Experimental Hearths and the Thermal Alteration of Caliche on the Southern High Plains

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Throughout the Holocene, caliche has been a ubiquitous technological resource for the people of the Southern High Plains. Archaeological sites on the Southern High Plains often contain thermal features that appear to utilize caliche nodules in various cultural processes. These processes usually involve some degree of thermal dynamic alteration to the caliche, identified in the archaeological record as fire-scorched or blackened nodules. Previous studies of the pyrodynamic properties of caliche have focused on quantification of color and fracture patterns within a laboratory setting, without direct involvement of cultural processes or problems associated with thermal features. Thermal alteration variables of caliche are examined from an actualistic perspective, utilizing previously excavated basin feature geometry and local caliche outcrops. Results indicate that sustained, intense heating of caliche (above 204°C) causes significant, but variable, structural transformations at the specimen level. The experimental use of shallow basin hearths demonstrates that hearth structures were easily capable of achieving and sustaining temperatures that would result in the physical alteration of individual caliche nodules, defined here as hearthstones. The broader implications of this study suggest that the interpretation of archaeological hearthstone assemblages should reflect variability, as observed during this experiment. © 2005 Wiley Periodicals, Inc.

INTRODUCTION

An experiment using shallow basins and the burning of locally obtained caliche nodules was designed to generate a greater understanding of the ubiquitous thermal basin features recorded in the archaeological record on the Southern High Plains. Previous experimental data have demonstrated that burned caliche nodules are hearthstones, produced through activities related to cultural actions rather than the product of natural processes (Lintz, 1989; Ladkin, 1993). Based on these results, hypotheses concerning caliche nodule-lined basins are straightforward but untested with actualistic experimental data. These hypotheses include: (1) high temperatures
will discolor (carbonize) caliche as a function of time; (2) high temperatures will fracture caliche as a function of time; and (3) caliche will retain sufficient heat for cooking activities after the primary fuel (wood) has been expended. Observations and quantifiable results gleaned from the hearth-basin experiments address these three hypotheses.

The analysis of thermal pit and basin features has received much attention (Frison, 1983; Groenendijk, 1987; Barfield, 1991; Collins and Ricklis, 1994; Black et al., 1997; Wandsnider, 1997; Lowell, 1999; Petraglia, 2002). The analysis of specific components of hearthstone or cookstone technology (Thoms, 1986, 2003) allows for a broader understanding of prehistoric cooking strategies (e.g., Atkins, 1988; Jackson, 1998; Gose, 2000; Quigg et al., 2001; Brink and Dawe, 2003; Thoms, 2003). Although the use of caliche hearthstone technology has been examined in several ecological settings (e.g., Tennis et al., 1997), the analysis from the Southern High Plains is limited (Lintz, 1989; Ladkin, 1993). The use of caliche hearthstones constitutes a major component of Southern High Plains aboriginal prehistoric thermal technologies (Johnson and Holliday, 1986; Johnson, 1987; Lintz, 1989). This study is a first approximation at expanding the inferential potential of burned caliche through the implementation of experimental hearths.

The results of the actualistic experiment indicate that empirical analysis of hearthstones can yield useful baseline data for assessing the archaeological record. Evidence of burning on individual hearthstone specimens is the result of the interaction of a complex set of variables. Cultural processes that result in the discard of spent hearthstones, therefore, cannot be elucidated easily from the archaeological record. This result has wider implications to the archaeological investigation of hot-rock technology that extend beyond the regional dataset presented.

Environmental Setting

The Southern High Plains (Llano Estacado) is a flat, virtually featureless plateau located in western Texas and eastern New Mexico (Figure 1). Bounded on three sides by an escarpment, the southern edge merges into the Edwards Plateau. The High Plains surface is blanketed by the aeolian sands of the Blackwater Draw Formation (Holliday, 1989). The local drainage system, cut through the bedrock, trends from northwest to southeast across the region and forms the headwaters for several major river systems in Texas.

Caliche nodules can be obtained from both the Blanco and Ogallala formations. The Blanco Formation, localized in certain areas of the Southern High Plains, often contains calcrete in its upper layers (Holliday and Welty, 1981). It is characterized as a lacustrine dolomite and clastic sediment deposited in large basins cut into the Ogallala Formation (Evans and Meade, 1945; Pierce, 1974; Harbour, 1975; Hawley et al., 1976; Holliday, 1988, 1997).

