Prehistoric Water Wells on the Southern High Plains: Clues to Altithermal Climate

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Prehistoric water wells were recently discovered at the Mustang Springs site (41 MT 2), along Mustang Draw on the southern Llano Estacado in west Texas. Associated radiocarbon and thermoluminescence dates indicate these features were dug approximately 5000 b.p. (radiocarbon years). The dates help bracket the age of well-digging on the southern High Plains, which is known from only two other sites: Blackwater Locality No. 1 and Rattlesnake Draw, both in New Mexico. The presence of water wells, along with stratigraphic and sedimentological evidence, indicates a period of lowered water tables and extreme aridity, perhaps the regional manifestation of the Altithermal climatic stage. This episode of climatic stress must have had a significant impact on human adaptation to the southern High Plains during the middle Holocene, particularly given its effects on bison populations, the animal species on which the human groups depended. Bison populations appear to have been greatly reduced at this time, as a consequence of a lack of available water and a reduction of surface vegetation—evidenced respectively by these water wells and carbon isotope ratios in fossil bison remains.

While these middle-Holocene water wells are morphologically almost identical to those being dug on the southern High Plains by native American groups in the late 19th century, the analogy extends no further. In the more ancient instance, well-digging represents an adaptive response to protracted aridity; in the other, a tactical response to warfare on the southern High Plains.

Introduction

If prehistoric water wells should prove to have more than local distribution on the High Plains, a study of such wells might reveal information of great value to archaeologists, geologists and climatologists. . . . dateable water wells might prove a most dependable source of data on former levels of water table, which on the High Plains is a sensitive indicator of climate (Evans 1951: 8).

Prehistoric water wells were recently discovered at the Mustang Springs site (41 MT 2), along Mustang Draw on the southern Llano Estacado in west Texas. Such wells have been reported previously at two other sites on the southern High Plains: Blackwater Locality No. 1, New Mexico (Evans 1951; Green 1962; Hester 1972; Warnica 1966) and in Rattlesnake Draw, New Mexico (Smith, Runyon, and Agogino 1966). Stratigraphic evidence presented in these earlier studies suggested that the wells were dug during periods of extreme aridity, and the features were linked to the Altithermal stage of Antevs (1955).

However, at the time these studies were undertaken, techniques did not exist for directly dating the sediments that comprised the well features. Thus, these studies were done without the benefit of radiocarbon or other absolute dates on the well features themselves (or, for that matter, dated artifacts within the wells), but relied instead on intra- and inter-site stratigraphic correlation with other radiocarbon-dated artifacts or features.

In these earlier studies, too, inferences that the wells were dug during periods of climatic stress were based partly on stratigraphic evidence, which indicated that the wells had been dug from a wind-scoured, erosional sur-
face, but largely on what well-digging seemed to imply about local water tables. It was presumed that well-digging indicated lowered water tables which, in the flat, poorly drained southern High Plains, could only be the result of extreme aridity. This chain of reasoning is compelling, but with one possible weak link: water wells were dug on the southern High Plains by native American groups during a relatively moist period of the late 19th century, when water tables were near the surface and water flowed in various spring and lake sites. To argue that prehistoric water wells indicate lowered water tables and thus extreme aridity requires stratigraphic evidence of a net trend from wet (pond deposits) to dry (aeolian sediments), and the demonstration that the needs that prompted well digging in the prehistoric past were different from those of the historical period.

In this paper we discuss the prehistoric water wells at Mustang Springs, including the associated radiocarbon and thermoluminescence dates that allow these features to be dated with precision. While such dates are directly relevant only to the Mustang Springs wells, they do help bracket the age of well-digging on the southern High Plains. This discussion is followed by a summary of the morphology, stratigraphic context, presumed age, and distribution of other prehistoric wells on the southern High Plains. This summary highlights a significant difference in the selective forces that prompted well-digging in prehistoric versus historical times: in one case, well digging represents an adaptive response to protracted aridity; in the other, a tactical response to warfare on the southern High Plains.

The climatic stress manifested by prehistoric water wells has significant implications for middle-Holocene environments and human adaptation. This is discussed in the concluding section, with the focus on the apparent reduction of regional bison populations (Dillehay 1974; MacDonald 1981). The extreme aridity and absence of abundant surface water, inferred in part from the presence of water wells, must have had a serious impact on bison populations in the region and thus on the humans who hunted them.

Prehistoric Water Wells on the Llano Estacado

The Llano Estacado (Fig. 1) is a flat, nearly featureless portion of the southern High Plains some 82,000 sq km in area (Stafford 1981: 549). The Llano Estacado is occasionally interrupted by NW–SE trending stream valleys, along with playa lake basins and extensive dune formations (Holliday 1985b: 331). The surface features are Quaternary in age, with Pleistocene and Holocene deposits lying unconformably on bedrock of Tertiary, Permian, Triassic, and Cretaceous age (Evans and Meade 1945: 485). Although the area is semi-arid today (annual rainfall is roughly 38 to 45 cm), the valleys and playa lake basins provide mute testimony to the water that once flowed in the area.

Lack of water was a fact of life on the Llano Estacado, and even until the mid-19th century the area was likened to the “Great Zahara (sic),” to be avoided or entered cautiously (Haley 1952: 2). In October of 1849, Captain Randolph B. Marcy, on a return march from Santa Fe, New Mexico, while under orders to “ascertain and establish the best route from [Fort Smith, Arkansas] to New Mexico and California” (Marcy 1850: 169), encountered surface water at a site on the southern Llano Estacado he named Mustang Pond after “the numerous trails of mustangs leading to it” (Marcy 1850: 207). In the map that accompanied his report, Marcy labeled the site Mustang Springs, not Mustang Pond, and “Springs” it has remained to this day.

Marcy reasoned that the small lake would hold water in all seasons, as the “horse requires water every day [and] probably would not stay at a place where it could not be found at all times” (Marcy 1850: 207). Mustang Springs was used intermittently from that time onward, serving as a watering spot for army engineers surveying along the 32nd parallel for southern transcontinental railroad routes (Pope 1855), for buffalo hunters and the occasional settlers moving west, and for army companies on military maneuvers against groups of Comanche.

But even with the discovery of this and other natural water sources, in the 1870s the southern Llano Estacado remained “almost entirely unknown, except to Indians” because “scarcely any living water was known” (Shafer 1933 [original 1876]: 82). All travel across the area was restricted to the trails blazed by Marcy and Pope (Haley 1952: 228), with movement tied to the known spring and pond sites. How the Indian groups had managed to survive in the unknown and apparently uninhabitable portions of the plains was obscure until the Indian Wars of the mid-1870s, when army personnel out of Fort Concho (San Angelo, Texas) discovered numerous artificial water wells.

Lieutenant-Colonel William R. Shafer’s 1875 punitive expedition against Comanche groups on the southern Llano Estacado encountered 20 water wells at one site, 50 at another, and 60 wells at a third (in the 1930s, Hoffman [1936: 3] reported an artificial well still visible in the bottom of Ward Draw; it is unclear whether or not this locality is one of those observed by Shafer). The wells—often within a few m of one another—ranged in width from 1.2 m to 3.0 m, and in depth from 1.2 m to 4.5 m (Shafer 1933 [1876]: 91–93). Water at depths of greater than 1 m stood in the basins. The wells were situated in what Shafer (1933 [1876]: 91–92) described as “ravines” or “narrow valleys” (today’s “draws”) that
Figure 1. The Llano Estacado of west Texas and eastern New Mexico, showing the location of Mustang Springs (41 MT 2) and other sites discussed in the text.
extended NW and SE across the plains and produced sufficient water for "several thousand" horses or cattle.

