells have been reported (Evans 1951; Green 1962; Hester 1972). More almost certainly once existed there, but must have been destroyed in the commercial excavations of the site. Only single wells were reported from both Marks Beach and Rattlesnake Draw (Honea 1980; Smith et al. 1966). Where are the other wellfields, and why have so few been found?

Lost in the Dust?

The answer to these questions returns the discussion to the geological conditions that allowed well digging. It could take place only in those settings where the caprock has been removed enabling access (by hand-dug wells) to the underlying aquifer. Recent field studies along the draws of the southern High Plains, which have the greatest potential for providing such settings, indicate that these kinds of localities are rare and not closely spaced (Holliday 1990; Meltzer, unpublished data). That in itself suggests the distances traveled for water were great, an inference substantiated by the observation that the artifacts associated with the wellfield are worn heavily and recycled, and made of stone from sources in some cases at least 70 km distant.

The Mustang Springs wellfield shows how easy it is to miss the Altithermal. On the southern High Plains, an archaeological record of the Altithermal has the best chance of being preserved in the draws, but almost all early and middle Holocene surfaces in the draws are buried under meters of late and post-Altithermal aeolian and lacustrine deposits. This renders the Altithermal archaeologically invisible, often inaccessible, and usually encountered only by chance, as the discoveries at Mustang Springs and other sites attest. Thus, the very settings where one would expect to see a well-preserved Altithermal archaeological record are those settings where the archaeological record often is unseen. On the southern High Plains, geoarchaeological evidence suggests that the Altithermal is not absent, just unseen and largely unexamined.

SUMMARY AND CONCLUSIONS

On the southern High Plains of North America, there is little doubt that the Altithermal—as conceived by Antevs (1948)—occurred (roughly) when he said it did and was as extreme as he said it was. The paleoecological evidence from Mustang Springs and other sites on the southern High Plains (Holliday 1989a) testifies to a dry, bleak, windswept landscape. Beginning soon after 8000 B.P., lake levels at Mustang Springs began to fall, the water became more brackish and by 6800 B.P. disappeared altogether. Once the water table dropped below the surface, wind erosion scoured the dry lake bed, sculpting its surface.

Just how far the water table dropped, and the rate at which it fell, can be inferred from the stratigraphic evidence in concert with the archaeological evidence (also Haynes 1975:76–78). Together, that evidence bespeaks a decline of nearly 3 m, over a period of approximately 200 years (roughly 1.5 cm/yr). Those estimates, of course, are only as robust as the underlying assumptions, and will change if those assumptions are wrong. What will not change is the fact that these were harsh times on the southern High Plains.

It was onto the dry lake bed at Mustang Springs that human groups came. Antevs's Altithermal is no longer the blank page it once was. Well digging at Mustang Springs occurred in the midst of the Altithermal, with wells following a dropping water table. It took place later than the latest available radiocarbon date (6600 B.P.), but how much later is unknown. Given the fact the wells were all dug from the same surface, and none were dug from atop stratum 4 sediments, there is no reason to suspect it lasted that much longer.

Speculation, based on available evidence, suggests that well digging at Mustang Springs ceased around 6500 to 6000 B.P. There are a number of reasons why this might have occurred. Water tables at Mustang Springs simply may have dropped beyond the reach of hand-dug wells. Alternatively, perhaps more sources of water became available on the High Plains. There is evidence from other sites on the southern High Plains—but not from Mustang Springs—of a mid-Altithermal wet phase (Holliday 1989a), with a short-term increase in precipitation and available surface water. Such an increase had no appreciable impact on the water levels at Mustang Springs (given the very slow aquifer recharge rates), save that it might have made well digging unnecessary since surface water could be had elsewhere.

The wells testify to the fact that at times during the Altithermal and in certain places, there were hunter-gatherers in the region. It was not wholly abandoned although it remains an open question whether the site was occupied by foraging groups living on the southern High Plains, or collectors intermittently exploiting its resources. Regardless, the wells were the solution to the problem of obtaining water on the dry southern High Plains.