Throughout the Southern High Plains, caliche comprises the upper section of the Miocene-Pliocene age Ogallala Formation in the form of a strongly indurated calcretic layer (Holliday, 1997). This well-developed layer is known as the Caprock. The Ogallala Formation is the most ubiquitous rock unit of the High Plains, out-
cropping nearly continuously along the eastern, northern, and western escarpments of the Llano Estacado (Holliday, 1997). Entrenched draw systems that cut the largely flat High Plains topography provide one form of access to exposures of the underlying caliche. Exposures are most often visible along valley walls where erosion processes break off caliche nodules that can be recovered from the surface.
Caliche nodules utilized in this experiment were obtained from an exposure of the Ogallala Formation located within Yellowhouse Canyon (Figures 1 and 2). The chemical composition of caliche varies. Calcium carbonate (CaCO₃) is the cementing agent, binding unconsolidated sediment and geologic material. Calcium carbonate levels vary, but it is always a major constituent (Sidwell, 1943; Evans, 1948; Bretz and Horberg, 1949; Gile et al., 1966; Reeves, 1976; Hennessy et al., 1983:723). The term caliche has been applied to calcareous caprocks, soil hardpans, and earthy or porous materials occurring at the surface or at shallow depths below the soil (Bretz and Horberg, 1949). Caliche is developed in lower soil horizons during pedogenesis (Gile, 1961; Gile et al., 1966; Reeves, 1976) and occurs in soils throughout the southwestern United States. Horizons on the Southern High Plains are among the most well-developed caliche deposits found worldwide (Alomar-Camacho, 2001).

Archaeological Background

Burned caliche hearthstones have been identified in a large number of archaeological excavations on the Southern High Plains (e.g., Biesaart et al., 1985; Johnson, 1987; Baxevanis et al., 1997; Brown, 1999). Burned caliche scatters are ubiquitous in surface surveys (e.g., Hughes and Willey, 1978; Hughes and Speer, 1981; Litwinionek et al., 1997; Mitchell, 2001; Gill, 2002) and, therefore, are a useful indicator of prehistoric land-use strategies. Excavations of discrete hearth-basin features have revealed persistent use of caliche in thermal-producing activities over a long time span (e.g., Johnson, 1987; Backhouse, 2002; Buchanan, 2002). While caliche is not the only rock type associated with thermal rock features on the Southern High Plains, it is the most prevalent. At Lubbock Lake, it accounts for approximately 98% of all hearthstone material recovered (Johnson, 1987, 1989, 1993, 1995, 2002). Burned caliche, however, has been historically underutilized by researchers as an inferential analytical tool in understanding past lifeways on the Southern High Plains.

Analysis of thermal features highlights a plethora of subtle variation in hearthstone usage associated with different thermal processes and hearth morphologies (Ladkin, 1993; Backhouse et al., 2001; Backhouse, 2002; Buchanan, 2002). A clear standard typology for the characterization of thermal-feature morphology has yet to be developed for the Southern High Plains. In the absence of such a system and based on the dynamic nature of the features themselves, the most convenient characterization of the type of feature addressed herein is a caliche rubble basin. Typically, these basin features are filled with hearthstones and sediment with no clear internal structure. A basin is identified on the basis of a high diameter-to-depth ratio (Ellis, 1997).

Caliche rubble basins have been excavated at a number of sites on the Southern High Plains, and, in particular, at the Lubbock Lake Landmark (Johnson, 1993, 1995, 2002). The Lubbock Lake Landmark (41LU1) is located on the northern edge of the City of Lubbock (Figure 1). The Landmark covers more than 300 acres of the valley axis and margins of Yellowhouse Draw and adjacent upland rims. In addition, it contains a well-dated stratigraphic record of valley-fill and upland sediments (Holliday et al., 1983; Holliday, 1983, 1985, 1989, 1995; Holliday and Allen, 1987; Johnson, 2002)
Figure 2. Ogallala Formation outcropping along the valley rim of Yellowhouse Canyon and collection area for the hearthstones used in the experiment.
in which numerous archaeological activity areas date from 11,100 years ago to the historic use of the area by Anglo settlers (Johnson, 1987).

At 41LU1 Area 10, located on the rim of the draw, an activity area has been occupied repeatedly over the last 1000 years or more and contains numerous hearth basins, some of which overlap and cross-cut one another (Backhouse, 2002; Buchanan, 2002). The basins are filled with burned and often highly fragmented caliche nodules (Figure 3). The basins themselves are generally around 1 m in diameter and fairly shallow (often less than 30 cm in depth). Caliche nodule counts for each basin are in excess of ca. 2000, although many pieces are fragmentary. Carbonized sediment and charcoal pieces occur throughout the matrix of these features, suggesting that fuel was loaded both above and below the hearthstones. The integrity of the internal basin structure suggests their use involved cooking on top of the hearthstones, not within the basin itself as inferred from pit ovens (e.g., Johnson and Holliday, 1986).