These historical wells provide a useful analogy to the documented prehistoric features. But lest this analogy be drawn too readily, we would observe that these 19th-century wells were excavated during a relatively wet period, sandwiched between the droughts of the 1860s and 1880s (Bark 1978). We shall return to this point after a discussion of prehistoric wells on the Llano Estacado.

**Prehistoric Wells at Mustang Springs**

The archaeology and geology of the southern Llano Estacado are currently being investigated by the authors as part of a long-term project on Paleo-Indian adaptations. In the summer of 1985, testing was conducted along Mustang Draw in Martin and Midland counties, Texas (FIG. 1). Like all the draws on the Llano Estacado, this long, narrow, and shallow drainage was cut during wetter times. Today, Mustang Draw carries water only.
after the occasional heavy rainstorm, and then not for great distances, most water being lost by seepage or evaporation (Evans and Meade 1945: 486).

Archaeological debris is scattered up and down the length of Mustang Draw and is concentrated in a number of localities along it. One of those concentrations is at Marcy’s Mustang Springs (41 MT 2), where the nearby surfaces are littered with archaeological materials, some of which are Paleo-Indian in age, some as recent as a 19th-century ranch house (Stickney 1967).

The 1985 archaeological and geological testing of this area was prompted by the presence of Clovis archaeological material, as well as by considerable local lore telling of the discovery of large bones, presumably of Pleistocene megafauna, exposed by erosion in Mustang Draw near the springs. This, and diatomaceous earth recovered by excavations for a power pole, seemed to point to subsurface late Pleistocene or early Holocene-age pond deposits. The depth, thickness, and extent of subsurface deposits was unknown, however. Limited trenching with a backhoe was carried out in a portion of them to define their stratigraphy and relative age.

Three trenches were excavated in the floor of Mustang Draw perpendicular to its N-S trending axis (FIG. 2). The northernmost (Trench 1) encountered caliche bedrock at 80 cm below the surface. In a trench roughly 215 m south of the first (Trench 3), bedrock was encountered at 1.25 m in depth. In both of these trenches the sediments were probably the result of recent (within 2000 years) cut-and-fill episodes in this narrow, shallow section of the draw.

By contrast, in the southernmost trench (Trench 2), 77.5 m south of the second one, and approximately 7 m long, sediments were nearly 4 m deep, with bedrock not encountered. Extrapolating from the basal deposits, bedrock was probably within 1 m of the base of the trench (the depth of which was limited by the length of the backhoe arm). These trenches indicate that the subsurface bedrock drops significantly in a short linear distance, though precisely where and at what angle remains undetermined. Late Pleistocene and early Holocene pond deposits and underlying alluvial deposits approximately 2 m thick are preserved within this bedrock basin.

It was on the southern and eastern faces of Trench 2 that two prehistoric wells, within 1.5 m of each other, similar in morphology to those reported at Blackwater Locality No. 1 (Evans 1951; Green 1962; Hester 1972; Warnica 1966) and Rattlesnake Draw (Smith, Runyon, and Agogino 1966) were discovered. Well 1 was complete; Well 2 was apparently abandoned before completion.

The complete well (hereafter Well 1) was almost perfectly bisected by the backhoe trench (FIG. 3, left; FIG. 4). After discovery, a 1 m x 2 m excavation unit was opened above the remaining portion of the well, the overlying sediments excavated by hand, and all fill screened through 0.63-cm mesh (a portion of the well-fill was fine screened in water). No artifacts were found associated with the well or its fill.

Well 1 was dug in prehistoric times from an erosional land surface (the top of Stratum 3H in FIG. 3, left), now buried roughly 1.75 m below the modern surface. The irregular shape of the upper boundary of that stratum in the immediate vicinity of the well reflects the prehistoric backdirt pile. The well was dug using a simple digging stick, the marks of which were still visible on the walls, through 1.1 m of massive, extremely hard and compact diatomaceous silts and clays (Strata 3A-H) to an underlying sandy zone (Stratum 2) at a depth of 2.85 m below the modern surface. The well extended only 8 cm into this sandy zone, suggesting that that zone was water-bearing. It is ironic that until large-scale drilling and irrigation irreversibly lowered the water table in this area, this same sandy horizon was known by local ranchers and farmers as the “water-sand” and it was tapped in many late 19th- and early 20th-century wells.

Well 1 was 70 cm in diameter at the top, closing to 40 cm at the base, and included a notch at the top that was most likely intentional, perhaps some form of handhold. Notches, as well as abrupt, step-like benches were observed in a number of the larger Blackwater Locality No. 1 wells. These were interpreted as “steps or foot supports in climbing in and out of the wells” (Evans 1951: 5).

Well 1 at Mustang Springs was not backfilled by those who dug it originally. The backdirt that resulted from the prehistoric excavation was left in place, and the well filled naturally with windblown silts and sands. The lack of well-defined internal stratigraphy suggests the well filled shortly after use; the absence of plastered walls or laminae within the fill (see Gould 1977: 76) also indicates that, after filling, the well was not re-dug and reused (as is evident in certain of the wells at Blackwater Draw [Green 1962]). The walls of Well 1 were remarkably intact, reflecting both the hardness of the sediments through which it was dug and the short period of time the well lay exposed before being filled by aeolian material.

Well 2 (FIG. 3, right) at Mustang Springs measured only 30 cm wide at the top and 25 cm wide at the base. It was dug from the same erosional surface as Well 1 (the top of Stratum 3H), though it was only 32 cm deep, bottoming-out a few cm into the underlying stratum (3G). If the digging of Well 2 started at the same time as Well 1, then the former represents an abandoned effort, for it never reached the water-bearing sands of
Stratum 2. The size and irregular shape of Well 2 support the suggestion that it was abandoned before completion. It is conceivable, though less likely, that Well 2 had been completed and used, having been dug later (or earlier) than Well 1 when the water table had risen to the top of Stratum 3G. Supporting this possibility is the relatively wide and flat base of Well 2: it is not the conical shape one would expect were the well simply abandoned while being dug.

The stratigraphy and depositional units at Mustang Springs are detailed in Hill and Meltzer (1986). Here, only some general observations of the depositional processes will be made. The lowermost strata (1 and 2) appear to represent an episode of fluvial sedimentation in the draw. The basal sand and gravel is roughly 1 m thick. Judging by the sand grains, which are well-rounded and slightly frosted, and the underlying gravels (Stratum 1), which are well-rounded and range up to cobble size (the largest of which observed was 15 cm in diameter), this was a fairly high-energy stream.

Stratum 3 represents a series of ponding and marshy episodes, where water ceased to flow continuously down the draw but collected in topographic low spots within it. This stratum, over 1 m thick, accumulated with a water table in some cases standing on the surface, indicated by the presence of diatoms in a number of the units within the stratum. The lowermost of the units within this stratum (3A) is texturally a sandy mud; the remainder of the units (3B–3H) are silts. At times the water table was just below the surface, indicated by silicified root remains of two marsh plants, Juncaceae (rushes) and Cyperaceae (sedges), recovered from a cienaga, or marshy, unit within this deposit. Pollen was rare or absent in the units within Stratum 3, but did include Typha (cat-tail).