But how a wellfield figured into the larger adaptive strategies remains unresolved, as are the precise details of the adaptive response. The issues remain unresolved because of the generally poor preservation of organic materials that might inform on subsistence, and the apparent tendency of these groups to leave most of their artifacts on upland surfaces, which nearly 7,000 years later are shallow, deflated, and badly mixed (Collins 1971). Even so, the presence of a wellfield, which appears to have been dug over a period of time of at least 200 years, and perhaps even by different groups, suggests frequent settlement moves, which by the evidence from the lithic artifacts was over a range of at least 70 km.

More important, the apparent mobility on the part of these groups points directly to the fact that there must be other well sites that were used during this period. Blackwater Locality No. 1 was one. Why have so few other Altithermal well sites been found? The geology of Mustang Springs, which made this a predictable water source during the Altithermal, and that preserved the record of wells, makes the answer to that question obvious. Wedel (1983a:223–224) was correct. Many sites may still lie deeply buried by centuries and millennia of deposits, awaiting discovery and recognition.

What becomes crucial at this juncture is the development of ways to locate and systematically test these deeply buried, difficult-to-discover low spots in the draws that have the potential to yield Altithermal age materials. This will test the hypothesis that there were other wellfields, and perhaps even recover a greater artifact sample and preserved organic remains that might reveal the nature of the subsistence strategies.

Ultimately, what may prove to be truly remarkable is not the particular wellfield at Mustang Springs, but the number of sites that will be just like it.

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This one is for my sweet Emily, who spent the first two summers of her life at Mustang Springs, and Suzanne, who made that possible.

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NOTES

[1] Samples from Strata 2 through 4 were analyzed for pollen at SMU and Texas A&M University. The analysis at Texas A&M was undertaken after the SMU effort was unable to detect pollen. Despite additional precautions, pollen was still not found by the A&M team, but since *Lycopodium* spp. tracer spores were abundant, it seems apparent that the pollen was not destroyed during processing, but had not preserved in the sediments (John Jones and Vaughn Bryant, personal communication 1988). Poor pollen preservation, unfortunately, is common in the region (Bryant and Holloway 1983; Bryant and Schoenwetter 1987:39–40; Hall 1985:97–98; cf. Oldfield and Schoenwetter 1975).

[2] Notably, a radiocarbon date (SMU-1664) on sediment from the bottom of Well 81 (Trench 2), and the theremoluminescence (TL) dates on sediments 1 m higher in the profile but from the same depositional unit differed by 2,800 years. Taken together these dates implied that Well 81 was dug and initially began to fill around 7600 B.P. (as indicated by the radiocarbon date), and took the next 2,800 years to fill to the surface (as indicated by the TL dates at 4800 B.P.). There was no stratigraphic or sedimentological evidence to support a 2,800-year filling episode, implying either the radiocarbon date was too old or the TL dates were too young (Meltzer and Collins 1987:16). At the time, we suspected the radiocarbon date was too old, and favored the TL

dates (Meltzer and Collins 1987:17). Subsequent testing has indicated that the radiocarbon sample exhibited a high amount of fulvic acids, more in character with Stratum 2 sediments than Stratum 4 sediments, thus corroborating the suspicion of contamination by older sediments. The addition of a series of essentially consistent radiocarbon dates on Stratum 4 sediments now makes it clear that the TL dates are also too young.

[3] The wells would bottom out at the same surface, as long as the water table was not fluctuating rapidly. Also, I assume that wells were dug to just at or *below* the level of the water table (within, say, 10 cm), but not significantly lower, and that this always was true. While that assumption seems reasonable, it need not be the case, and if it is not, my discussion will require revision.

[4] Alternatively, this evidence could be interpreted as wells dug to different depths but which tapped water at the same level (violating the assumption made earlier). This would imply that the deepest well was dug down 2.17 m below the water table. While this might have produced a fine pool, it would had to have been dug under half a meter of standing water at the site. There is no evidence for that. Alternatively, they could represent the same episode of occupation during which time the water table fluctuated rapidly. This latter possibility is not quite so farfetched as the excruciatingly slow rate of aquifer recharge might imply. The site is in a valley bottom, and intense rainy episodes quickly could have raised the groundwater level in the valley fill, which then might have been tapped in shallower wells. The sheer number of wells at different depths suggests far more rainfall than is indicated by other lines of evidence. Neither of these possibilities seem, a priori, as likely as different episodes of occupation, but at this point neither can be dismissed entirely.

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