**EXPERIMENTAL METHODOLOGY**

Caliche nodules were collected from an exposed Ogallala Formation outcrop on the rim of Yellowhouse Canyon, approximately 4 miles downstream from the Lubbock Lake Landmark (Figure 2). Nodules of varying sizes (20–2447.5 g) were collected for use in the experiment (Figure 3). Some caliche nodules had a significantly higher density than others of similar proportion; the cause of this variation was not identified. During the process of volume quantification using water displacement, very little slaking (crumbling with treatment by water) was present when nodules were immersed in water, suggesting the vast majority of the nodules used in this experiment were hard caliche (sensu Gile, 1961).

The caliche nodules were assigned tag numbers for identification purposes. Prior to experimental burning, the nodules were tagged by stamping their individual caliche identity number on a steel tag and attaching the tag to the nodule with a thin band of steel wire.
A color designation using a standard 1994 U.S. Munsell color chart was determined for each nodule prior to the experiment (Table I). Munsell colors were assigned in the ranges Gley 1 through 2.5Y. The color value was recorded for the largest percentage of the visible exterior surface for each caliche nodule. Interobserver variability tests were used as a check on the validity of the color results. Two of the authors (P.B. and B.B.) reanalyzed a random sample from all three experiments. The results revealed relatively minor variation in the colors recorded by the different observers.

Weight values were recorded in grams with a Triple Beam Balance 700. Fracture patterns were recorded by visual inspection. To aid in the quantification of the observed fracturing, only two categories were used: when significant fracture was present (i.e., pronounced angularity, a broken edge, or cracking), it was designated as fractured (F); if none of these characteristics were visible, it was designated as stable (S) (Table I).

### The Experiment

Cultural and natural processes are active variables in the modification of rocks for use as hearthstones. The research objectives of the experiment explicitly anticipate a wide range of variability inherent in the processes that act to structure the archaeological record. Interpretations derived from this experiment, therefore, are not applicable precisely to the interpretation of individual site-level structures. Rather, the objectives focus on generating broader interpretive statements with emphasis on the physical material transformation of hearthstones within a framework of hunter-gatherer thermal-feature technology.

Four basins were hand-excavated in a culturally sterile area at the Lubbock Lake Landmark during the spring of 2002 (Figure 4). The experimental basins were assigned control designations EXP-1, EXP-2, EXP-3, and EXP-4. Basins EXP-1 through EXP-3 were designed as three repetitions of the same experimental design. EXP-4 was used to test a number of external variables prior to and after the experimental burns in the other basins. Basin geometry was ca. 50 cm × 50 cm × 30 cm, based on previously excavated basins at 41LU1 Area 10 (Backhouse, 2002; Buchanan, 2002).

Mesquite (*Prosopis glandulosa*) was chosen as the primary incendiary material based on several factors: (1) Mesquite is a native plant (Thompson, 1987) and the

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**Table I.** Quantification summary of caliche nodule variables for all experimental basin hearths prior to burning.

<table>
<thead>
<tr>
<th>Experiment No.</th>
<th>Total No. Caliches</th>
<th>No. of Caliches Stable</th>
<th>No. of Caliches Fractured</th>
<th>Most Frequent Color Value</th>
<th>Volume Range (mL)</th>
<th>Weight Range (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>34</td>
<td>16</td>
<td>10YR8/2</td>
<td>10–700</td>
<td>60.0–1674.6</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>28</td>
<td>12</td>
<td>7.5YR8/2</td>
<td>10–900</td>
<td>22.6–2068.5</td>
</tr>
<tr>
<td>3</td>
<td>49</td>
<td>27</td>
<td>22</td>
<td>10YR8/2</td>
<td>20–1000</td>
<td>55.7–2447.5</td>
</tr>
</tbody>
</table>

*Note.* Complete data on archive at the Museum of Texas Tech University.
results of tree identification based on charcoal from a number of Southern High Plains thermal features have indicated the presence of mesquite (Backhouse et al., 2001; Johnson, 2003); (2) mesquite represents the most ubiquitous hard wood resource on the Southern High Plains (Anonymous, 1992); and (3) dead mesquite limbs can be harvested easily from the landscape with minimal expended effort. A variety of grasses were used as the initial kindling and tinder (pyrotechnic catalyst), followed by snapped mesquite limbs to fuel the fires. The wood used in each experimental burn weighed ca. 11,000 g. The fuel was split into bundles consisting of limbs with a diameter larger than 50 mm and bundles consisting of limbs with a diameter smaller than 50 mm as kindling. Approximately half of the total fuel for each experiment was burned prior to the introduction of the caliche nodules, and the remainder added above the coals and surrounding the newly added caliche layer.