This moist period was followed by one of substantial aridity, indicated by the erosional unconformity marking the boundary between the uppermost unit in Stratum 3 (Unit 3H) and the overlying unit in Stratum 4 (Unit 4D). The top of Unit 3H has been eroded, presumably by wind (overlying 3H are aeolian sediments). At least some of the pond deposits once present in the draw have probably been lost.

Stratum 4, which is over 60 cm in thickness and lies
unconformably over Stratum 3, represents a period of massive aeolian deposition of silts that completely filled the wells. Within this deposit was a series of terrestrial and freshwater snails (Table 1). Of greatest interest are the freshwater species, *Fossaria dalli* and *Fossaria obrussa* (Family Lymnaeidae) that occur only as fossils in Texas, and the terrestrial genera *Succinea*. The latter is semi-amphibious, not necessarily living in water but generally close by (R. W. Fullington, personal communication, 1986). The habitats of these gastropods are ponds and still water, spring seeps, or the edges of lakes. They generally do not occur in flowing streams (and, conversely, no freshwater gastropod species common to stream beds were found in the fill). It is possible that the freshwater snails recovered in the fill had been re-deposited from the pond sediments, or perhaps that these species were living in the well during the time it was open.

Finally, Strata 5 through 7 are all sandy silts and represent recent aeolian, fluvial, and pedogenic processes in the draw. Unlike the other, lower strata of the Mustang Springs profile, these strata are also found in the shallower portions of this draw.

There are six radiocarbon and two thermoluminescence (TL) dates for the depositional units at Mustang Springs (Table 2). Samples for dating were taken from the Well 1 profile (see Fig. 3, left, for locations). All radiocarbon dates were determined by the Radiocarbon Laboratory of Southern Methodist University (SMU) on NaOH-soluble, HCl-insoluble (humic acid) fractions from organic carbon-rich deposits. Pretreatment included hand-sorting of the samples to remove contaminants and a series of chemical baths (HCl, NaOH, H₃PO₄) prior to combustion. All age calculations are based on a radiocarbon half-life of 5568 years, and corrected for ¹³C/¹²C fractionation.

TL dates were determined by Alpha Analytic, Inc. from two samples of windblown silts in Stratum 4. After removal of the outer layers of the sample, the remainder was disaggregated and treated with acids and peroxides to remove groundwater carbonates or humics that might create spurious signals. The 4- to 11-micron polyminer-alic particle-size fraction was then separated for multiple glow analysis. Dose rate was calculated from uranium, thorium, and potassium contents determined independently, with both samples producing very good internal agreement of R-Beta, Residual, and Regan dating techniques (J. Stipp, personal communication, March 1986).

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Table 1. Land and freshwater snails recovered from fill, Well 1, Mustang Springs (41 MT 2).

<table>
<thead>
<tr>
<th>Terrestrial Gastropods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pupillidae</td>
</tr>
<tr>
<td><em>Gastropoda procera</em></td>
</tr>
<tr>
<td><em>Gastropoda contracta</em></td>
</tr>
<tr>
<td><em>Pupoides albilabris</em></td>
</tr>
<tr>
<td>Succineidae</td>
</tr>
<tr>
<td><em>Succinea</em></td>
</tr>
<tr>
<td>Zonitidae</td>
</tr>
<tr>
<td><em>Hawaiiia minuscula</em></td>
</tr>
<tr>
<td><em>Zonitoides arbores</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Freshwater Gastropods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lymnaeidae</td>
</tr>
<tr>
<td><em>Fossaria dalli</em></td>
</tr>
<tr>
<td><em>Fossaria obrussa</em></td>
</tr>
</tbody>
</table>
Table 2. Radiocarbon (SMU) and thermoluminescence (ALPHA Analytic) dates for deposits at Mustang Springs (41 MT 2).

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Age (B.P.)</th>
<th>Lab No.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>140 ± 30</td>
<td>SMU-1589</td>
<td>Soil humates, from near surface; organic rich zone, perhaps representing recent grass fire.</td>
</tr>
<tr>
<td>5</td>
<td>1,970 ± 30</td>
<td>SMU-1588</td>
<td>Soil humates, from recent alluvial fill in draw. Stratum covering aeolian fill.</td>
</tr>
<tr>
<td>4D</td>
<td>4,720 ± 900</td>
<td>ALPHA-2843</td>
<td>Sample from aeolian sediments deposited on surface through which well was cut. Same depth, but 1.5 m east of ALPHA-2842.</td>
</tr>
<tr>
<td>4D</td>
<td>5,000 ± 1,200</td>
<td>ALPHA-2842</td>
<td>Same depositional unit and depth, but 1.5 m west of ALPHA-2843.</td>
</tr>
<tr>
<td>4A</td>
<td>7,620 ± 50</td>
<td>SMU-1664</td>
<td>Soil humates, sediments from aeolian fill in base of Well 1.</td>
</tr>
<tr>
<td>3G</td>
<td>8,260 ± 50</td>
<td>SMU-1587</td>
<td>Soil humates, from diatomaceous pond deposits.</td>
</tr>
<tr>
<td>3E</td>
<td>9,650 ± 60</td>
<td>SMU-1586</td>
<td>Soil humates, from diatomaceous pond deposits.</td>
</tr>
<tr>
<td>3A</td>
<td>10,130 ± 30</td>
<td>SMU-1585</td>
<td>Soil humates, from diatomaceous pond deposits.</td>
</tr>
</tbody>
</table>

All TL date calculations assume a water content of 75 ± 25% of saturation.

The dates indicate that slackwater pond or lake deposits (Stratum 3) filled this basin from latest Pleistocene times (ca. 10,000 b.p.) until at least 8260 b.p. (radiocarbon years). There is no evidence of any erosional disconformity within this lacustrine unit (Stratum 3), suggesting the basin essentially held water continuously during the first few millennia of the Holocene.

While the 8260 b.p. date marks our final age determination on the pre-Alithermal pond deposits, we would hasten to observe that this age does not mark the end of the moist period and the onset of drier conditions. For not only was the 8260 b.p. date run on the penultimate deposit in this unit (and thus not the youngest of the pond deposits), but the surface of stratum 3H (the contact between 3H and 4D) was wind-scoured, implying that an unknown amount of even younger pond deposits may have been removed.

The 8260 b.p. date provides at best a maximum estimate for the onset of drier conditions. Determining a minimum age is complicated by the radiocarbon and thermoluminescence dates on Strata 4A and 4D. Despite the fact that these dates are in correct stratigraphic relation to each other and to the Stratum 3 dates, an anomaly exists. The Stratum 4A and 4D dates, taken together, suggest that the well was dug around 7600 b.p., but did not backfill until ca. 4800 b.p. This scenario is troubling for a number of reasons. Analysis of the sediments in Stratum 4 indicates that this unit represents a single depositional event that took place over a relatively brief period of time; it lacks pronounced stratification, horizonation, or detritus from having been left exposed. There is no evidence for long-term (nearly 3000-year) sediment accumulation, episodes of deposition separated by long periods lacking deposition, or use and reuse of the well over a long period of time.

This evidence, in turn, suggests that either the TL dates on Stratum 4D are too young or the radiocarbon date from 4A is too old. The two thermoluminescence dates, run on independent samples at the same depth, though separated horizontally by 1.5 m, are statistically identical ($t = .1866$) and thus appear reliable. They indicate that by roughly 4820 b.p. (the average of the two dates) this portion of the profile was covered with windblown sediments.