A thermocouple (electronic temperature probe; Barant Type K) was used to take temperature readings at half-hour intervals during the basin firing. In order to obtain a standardized temperature reading, the thermocouple was positioned in the center of the basin embers for 2 minutes before a temperature reading was

Figure 4. Experimental area at Lubbock Lake Landmark.
recorded. The thermocouple was stored in the shade between readings, and ambient environment temperature readings were noted prior to interior basin readings. Resultant temperature data were corrected by subtracting the ambient temperature from the hearth-basin reading. Ambient environmental conditions for the local area were recorded from the Lubbock International Airport NEXRAD weather station (LBB/KLBB), situated ca. 2 miles north of the experiment location (Table II).

Each experiment was conducted for 6 hours, with 3 days required for all experiments to be completed. The experimental pyrotechnic methodology attempted to standardize a series of set procedures in order to produce comparable data sets for analysis (Figure 5). On completion of an experiment, all caliche nodules were photographed and mapped with a total station before being systematically removed from the basin (Figure 6). Upon completion of all three experiments, the caliche nodules were brought to the laboratory for reanalysis. Reanalysis involved the quantification of the same set of variables recorded prior to burning (Munsell color, weight, and fracture; Table III).
### Table II. Ambient environmental conditions recorded from Lubbock LIA (LBB/KLBB) weather station.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Time</th>
<th>Temp. (°C)</th>
<th>Humidity</th>
<th>Pressure</th>
<th>Wind Direction/ Speed (mph)</th>
<th>Dew Point</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXP-1</td>
<td>8:00 am</td>
<td>16.11</td>
<td>19%</td>
<td>29.96</td>
<td>SW 7</td>
<td>58</td>
<td>Partly cloudy</td>
</tr>
<tr>
<td>EXP-1</td>
<td>11:30 am</td>
<td>24.44</td>
<td>51%</td>
<td>29.99</td>
<td>W 13</td>
<td>57</td>
<td>Cloudy</td>
</tr>
<tr>
<td>EXP-1</td>
<td>2:00 pm</td>
<td>28.33</td>
<td>25%</td>
<td>29.97</td>
<td>W 9</td>
<td>44</td>
<td>Cloudy</td>
</tr>
<tr>
<td>EXP-2</td>
<td>8:00 am</td>
<td>13.89</td>
<td>66%</td>
<td>29.98</td>
<td>W 6</td>
<td>46</td>
<td>Mostly Sunny</td>
</tr>
<tr>
<td>EXP-2</td>
<td>11:30 am</td>
<td>27.22</td>
<td>24%</td>
<td>30.40</td>
<td>NW 12</td>
<td>41</td>
<td>Partly Sunny</td>
</tr>
<tr>
<td>EXP-2</td>
<td>2:00 pm</td>
<td>30.56</td>
<td>25%</td>
<td>30.07</td>
<td>N 21</td>
<td>48</td>
<td>Clear</td>
</tr>
<tr>
<td>EXP-3</td>
<td>8:00 am</td>
<td>12.78</td>
<td>71%</td>
<td>30.04</td>
<td>W 6</td>
<td>46</td>
<td>Cloudy</td>
</tr>
<tr>
<td>EXP-3</td>
<td>11:30 am</td>
<td>18.89</td>
<td>43%</td>
<td>30.04</td>
<td>W 7</td>
<td>43</td>
<td>Cloudy</td>
</tr>
<tr>
<td>EXP-3</td>
<td>2:00 pm</td>
<td>26.67</td>
<td>21%</td>
<td>30.04</td>
<td>W 9</td>
<td>37</td>
<td>Cloudy</td>
</tr>
</tbody>
</table>

**Figure 6.** EXP-1 post-burn: (a) post-burn; (b) first caliche nodule removal; (c) second caliche nodule removal; (d) third caliche nodule removal; (e) fourth caliche nodule removal; (f) fifth caliche nodule removal.

### Table III. Quantification summary of burned caliche nodules for all experimental basin hearths post-burn.

<table>
<thead>
<tr>
<th>Experiment No.</th>
<th>Total No. of Caliches</th>
<th>No. of Caliches Stable</th>
<th>No. of Caliches Fractured</th>
<th>Most Frequent Color Value</th>
<th>Weight Range (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>52</td>
<td>24</td>
<td>28</td>
<td>Gley1 5/N</td>
<td>5.7–1649.2</td>
</tr>
<tr>
<td>2</td>
<td>49</td>
<td>27</td>
<td>22</td>
<td>Gley1 4/N</td>
<td>2.5–1897.0</td>
</tr>
<tr>
<td>3</td>
<td>48</td>
<td>22</td>
<td>26</td>
<td>10YR4/1</td>
<td>19.9–2405.4</td>
</tr>
</tbody>
</table>

*Note.* Complete data on archive at the Museum of Texas Tech University.
RESULTS

The basin temperature data generally indicate that the highest temperatures were logged in the first 3 hours after burning (Table IV). Subsequent temperatures steadily decreased. EXP-2, on the other hand, remained at a steady burn temperature for the entire 6 hours of the experiment (Figure 7). Variability in temperatures between the three experimental basins is likely the result of several factors, including the prevailing weather, source-material variability, basin geometry, fuel variability, fuel-load placement, caliche nodule placement, ignition material, and location of primary ignition.