In contrast, there are a number of reasons to view the radiocarbon date from Stratum 4A (SMU-1664) with some suspicion, the most important of which is that the sample had a very high humate content, unexpected for
an aeolian deposit and similar to that in the Stratum 3 samples. Given the position of Stratum 4A, there is a strong possibility of humate contamination by horizontal water movement from the surrounding and older Stratum 3 sediments, or by aeolian redeposition of Unit 3H into the well.

For these reasons, and because of the relative lack of erosion between the time the wells were filled and the time when they were buried beneath later sediments (evidenced by relatively intact backdirt piles surrounding the well and the remarkable preservation of the well interior), we favor the TL dates as indicating that the Mustang Springs wells were dug around 5000 b.p.

**Prehistoric Wells at Blackwater Locality No. 1**

Since 1951, some 19 prehistoric water wells have been reported, and hints of others detected, in the various excavations at Blackwater Locality No. 1, New Mexico (Evans 1951; Green 1962; Hester 1972; Warnaica 1966). The stratigraphic position of these wells was similar but not identical across the site; save, perhaps, one noted by Hester (1972: 86), all appear to have been dug from the same buried erosional surface. In the current stratigraphic scheme, this is the top of Unit E, or the Carbonaceous Silt (Haynes 1975: table 4.1 provides a correlation of the different schemes used at Blackwater Draw). All wells were dug through Unit D (the Diatomaceous Earth zone). The wells reported by Hester (1972: 82, 86–87) bottom out in Unit C (the Brown Sand Wedge); those reported by Evans (1951) and Green (1962) bottom out stratigraphically lower (though not necessarily topographically lower) in the late Pleistocene deposits of Bed A (Bedrock Sand and Gravels).

If there is variation in the base level of these wells (which in the absence of absolute elevations cannot be demonstrated), this indicates a shifting water table and thus, presumably, different times at which the wells were dug. It is difficult to determine, nonetheless, whether or not shallower wells indicate a dropping water table (and thus the beginning of a drying period), a rising water table (marking the end of a drying period), or simply seasonal fluctuation in water tables confined to the valley fill.

These wells ranged in depth from 1.5 m to 2.0 m. Width varied from 75 cm to 1.5 m at the top to between 30 cm and 1.2 m at the base (Evans 1951: 5; Green 1962: 231). Well walls varied from vertical through stepped to steeply inclined. No artifacts were found in the well fills or on the surface from which they were dug (Evans 1951: 6; Green 1962: 232).

All of the wells examined by Evans (1951) had been refilled, probably by the original excavators, shortly after their use. There were no backdirt piles surrounding any of the wells, and the fill comprised large diatomaceous earth blocks removed when the well was dug. There was only minor evidence of weathering or caving of the sides, and there was no evidence of settling in the base of the well (Evans 1951: 5). What motivated this refill—whether fear of drying, contamination, or use by enemies—is unknown (Evans 1951: 5). Green (1962) reported that backfilling was not always permanent: two of the wells had a lining of red clay, perhaps the result of efforts to plaster side walls of reused wells to prevent caving of poorly consolidated sediments (Green 1962: 232).

The blocks of diatomaceous earth in the well fill reveal that the wells were dug in a process not unlike cutting turf blocks. A circle was cut through the massive clay and diatomaceous earth layer down to the underlying sand. This easily-removed sand was then scooped out, and the block of diatomite lifted (Evans 1951: 6). There were no tools or tool markings found in any of the wells.

Based on the presumed age of the bracketing strata, Evans inferred that the wells were “considerably later than the Folsom and other early archaeological horizons, and probably considerably earlier than the late Prehistoric Indian horizons of the region” (Evans 1951: 8). They had been dug following “a long period of time in relatively arid climatic conditions,” as evidenced by a substantial (2.5 m to 3 m) drop in the water table and the deep erosion into the lake sediments (Units C–E). The “only minor” additional erosion between the time when the wells were filled and the time they were buried beneath later sediments (Unit F, the Jointed Sand) placed well-digging “near the end of the local erosional activity” (Evans 1951: 7).

A decade later, Green (1962: 233–234) interpreted the erosional disconformity separating Units E and F as representing the entire Altithermal stage of Antevs (1955). Green then adopted Antevs’ ages for the Altithermal, concluding that the uppermost portion of Unit E had an age of greater than 7500 years and Unit F an age of less than 4000 years. Following Evans’ (1951) argument that the wells were dug near the end of this erosional period, Green narrowed the estimated age of the wells to “somewhere between 4000 and 5000 years ago” (Green 1962: 234).

At the time Green wrote this, there were three radiocarbon dates available for relevant depositional units at Blackwater Locality No. 1 (Table 3, lab numbers O-157, O-169, O-170), but he dismissed these as either too young or too old, based on his assignment of an Altithermal age to the wells. There have since been other radiocarbon dates determined for the site (Table 3), but none appear to have been derived in direct association

<table>
<thead>
<tr>
<th>Unit*</th>
<th>Age (B.P.)</th>
<th>Lab No.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>4,950 ± 150</td>
<td>O-157</td>
<td>Charred bison bone</td>
</tr>
<tr>
<td>E</td>
<td>4,885 ± 90</td>
<td>SI-4585</td>
<td>Soil humates</td>
</tr>
<tr>
<td></td>
<td>6,230 ± 150</td>
<td>O-170</td>
<td>Charred bison bone</td>
</tr>
<tr>
<td></td>
<td>6,300 ± 150</td>
<td>O-169</td>
<td>Uncharred bison bone</td>
</tr>
<tr>
<td></td>
<td>8,560 ± 350</td>
<td>A-512</td>
<td>Charred bison bone, fractionation corrected</td>
</tr>
<tr>
<td></td>
<td>9,890 ± 290</td>
<td>A-489</td>
<td>Carbonized plants</td>
</tr>
<tr>
<td>D</td>
<td>9,900 ± 320</td>
<td>A-379</td>
<td>Carbonized plants</td>
</tr>
<tr>
<td></td>
<td>10,600 ± 320</td>
<td>A-380</td>
<td>Carbonized plants</td>
</tr>
<tr>
<td></td>
<td>10,490 ± 900</td>
<td>A-386</td>
<td>Carbonized plants</td>
</tr>
<tr>
<td></td>
<td>10,170 ± 250</td>
<td>A-488</td>
<td>Carbonized plants</td>
</tr>
<tr>
<td></td>
<td>10,490 ± 200</td>
<td>A-492</td>
<td>Carbonized plants</td>
</tr>
<tr>
<td>C</td>
<td>11,630 ± 400</td>
<td>A-491</td>
<td>Carbonized plants</td>
</tr>
<tr>
<td></td>
<td>11,170 ± 360</td>
<td>A-481</td>
<td>Plant remains in <em>Mammuthus</em> skull</td>
</tr>
<tr>
<td></td>
<td>11,040 ± 500</td>
<td>A-490</td>
<td>Carbonized plants</td>
</tr>
</tbody>
</table>

*Unit F = Jointed Sand; Unit E = Carbonaceous Silt; Unit D = Diatomaceous Earth; Unit C = Brown Sand Wedge.

with a well feature. Thus, these dates only provide general ages for the broad depositional units at the site.

There is still only a single radiocarbon date for the Jointed Sand (Unit F): 4950 ± 150 (O-157), run on burned bison bone. There is a discrepancy, however, in the descriptions of the location of the dated sample in the Jointed Sand unit. Wendorf and Krieger (1959: 77) place the source of the sample in the “Upper Jointed Sand,” while Hester (1972: 175) assigns it to the base of the Jointed Sand. Green (1962: 234) argued that if the former were correct, then the date seemed “slightly excessive,” insofar as it implied a greater age for the termination of the Altithermal than he thought likely. Haynes (1968: 621), however, suggested that the date was too young. The recent determination from the top of Unit E indicates that “O-157 is reliable” (Holliday 1985d: 393).

There are five radiocarbon dates available for the Carbonaceous Silt (Unit E). Wendorf (1961a: 117, 1961b: 134) feels that the two Humble Oil dates on bison bone (O-169 and O-170) “appear to be about 1,000 years too recent,” given radiocarbon ages of similar artifact assemblages at the Horner and Allen sites (Wendorf 1961b: 134; see also Hester 1972: 174). Green (1962: 233) feels the radiocarbon dates are too young by at least 1,500 years, since they do not conform with Antevs’ estimate of the age of the Altithermal. The stratigraphic position of these dates is unknown.

There are two dates on samples recovered at the top of Unit E. One (SI-4585) is from the top of the A horizon in Unit E (Holliday 1985d: 391); the other (A-512) was on burned bone from a fireplace “at the eroded contact between the Carbonaceous Silt (Unit E) and Jointed Sand (Unit F)” (Haynes, Damon, and Grey 1966: 13). It is unknown whether the fireplace was on a buried erosional surface or exposed by erosion before the deposition of Unit F (Haynes et al. 1967: 14). The age difference between SI-4585 and A-512 likely results because the samples were collected on different sides of this complex basin, and thus reflect variation in erosion/deposition that took place across the basin along the top of Unit E (Vance T. Holliday, personal communication, 1986). Determination A-489, stratigraphically lower than A-512, was run on humates and soluble lignins extracted from plant materials in the Carbonaceous Silt.

Since the location of the radiocarbon samples cannot be related to the location of the Blackwater Locality No. 1 wells with precision, we can only bracket the age of those wells between approximately 5000 and 8500 b.p. A maximum age for the onset of drier, erosional conditions is roughly 8500 b.p. (Holliday 1985d: 391; Stafford 1981: 551, 1984: 44–45). Green (1962) and Evans’ (1951) observations that the wells were dug at the very end of the period of aridity would imply that the true age is closer to the younger date. This, in turn, suggests that the Blackwater Locality No. 1 wells dug to shallower horizons (Hester 1972: 82, 86–87) reflect a water table on the rise.

A Prehistoric Well at Rattlesnake Draw

The other discovery of a prehistoric well on the southern High Plains (but just off the edge of the Llano Estacado) occurred during the archaeological study of Rattlesnake Draw (FIG. 1), Lea County, New Mexico (Smith, Runyon, and Agogino 1966). Fieldwork concentrated on a playa lake deposit, around which were found materials of Clovis though Archaic age. Testing in the former lake basin revealed an almost perfectly circular “disconformity,” some 76 cm in diameter. A vertical cross-section showed a well similar in morphology to those described at Blackwater Locality No. 1. During excavation of the well, four artifacts (three flakes and a stick of red ochre) were recovered, along with the lumbar vertebra of a bear (Smith, Runyon, and Agogino 1966: 304).

The stratigraphic situation of the prehistoric well at Rattlesnake Draw is roughly similar to those at Black-
water Locality No. 1. When dug in prehistoric times the well was cut through a Pleistocene lake formation roughly 1 m thick, an underlying “anhydrous quartz zone,” and into a basal zone of alluvial sediments derived from erosion of the Ogallala formation. The well was capped—and presumably filled—by a sand layer some 15–20 cm in thickness (Smith, Runyon, and Agogino 1966: 305).

Faunal remains, freshwater snails, and alluvium all date the lake deposit to the Pleistocene. The absence of plant material and land snails, along with the presence of well-rounded quartz grains, led to the inference that the well-capping sand was deposited during the Altithermal. Smith, Runyon, and Agogino (1966: 306) therefore concluded that the Rattlesnake Draw well was excavated “at about 5000 B.C.” (emphasis ours), suggesting it was dug at the onset of the Altithermal period.

Wells and Water Tables

The mere presence of these water wells—the fact that people had to dig “artificial wells in an attempt to improve their dwindling water supply” (Smith, Runyon, and Agogino 1966: 303)—indicates substantial aridity on the Llano Estacado during the middle Holocene. The wells provide unmistakable evidence that at the time they were dug the water table had dropped considerably, and occurrences of surface water and perhaps even spring sites were substantially reduced.

The wells at Blackwater Locality No. 1 indicate that the valley water table, which at 10,000 b.p. stood near the top of Unit D, had dropped some 2.5 m to 3 m by 5000 b.p. (Haynes 1975: 76, fig. 4.9). The wells at Rattlesnake Draw and Mustang Springs indicate a water table drop of at least 1 m over a shorter time. These are, again, minimum estimates since the surfaces from which these wells were dug show considerable wind-scouring and erosion, and thus the rate and amount of the drop may have been even greater.

As Evans (1951: 7) has argued, a drop of 1 m to 3 m in the water table in an area as remarkably flat, undissected, and feebly drained as the Llano Estacado can likely only result from extremely dry climatic conditions.

Roughly (though not precisely) synchronous, regional aridity is evidenced by 1) the distribution of the wells in the NW and SE corners and just off the SW edge of the Llano Estacado; 2) the corresponding depositional and erosional episodes at each of the sites; 3) an overlap in radiocarbon ages (where available); and 4) the observation that all the wells appear to have been dug from a wind-scoured erosional surface (see also the region-wide changes in the timing of erosion and deposition: Haynes 1968; Holliday 1985c; Holliday and Johnson 1986).

The argument that middle-Holocene-age wells indicate a drop in water table and thus a period of protracted aridity may at first glance seem contradicted by the fact that wells were also dug on the southern High Plains in the late 19th century during a relatively moist period (Bark 1978). But middle-Holocene and late 19th-century wells differ in one very important respect, which clearly demonstrates that well-digging in the earlier case was prompted by aridity and a lowered water table, while in more recent times it was carried out primarily for nonclimatic reasons.

None of the wells seen by Shafer in 1875 were found at springs or lakes. Instead, the wells had been dug in isolated areas far from natural water sources. Shafer records that in one area where wells were discovered, he examined the draw “for several miles each way without finding any other water” (Shafer 1933 [1876]: 91). He does not record any wells at Mustang Springs, where spring water flowed “in great abundance, [with] hundreds of buffalo watering at [the site] daily, [and] not exhausting [it]” (Shafer 1933 [1876]: 91). In late 19th-century times surface water was readily available.

But then why did Comanches and other native groups dig wells when springs and lakes were within a couple of days’ walk? The location of these wells provides a clue. With Euro-American expansion onto the Llano Estacado in the late 19th century, water became a competitive resource, one to which safe access could not be guaranteed. Shafer’s troops, among others, marched from spring to spring, under orders to attack any Comanche groups encountered on the march or at those sites. As later related by a captive among the Comanche during the 1870s, the army presence was pervasive: “we came back into the plains only to find soldiers camped at every watering place” (Jones 1976 [original 1899]: 179). Obviously, with United States Army troop movement centered around spring sites, native American peoples had to satisfy their water needs far from the springs and lakes, and this they accomplished by digging wells in otherwise uninhabitable areas. Well-digging on the Llano Estacado in the late 19th century was not prompted by a deteriorating climate but was an adaptive response by native American groups to water their stock and themselves without risk of deadly confrontation with armed troops.