Results showed a heat curve with a maximum acquired temperature of 673°C during the initial burn. Temperatures of between 275°C and 425°C were recorded after the initial fuel had been added and exhausted (Figure 7). However, a high degree of variability existed in the fall-off readings, with spikes of very hot temperatures up to 6 hours after the initial burn. Mesquite proved to be a high-energy primary pyrotechnic medium.

Ambient environmental data recorded from the Lubbock LIA weather station show that on the day of the EXP-2 burning, higher winds and higher temperatures occurred throughout the day than for either EXP-1 or EXP-3 (Table II). This situation is likely a cause of the comparatively high, sustained temperatures in EXP-2. EXP-3 has an average temperature of 279°C, but the readings demonstrated high variability (Std. Dev. = 49.65). The third day was the coolest and least windy day of the three, and is probably responsible for EXP-3 producing the least number of highly burned hearthstones. Of the three experimental basins, EXP-1 yielded the second-highest number of highly burned hearthstones, due most likely to the initial high temperatures in the first 3 hours of burning (Table II).

Table IV. Temperatures of all experimental basin hearths taken at half-hour intervals over 6 hours and compensated for ambient temperature.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Compensated Hearth Temp. EXP-1 (°C)</th>
<th>Compensated Hearth Temp. EXP-2 (°C)</th>
<th>Compensated Hearth Temp. EXP-3 (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>499.22</td>
<td>673.22</td>
<td>340.61</td>
</tr>
<tr>
<td>60</td>
<td>481.78</td>
<td>237.94</td>
<td>98.22</td>
</tr>
<tr>
<td>90</td>
<td>621.33</td>
<td>295.33</td>
<td>370.11</td>
</tr>
<tr>
<td>120</td>
<td>407.22</td>
<td>378.83</td>
<td>414.67</td>
</tr>
<tr>
<td>150</td>
<td>274.50</td>
<td>425.44</td>
<td>326.44</td>
</tr>
<tr>
<td>180</td>
<td>346.61</td>
<td>349.94</td>
<td>284.17</td>
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<tr>
<td>210</td>
<td>255.94</td>
<td>346.00</td>
<td>233.33</td>
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<td>240</td>
<td>254.39</td>
<td>321.44</td>
<td>273.17</td>
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<tr>
<td>270</td>
<td>219.11</td>
<td>353.61</td>
<td>252.00</td>
</tr>
<tr>
<td>300</td>
<td>248.28</td>
<td>349.61</td>
<td>262.78</td>
</tr>
<tr>
<td>330</td>
<td>251.44</td>
<td>356.50</td>
<td>232.89</td>
</tr>
<tr>
<td>360</td>
<td>195.89</td>
<td>340.94</td>
<td>260.83</td>
</tr>
<tr>
<td>Mean temperature</td>
<td>337.98</td>
<td>369.07</td>
<td>279.10</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>134.65</td>
<td>105.81</td>
<td>80.36</td>
</tr>
<tr>
<td>Range</td>
<td>195.89–621.33</td>
<td>237.94–673.22</td>
<td>98.22–414.67</td>
</tr>
</tbody>
</table>
Gross comparison of Munsell color designations, obtained before and after experimentation, reveals significant color transformations on the outer surfaces of the caliche nodules (Table V). A general trend from color designations dominated by white, pink, and pale hues prior to burning is replaced by designations dominated by browns and grays after burning (Table V). A higher degree of variability is represented in the coloration of the post-burn assemblages as compared to the pre-burn assemblages. Nevertheless, the post-burn assemblage is dominated by high frequencies of gray and dark gray nodules.

The number of caliche nodules that were both stable and fractured before and after firing showed significant variation (Table VI). The collection of the fragmented hearthstones was as comprehensive as possible and involved hand sifting the ash remaining in the basins to recover the tiny hearthstone spalls. In each case, the quantity of extra-fragmented hearthstones was accounted for in the decrease in the quantity of stable caliche nodules post-burn (Table VI). EXP-1 produced the highest frequency of newly fractured hearthstones (12) and an additional 10 nodules, characterized as stable prior to burning but now fractured (Figure 8). EXP-2 had a high burn temperature (Table IV) and caused 10 new fractures but only one less-stable hearthstone (Table VII). EXP-3 yielded similar results to EXP-1 and yielded six newly fractured and four less-stable caliche nodules. EXP-3 had a low burn rate throughout the 6 hours, but its temperature oscillated continuously, on average from 288°C to 232°C. The lower overall temperatures may have caused less fracturing to occur in comparison with EXP-1 and EXP-2 (Tables VI and VII). These data suggested the high initial temperatures followed by a rapid decrease can lead to a general fracturing over a greater number of hearthstones.

A loss of weight from pre-burn to post-burn in each experimental caliche assemblage was noted (Table VIII). This result suggested that a loss of internal water occurred

Figure 7. Hearth temperature taken by thermocouple probe.
within individual nodules (Hennessey et al., 1983), combustion of carbonates had occurred within the hearthstone, a degree of microfracturing (small pieces of hearthstone not collected post-burn) existed, or some combination of these processes had

<table>
<thead>
<tr>
<th>Munsell Color</th>
<th>Color Description</th>
<th>EXP-1 Pre-Burn</th>
<th>EXP-1 Post-Burn</th>
<th>EXP-2 Pre-Burn</th>
<th>EXP-2 Post-Burn</th>
<th>EXP-3 Pre-Burn</th>
<th>EXP-3 Post-Burn</th>
<th>Total Pre-Burn</th>
<th>Total Post-Burn</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5YR/4 Pink</td>
<td>2 0 4 0 3 0 9 0</td>
<td>10YR/4 Very pale brown</td>
<td>2 0 1 0 2 0 5 0</td>
<td>7.5YR/3 Pink</td>
<td>9 0 7 0 5 0 21 0</td>
<td>10YR/3 Very pale brown</td>
<td>8 0 4 0 0 0 21 0</td>
<td>7.5YR/2 Pinkish-white</td>
<td>9 0 7 0 6 0 22 0</td>
</tr>
<tr>
<td>7.5YR 8/1 White</td>
<td>1 0 1 0 3 0 5 0</td>
<td>10YR 8/1 White</td>
<td>5 0 7 0 6 0 19 0</td>
<td>7.5YR 7/4 Pink</td>
<td>1 0 0 0 0 0 1 0</td>
<td>10YR 7/4 Very pale brown</td>
<td>1 0 0 0 0 0 4 1 4</td>
<td>7.5YR 7/3 Pink</td>
<td>1 0 1 0 0 0 2 0</td>
</tr>
<tr>
<td>10YR 7/1 Light gray</td>
<td>0 0 0 0 1 0 1 0</td>
<td>7.5YR 7/2 Pinkish-gray</td>
<td>1 0 1 0 0 0 2 0</td>
<td>10YR 6/6 Brownish-yellow</td>
<td>0 0 0 1 0 5 0 6</td>
<td>10YR 6/4 Light yellowish-brown</td>
<td>0 0 0 1 0 0 0 1</td>
<td>10YR 6/3 Pale brown</td>
<td>0 2 0 1 0 3 0 6</td>
</tr>
<tr>
<td>10YR 6/1 Gray</td>
<td>0 4 0 1 0 2 0 7</td>
<td>2.5Y/1 Gray</td>
<td>0 2 0 2 0 7 0 14</td>
<td>10YR 5/3 Brown</td>
<td>0 0 0 1 0 0 0 1</td>
<td>10YR 5/2 Grayish-brown</td>
<td>0 0 0 3 0 3 0 6</td>
<td>10YR 5/1 Gray</td>
<td>0 6 0 6 0 7 0 19</td>
</tr>
<tr>
<td>10YR 4/2 Dark gray</td>
<td>0 1 0 0 0 0 0 1</td>
<td>10YR 4/1 Dark gray</td>
<td>0 12 0 9 0 8 0 29</td>
<td>2.5Y/4/1 Dark gray</td>
<td>0 2 0 0 0 1 0 3</td>
<td>10YR 3/1 Very dark gray</td>
<td>0 1 0 0 0 0 0 1</td>
<td>Gley1 7/N Light gray</td>
<td>0 1 0 1 0 0 0 2</td>
</tr>
<tr>
<td>10YR 5/1 Gray</td>
<td>0 1 0 1 0 0 0 1</td>
<td>Gley1 5/N Gray</td>
<td>0 14 0 11 0 6 0 31</td>
<td>Gley1 4/N Dark gray</td>
<td>0 1 0 10 0 1 0 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table VI. Number of burned caliche nodules recorded as either fractured or stable before and after burning.