In marked contrast, middle-Holocene wells were dug at springs and lake sites. But why expend the considerable effort to dig a well through over 1 m of massive, compact, and hard diatomaceous silts using only a sharpened stick if springs were flowing scarcely 50 m away? The answer is simply that in middle-Holocene times the water table had dropped and the springs had ceased flowing. Spring and surface water was unavailable; water could be had only by digging.
These points considered, we would conclude that well-digging in the middle Holocene was prompted by extreme aridity and reflects lowered water tables. In contrast, well-digging by native peoples in the late 19th century was prompted by strategic avoidance of spring sites and the United States Army units that frequented them.

The Altithermal and Human Adaptation on the Llano Estacado

The arid climatic conditions of the middle Holocene had a profound impact on the environment of the Llano Estacado, as evident in the stratigraphic, floral, faunal, and archaeological records. During the earlier full glacial period, the Llano Estacado had been covered by a mixture of savannas and scrub grasslands (Bryant and Holloway 1985: 47; see Oldfield and Schoenwetter 1975). The fauna was diverse and included a series of extinct mammals, many extralimital “boreal” forms (whose modern Plains distribution is now restricted to areas at higher elevations or substantially north of west Texas) as well as many water-dwelling species, including muskrat, and a variety of turtles, ducks, and fish (Johnson 1974, 1983: table 6; Slaughter 1975; Wendorf 1961a). Surface water stood in the many thousands of playa lakes that now dot the Plains (Evans and Meade 1945; C. C. Reeves 1966a, 1966b). Precipitation was perhaps twice that of the present, along with at least a 25% reduction in evaporation (C. C. Reeves 1966a: 288, 1966b: 646).

Full glacial conditions were substantially cooler and wetter than the present, but in late glacial times these conditions gradually began to deteriorate. There was a reduction of arboreal pollen concurrent with an increase in non-arboreal pollen, including grass, compositae, and Ephedra, indicating a gradual loss of parkland areas and replacement by open grassland (Hafsten 1961; Bryant and Holloway 1985: 50–52). Extinction of megafaunal species was complete by 10,500 b.p. (Meltzer and Mead 1985), accompanied by the dissolution of Pleistocene mammalian communities and the disappearance of many woodland or wet-environment vertebrate and invertebrate forms (Johnson 1983: 90–91).

By the terminal Pleistocene, most of the pluvial lakes had dried, and surface water became restricted to those lake basins or topographic low spots—such as the basin in Mustang Draw—where near-surface or perched water tables and springs combined to exceed yearly evaporation (C. C. Reeves 1976: 227; see also Haynes 1984). This drying process marked the beginning of a protracted period of aridity which by middle Holocene times manifested itself as extremely hot and dry climatic conditions, called by Antevs (1955) the Altithermal. Antevs saw evidence for the “Altithermal [or] so-called Long Drought” in the “maxima of grass-chenopod-composite pollens, low lake levels, wind erosion, dunes, arroyo cutting, and calichification in practically the same area” at roughly the same period in time (Antevs 1955: 320).

He inferred that Altithermal conditions extended across the west, including the Llano Estacado (his discussion relied in part on the work of Evans and Meade [1945]). Antevs argued that since modern moisture conditions in the American Southwest are greatly dependent on evaporation and thus on temperature, Altithermal conditions probably reflected “temperature[s] of a distinctly higher level than prevails at present” (Antevs 1955: 328). The age of the Altithermal was extrapolated by long distance correlation:

... the long drought began about 7500 b.p. according to Frie's temperature graph [based on vegetation changes in southern Sweden]. It ended 4000 years ago as calculated from the salt content half a century ago of Albert, Sumner [Oregon], and Owens [California] lakes and as estimated from the temperature graph (Antevs 1955: 329).

The Altithermal has been controversial since it was proposed, not because its existence is doubted (though see Martin 1963, 1975; Martin and Mahringer 1965; B. Reeves 1973) but primarily because its geographic extent, timing, severity, causes, and consequences have been difficult for archaeologists, geologists, and paleoecologists to pin down. Indeed, it is unclear whether the climatic changes of the Altithermal were a result of increased temperature and evaporation, decreased moisture, or (most likely) complex seasonal shifts in both of these conditions (C. C. Reeves 1976: 227; Wells 1970: 195).

Such arguments notwithstanding, there are local manifestations of this climatic episode on the Llano Estacado and southern High Plains. A middle-Holocene, presumably drought-induced, erosional unconformity occurs throughout this region, as has long been known (Albritton and Bryan 1939: 1462–1467; Bryan and Albritton 1942: 1415; Evans 1951: 4; Evans and Meade 1945: 498–499; Huffman and Albritton 1941: 336–338; Judson 1953: 63–64; see also Haynes 1968: 607). There is, in addition, a substantial record of middle-Holocene aeolian deposition on the Llano Estacado (this paper; Johnson and Holliday 1986).

The timing of these events varies, but they mark an overall decrease in effective precipitation, which probably reflects a general warming trend (Johnson and Holliday 1986) and dropping water tables accompanied by weathering of sediments and arroyo cutting (Haynes 1968: 612–614; Holliday 1985e: 1491–1492; Stafford 1984: 133). The “Jointed Sand” (Unit F) at Blackwater Locality No. 1, Strata 3 and 4B at Lubbock Lake (Hol-
liday 1985c: 946, 1985e: 1491; Stafford 1984: 71), and Stratum 4 at Mustang Springs mark these episodes.

Pollen evidence for middle Holocene vegetation on the Llano Estacado is understandably scarce (e.g., Hafstcn 1961; Oldfield 1975; Oldfield and Schoenwetter 1975; Schoenwetter 1975; see summary in Bryant and Holloway 1985: 56–60). This period was marked by a continued decrease in parkland areas and the emergence of a “dry steppe environment dominated by grasses mixed with chenopods, composites, Artemesia, and Ephedra” (Bryant and Holloway 1985: 56; see Hafstcn 1961: 91 and Schoenwetter 1975: 116). Unfortunately, identification of the grasses did not reach the generic or specific level (Hafstcn 1961: 73–74; Oldfield 1975: 130).

The faunal record for the Altithermal is equally sketchy. Following the extinction of the large Pleistocene grazers who once frequented this area, the Holocene fauna of the southern High Plains came to be dominated by a single large mammal (bison), although it included many smaller herbivorous and carnivorous species as well (Guthrie 1980; Johnson 1983: table 6).

During the early Holocene human groups on the southern High Plains focused their subsistence strategies predominantly on the exploitation of bison, though they occasionally utilized deer, antelope, and other animals (Collins 1971: 97). Bison remains occur at a number of early Holocene Paleo-Indian sites on the Llano Estacado (fig. 1), such as Blackwater Locality No. 1 (Hester 1972), Lubbock Lake (Johnson 1978), Milnesand (Sellards 1955), Plainview (Sellards, Evans, and Meade 1947), Rex Rodgers (Spee 1978), San Jon (Judson 1953; Roberts 1942), and Schraber (Wendorf et al. 1955; Wendorf and Krieger 1959). Bison remains also occur in a few sites just off the Llano Estacado: Lake Theo (Harrison and Killen 1978), Lipscomb (Schultz 1943), and Lone Wolf Creek (Cook 1925).

Several authors argue that bison were reduced in number or were absent on the plains during much of the Altithermal period (Dillehay 1974; MacDonald 1981), an idea first proposed in the late 1950s as an explanation for an apparent cultural hiatus in the northern Plains (Frison 1978: 20).