<table>
<thead>
<tr>
<th></th>
<th>EXP-1 Prior to Burn</th>
<th>EXP-1 Post-Burn</th>
<th>EXP-2 Prior to Burn</th>
<th>EXP-2 Post-Burn</th>
<th>EXP-3 Prior to Burn</th>
<th>EXP-3 Post-Burn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fractured</td>
<td>16</td>
<td>28</td>
<td>12</td>
<td>22</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>Stable</td>
<td>34</td>
<td>24</td>
<td>28</td>
<td>27</td>
<td>26</td>
<td>22</td>
</tr>
</tbody>
</table>

Table VII. Number of fractured and stable burned caliche nodules with and without newly fractured nodules.

<table>
<thead>
<tr>
<th></th>
<th>EXP-1 Prior to Burn</th>
<th>EXP-1 Post-Burn</th>
<th>EXP-2 Prior to Burn</th>
<th>EXP-2 Post-Burn</th>
<th>EXP-3 Prior to Burn</th>
<th>EXP-3 Post-Burn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fractured (F)</td>
<td>F</td>
<td>S</td>
<td>F</td>
<td>S</td>
<td>F</td>
<td>S</td>
</tr>
<tr>
<td>Stable (S)</td>
<td>F</td>
<td>S</td>
<td>F</td>
<td>S</td>
<td>F</td>
<td>S</td>
</tr>
<tr>
<td>Including newly fractured caliche nodules</td>
<td>16</td>
<td>34</td>
<td>28</td>
<td>24</td>
<td>12</td>
<td>28</td>
</tr>
<tr>
<td>Excluding newly fractured caliche nodules</td>
<td>27</td>
<td>23</td>
<td>21</td>
<td>19</td>
<td>26</td>
<td>20</td>
</tr>
</tbody>
</table>

Figure 8. Example of a caliche nodule fracture after burning.
taken place. With the proportion of weight loss recorded after burning, it may be possible to approximate the number of burning episodes that a caliche hearthstone assemblage is likely to cycle through before all the nodules are exhausted. A direct relationship likely existed between nodule size and heating efficiency. However, the results of these initial experiments did not attempt to quantify this relationship directly and would require a new experimental setup and sufficient repetition.

**DISCUSSION**

The data generated from these preliminary experiments highlight the utility of conducting actualistic research into the physical properties of burned caliche nodules. By testing basic assumptions concerning the use and reuse of caliche, and the transformations individual nodules undergo when heated, a comparative database can be generated to assess burned caliche hearthstones recovered from the archaeological record.

Variability within the data sets for all criteria makes quantification a complex task and is best viewed at a feature scale (i.e., by quantifying the characteristics for each of the features). In general, at least three physical alterations are observable once a caliche nodule is burned. Coloration becomes distinctly darker; total weight of individual nodules is reduced; and fracturing occurs. Two of the implicit assumptions associated with the thermal alteration characteristics of caliche proved to be confirmed: High temperatures will discolor caliche; and fracture is a function of intense heat.

The coloration data provide an adequate inferential tool for analyzing burned caliche. The current data set indicates a correlation between acquired basin temperature and subsequent caliche nodule coloration, as demonstrated in laboratory experiments (Linton, 1989). Coloration (burning of the nodule surface) is achieved in the actualistic experiments at hearth basin temperatures of 204–371°C, while coloration occurred above 300°C in the laboratory experiment (Linton, 1989:328). Data from natural range fires indicate temperatures of 84–388°C are reached, with up to 682°C under optimal conditions (Stinson and Wright, 1969). However, given

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**Table VIII.** Average nodule and total assemblage weight loss, including the newly fractured nodules and excluding the newly fractured nodules, for each experiment.

<table>
<thead>
<tr>
<th></th>
<th>Average Nodule Weight (g)</th>
<th>Total Nodule Weight (g)</th>
<th>Total Nodule Weight Loss (%)</th>
<th>Average Nodule Weight (g)</th>
<th>Total Nodule Weight (g)</th>
<th>Total Nodule Weight Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXP-1 Pre-Burn</td>
<td>505.72</td>
<td>25,286.1</td>
<td>1.44</td>
<td>25,286.1</td>
<td>505.72</td>
<td>1.44</td>
</tr>
<tr>
<td>EXP-1 Post-Burn</td>
<td>497.96</td>
<td>24,921.1</td>
<td>1.53</td>
<td>24,921.1</td>
<td>497.96</td>
<td>1.53</td>
</tr>
<tr>
<td>EXP-2 Pre-Burn</td>
<td>442.26</td>
<td>17,690.6</td>
<td>0.60</td>
<td>17,690.6</td>
<td>442.26</td>
<td>0.60</td>
</tr>
<tr>
<td>EXP-2 Post-Burn</td>
<td>358.59</td>
<td>26,394.1</td>
<td>0.91</td>
<td>26,394.1</td>
<td>358.59</td>
<td>0.91</td>
</tr>
<tr>
<td>EXP-3 Pre-Burn</td>
<td>573.78</td>
<td>26,394.1</td>
<td>0.33</td>
<td>26,394.1</td>
<td>573.78</td>
<td>0.33</td>
</tr>
<tr>
<td>EXP-3 Post-Burn</td>
<td>549.18</td>
<td>26,360.7</td>
<td>0.13</td>
<td>26,360.7</td>
<td>549.18</td>
<td>0.13</td>
</tr>
</tbody>
</table>