B. Reeves has countered this argument by claiming that any cultural hiatus is more apparent than real, the result of few sites having been tested in the true shortgrass environment and geological processes that have destroyed or deeply buried the Altithermal archaeological record (B. Reeves 1973: 1231–1243). He has, in addition, argued from historic analogues that Altithermal shortgrass plains “were not reduced to a hot, dry desert incapable of supporting a viable bison population” (B. Reeves 1973: 1231). Instead, these plains actually expanded, compensating for any loss in carrying capacity by an increase in area, with the net result that bison populations “may have exceeded that of any subsequent time” (B. Reeves 1973: 1228).

An additional decade of work has failed to substantiate Reeves’ claim that the “cultural hiatus” in the record is merely a sampling phenomenon. In the northern Plains, even in cases of favorable deposition and preservation, the Early Plains Archaic is rare or missing entirely (Frison 1978: 371). On the Llano Estacado there is evidence of Early and Middle Archaic occupations at Lubbock Lake (Johnson and Holliday 1986), but since surface water was present there throughout this time (though occasionally brackish) the site may be unusual. In their review of Archaic occupations on the Llano Estacado, Johnson and Holliday (1986) note only two other sites having occupations of this age.

Moreover, the historically-derived inference that grasslands expanded during this time is probably erroneous. Altithermal climatic changes occurred on an order of magnitude far greater than any historic drought (Reher 1977: 28), and certainly the widespread middle-Holocene erosional surfaces and aeolian deposition indicate sparser ground-cover and greater drought-related erosion and deposition than recorded historically. The middle-Holocene evolution toward the smaller Bison bison (Reher 1977: 31) and the unusually heavy and irregular wear in bison teeth of this age (Johnson and Holliday 1986) document an environment “not too favorable for the propagation of bison herds” (Frison 1978: 201).

Variation in the abundance of bison populations through the early and middle Holocene appears to bear this out. Based on an examination of bison remains in 160 archaeological and paleontological sites on the southern Plains (Texas, Oklahoma, and New Mexico), Dillehay concluded that bison were present on the southern Plains between 12,000 and 8000–7000 b.p., but were absent between 8000–7000 and 4500 b.p. (Dillehay 1974: 181). MacDonald (1981) mapped radiocarbon-dated bison remains from archaeological and paleontological sites over the entire plains area (Alberta to Texas) and reached a similar conclusion. During the period between 11,000 and 9500 b.p., bison populations were relatively small and confined to a minimum range; after 9500 b.p., bison range and population increased dramatically, as they spread onto the expanding grasslands (MacDonald 1981: 249–250). The onset of the Altithermal and the dessication of the southern Plains led to a northward and eastward shift of the bison range, and to the animals being “virtually eliminated” from the southern and central Plains (MacDonald 1981: 250, figs. 99–101).

There are certain biases coincident with these studies, whose main conclusions are based on the absence of
evidence (and not on evidence of absence). There are potential problems with the dating, which in Dillehay’s (1974) case relies heavily on grossly-dated projectile point styles and in MacDonald’s study assumes that the radiocarbon record provides a “representative sampling of potentially datable sites” (MacDonald 1981: 244). And there are questions of sample representativeness. In the Llano Estacado portion of the southern Plains, for example, Dillehay lists only five sites that date between 12,000 and 8000–7000 b.p., and all have bison. Three sites date to the later “Absence” period (8000–7000 to 4500 b.p.), and all (Blackwater Draw Locality No. 1, Lubbock Lake, and San Jon) have bison. Clearly bison are present in the latter period, and while it appears they occur in lower frequencies that remains an open question.

But possible sampling and analytic problems aside, these studies together hint at a significant reduction in bison numbers across the southern Plains during the middle Holocene. Dillehay attributes that drop to “desiccation of the grasslands as a food source” (1974: 185), whereas MacDonald (1981: 250) attributes it to a reduction in carrying capacity.

Evidence gathered in this paper and in recent analyses by Stafford (1984) may shed some light on the cause of bison reduction. While there is a discrepancy in historical accounts regarding the water needs of bison (Roe 1970), all commentators agree that bison require water on a regular basis—how regular varying from “almost daily” (Van Dyne et al. 1980: 334) to at least every few days (Dary 1974: 32; Roe 1970: 105–112). Even in historical times bison did not venture onto extremely dry portions of the Llano Estacado; the site of Mustang Springs marks one of the westernmost limits of the range (Shafter 1933 [1876]: 93). Prehistoric water wells document a significant drop in the water table and the disappearance of spring and lake sites. This must have had a detrimental effect on bison who, unlike the human populations, could not dig wells.

Moreover, drought-produced erosion and dormancy of the vegetation would have had an equally adverse impact, either through the reduction of all food sources (massive aeolian deposition appears to indicate that much of the surface was considerably thinned of vegetation) or, perhaps, the selective reduction of certain preferred foods.

Studies on the feeding habits of modern bison have documented that their diet was composed of approximately 80% warm-season grasses (Peden 1976: 228), which have maximum growth during the summer months but furnish high-quality nutrients well into the autumn and provide good winter range (Guthrie 1980: 68; Speth 1983: 139). This dietary preference has co-evolved with the expanding Plains grasslands (Guthrie 1980: 67; Wells 1970), as is evident in the steady increase in the percentage of warm-season grasses in bison diet over the last 10,000 years (Stafford 1984: 116–118).

Increased diet selectivity on warm-season grasses, however, carries certain liabilities. Such grasses are more resistant to high evaporation and dryness than cool-season grasses (Stowe and Terry 1978: 618; Waller and Lewis 1979: 14) but are adversely affected by certain drought conditions, notably reduction of rainfall during their peak growing season of the summer months. Such drought conditions occurred between 1933 and 1939, when annual precipitation dropped nearly 18 cm below average, with most of the deficit occurring during the summer months (Weaver and Albertson 1956: 86–87).

During this historical drought warm-season grasses, notably buffalo and blue grama grass, the prime constituents of modern bison diets (Peden 1976: 228), were substantially reduced (Weaver and Albertson 1956: 79, 93). Basal cover of these two species, which exceeded 85% prior to the onset of drought conditions, dropped to 17% after the drought (Tomanek and Hulett 1970: 208).

If the Altithermal drought conditions were also characterized by summer rather than winter rainfall reduction, this suggests that the reduction of bison populations on the Plains was partly a result of drought conditions that reduced summer rainfall and also, therefore, preferred food sources. If this hypothesis is correct, during Altithermal times there should be a temporary reversal in the overall Holocene trend toward increasing dominance of warm-season grasses in bison diets.

This hypothesis can be readily tested in the fossil record utilizing bison bone carbon-isotope data. The warm-season grasses that dominate modern bison diet and the contemporary southern High Plains have a characteristic photosynthetic pathway, in which CO₂ is initially incorporated in 4-carbon compounds (such as malic, aspartic, or oxaloacetic acid) prior to transfer to sugars. Plants sharing this pathway are labelled C₄ plants and differ anatomically and isotopically from cool-season plants whose photosynthetic pathway involves production of a 3-carbon compound (C₃ plants) and those succulents whose pathway involves crassulacean acid metabolism (CAM plants). This variability in photosynthetic pathways is manifest in different photosynthetic rates and products, leaf anatomy, and, most important for this study, carbon isotope discrimination (Waller and Lewis 1979: 12–13).

These three different pathways differ in the degree to which they fractionate against ¹³C, which in turn produces different carbon isotope ratios (¹³C/¹²C) in plant tissue. Since the isotopic composition of an animal mirrors the isotopic composition of its food source (though
some $^{13}$C isotopic enrichment from source to product occurs), analysis of the $^{13}$C/$^{12}$C ratio in animal bones will reflect the diet of the animal. In individuals utilizing solely C$_4$ plants, $\delta^{13}$C values will average $\sim$7.5 per mil (measured in terms of the PDB Belemnite standard: Craig 1953), while pure C$_3$ diets will average $\sim$21.5 per mil (Vogel and Van der Merwe 1977: 240; Vogel 1986).

Thus, if the Altithermal was characterized by late summer drought conditions, then an examination of $^{13}$C/$^{12}$C ratios in bison bone through time should show lower $\delta^{13}$C values (a drop in percentage of C$_4$ plants and a relative increase of more cool-season C$_3$ plants) in bison diet during the Altithermal.

While not testing this specific hypothesis, Stafford (1984: 94–120) analyzed $^{13}$C/$^{12}$C ratios in fossil bison bone from the Lubbock Lake site. He observed that bison remains are rare in Altithermal-age deposits of Stratum 3: only two concentrations of bones amounting to less than 50 skeletal elements have been found (Stafford 1984: 43; but see Johnson and Holliday 1986). This scarcity is in keeping with the pattern observed by Dillehay (1974) and MacDonald (1981), but leads to a 3000-year gap (between 8000 b.p. and 5050 b.p.) in Stafford’s isotopic data.

The gap notwithstanding, Stafford’s results provide tentative support for the hypothesis raised here. His results document a steady increase in the percentage of C$_4$ plants in bison diet through the Holocene; this trend of increased C$_4$ plants is generally supported by carbon isotope measurements derived from Lubbock Lake soil humates (Herbert Haas, personal communication, 1986; Haas, Holliday, and Stuckenrath 1986). More important, also evident in Stafford’s data (fig. 5) is the predicted drop in the percentage of C$_4$ plants in bison diet around 8000 b.p. This may indicate, as hypothesized here, a decrease in the percentage of C$_4$ grasses in the environment. While provocative, these results are based on only 18 samples, none of which falls into the critical time period of 8000 to 5050 b.p., and much more data are needed to test the hypothesis.

We would conclude, therefore, that a lack of water and, perhaps, a lack of preferred food types led to the reduction of bison on the Llano Estacado during the Altithermal. The reduction in number of bison would certainly have forced human groups dependent on the animal to alter their settlement and subsistence strategies if they were to survive on this bleak landscape.

But any such responses were necessarily constrained by the lack of water. Water shortages pose significant physiological constraints on the distances one can travel: attainable distances decrease as temperature increases and the water available for transport decreases (Larson 1977: 184). Therefore, in times of drought water sources such as springs, hard-water lakes, and artificial wells would most likely have served as key determinants in the settlement systems, with the groups positioning themselves on the landscape to gain access to both water and food resources (Gould 1977: 28).

Given an apparent reduction in the amount of available resources, settlement dispersion likely occurred, if not abandonment of the southern High Plains and movement to more favorable habitats off the High Plains, either west to the Sangre de Cristos, east to the more wooded riverine areas of central Texas, or south to the Trans-Pecos. Johnson and Holliday (1986) observe that the effects of the Altithermal were not as pronounced in the latter two areas as on the Llano Estacado.

For groups inhabiting the southern High Plains during the Altithermal, a shift in diet to plants and animals that were able to survive on little water, notably reptiles, and mammals such as kangaroo rats, pocket mice, jackrabbits, and pronghorn antelope, would also have been selectively advantageous. This response would have been similar to that taking place further to the south, where plant macrofossil, pollen, faunal, and coprolite evidence from the Lower Pecos provides a “convincing argument that around 6000 years ago local aboriginal groups were forced to adjust to vegetation and climatic conditions that were becoming increasingly more xeric and drier” (Bryant and Holloway 1985: 57).

![Figure 5. Plot of collagen $\delta^{13}$C vs. geologic age for fossil Bison spp. from the Lubbock Lake site (after Stafford 1984: fig. 21).]
Summary and Conclusions

Prehistoric water wells have been found at three widely-separated sites on the southern High Plains. They are remarkably similar in size and are roughly the same shape. A number were refilled soon after use, either by those who dug them, as was the case with certain wells at Blackwater Locality No. 1, or by naturally-deposited wind-blown sediments, as was the case at Mustang Springs and for some of the wells at Blackwater Locality No. 1. Artifacts associated with a well were recovered only at Rattlesnake Draw, and those were non-diagnostic.

Radiocarbon and TL age determinations at Mustang Springs and Blackwater Locality No. 1 indicate that the wells were dug between 8000 and 5000 b.p. The stratigraphic record suggests an age closer to the latter date. Since not all wells at Blackwater Locality No. 1 were dug to the same vertical depth, it would appear that they could have been dug as the water table was rebounding—perhaps marking climatic amelioration.

The wells provide a record of extremely arid climatic conditions: most, if not all, were dug from eroded, wind-scoured surfaces to reach a water table that had dropped 1–3 m, possibly in the space of a few thousand years. Those surfaces were subsequently buried under thick aeolian deposits. Implied by such features are significant changes in the biomass of the Llano Estacado during the Altithermal.

Following megafaunal extinction (ca. 10,500 b.p.), bison emerged as the largest and most abundant mammal on the High Plains (Guthrie 1980), not to mention the primary constituent of the human diet in the early Holocene. The reduction in available surface water, erosion of the grasslands, and, as implied by the data in Stafford (1984), the loss of preferred food sources, would have put severe selective pressure on middle-Holocene bison populations. That pressure is manifested in a drop in bison numbers (Dillehay 1974; MacDonald 1981) and evolutionary changes in certain anatomical attributes of the bison populations (Frison 1978; Reher 1977) on the plains during Altithermal times.

The reduction of bison populations would have forced human groups to shift their adaptive strategies during middle-Holocene times, which probably involved settlement dispersion and an expansion of the diet to incorporate other animals and plants better suited to drought conditions.

Despite formal similarities to wells dug on the Llano Estacado during historical times, the excavation of the Altithermal wells was prompted by different needs. The 19th-century wells were in use during a moist climatic interval; there were a number of spring sources that could provide abundant water, and the shallowness of the water table allowed ready access to subsurface water. The Altithermal wells were cut under much more arid conditions; springs had ceased to flow, the water table had dropped significantly, and there was little available surface water. Drought conditions evidently prompted the excavation of the Altithermal wells. In contrast, it is likely that the deadly competition for water between native American groups and U.S. Army troops forced Comanche and other native groups to dig water wells out on the plains far from known and permanent sources of water.

Addendum

Subsequent fieldwork by Meltzer at the Mustang Springs site in 1986 led to the discovery of an additional four wells. All were dug from the top of Stratum 3 and had filled naturally with the aeolian silts of Stratum 4. Their size and morphology indicated they had been completed and used, although they were dug to different depths, evincing variation in the water table that, in turn, suggests they were not contemporaneous. Two of these wells, though similar in morphology to Well #1 (Fig. 3, left), had vertical “bore” holes in their base; these were cylindrical shafts, each approximately 10 cm in diameter, sunk to depths of 15 cm and 25 cm (respectively) below the floor of the wells. These features, not previously recorded in prehistoric wells, indicate the use of hydrostatic pressure to “lift” water from underlying water-bearing levels into the well basin. Given the hard, resistant sediment through which these wells were dug, and the tools available for the work, the use of such a labor-saving feature is not unexpected. These new wells, associated radiocarbon dates, and recent geoarchaeological work at the site will be reported in subsequent papers.

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