* Including analysis data from the newly fractured caliche nodules.

* Excluding analysis data from the newly fractured caliche nodules.
the characteristics of range fires, such temperatures would be maintained for only a short period of time (Stinson and Wright, 1969; Seabloom et al., 1991).

Caliche nodules subjected to prescription burning (quick burning, hot fire) are scorched superficially, but not burned nor burned throughout (Thoms and Proctor, 1977; Ladkin, 1993). Generally, range fires do not burn hot enough nor long enough to cause the type of coloration recorded with the experimental nodules or the archaeological assemblages. These data indicate hearth temperatures need to be sustained at a minimum of 204°C to produce true coloration and, therefore, cultural burning. It may be possible in future experiments to ascertain color ranges for different firing temperatures, thus providing important data on potential basin function and technological process.

Insufficient data have been generated to test the internal temperatures of individual nodules or the dissipation of heat retained in individual nodules as a function of time. However, the coloration and temperature data sets indicate a sustained minimum overall hearth temperature of 204°C. In general, such a maintained temperature would be adequate to grill foodstuffs. The duration of time nodules retain sufficient heat to bake foodstuffs still needs to be explored, along with minimum temperature and minimum length of time needed when baking various foods.

Spatial variability in coloration throughout the burned nodules has been observed from within all three basins. This variability appears related to several factors, namely, fuel-load placement, wind direction, nodule positioning, and subtle differences in the internal structure of nodules. The simple assumption that caliche at the center of the basin would be burned the most did not hold true, as a high degree of variability existed even within the internal structure of the basin. Basin features observed during fieldwork often contain seemingly unburned or scorched nodules within a concentration of highly burned specimens. Data suggest that interpretation of these specimens as in situ, rather than as post-depositional inclusions, requires serious consideration. Future work will need to contend with post-depositional taphonomic factors, such as freeze/thaw cycles and trampling.

Fracture analysis (Tables VI and VII) yielded unexpected results. The low degree of fracture during firing may relate to the hearth-basin temperature, type of caliche used, or water content of caliche nodules during firing. Observations during the experimental work suggest that fracture was more likely to occur due to physical impact or thermal shock when the caliche nodule was placed in the basin. Each of the experiments produced a number of tiny hearthstone spalls (less than 5 g) (Table VII). It appears these spalls came off the outer surface of individual nodules due to thermal shock.

The location of spalled pieces within the basin matrix reveals a distinct concentration of small angular spalls at the bottom of the basin (Figure 9). This result has the potential to determine hearth-basin contextual integrity in archaeological settings with higher concentrations of small hearthstone pieces expected from the lower levels of intact thermal-basin features. These angular spalled pieces are different from the rounded hearthstone bits frequently recovered, indicating that spalls and bits may be produced through different mechanisms in the hearth process. Fracture has often been linked with utilization processes in the archaeological literature (e.g., Black et
The dynamics of water-boiling activities and nodule re-use remain to be investigated and integrated with these preliminary results to assess the relationship between technological activity and caliche nodule structure.

All the experimental caliche nodule assemblages have undergone a loss in weight between their pre-burn and post-burn states (Table VIII). The inference is that intense heating of caliche nodules is a reducing process, and that the effective mass of individual nodules is being transformed as a function of heating. A similar reduction is noted by Lintz (1989), in which a loss of approximately 0.76 gram per 100°C at temperatures below 700°C was calculated. Because the assemblages examined here were subjected to only one heating event, it is uncertain how subsequent heating events will further affect the weights of the hearthstones.

Importantly, the reducing process of weight loss and fracturing characterizes burned caliche nodules as an expendable resource type. Discard of spent hearthstones is usually associated with activities secondary to the hearth basin itself, such as water boiling (Ellis, 1997). The results of this experimental program suggest that hearthstone reduction is significant after one heating event and need not be a product of secondary activities. Another interpretation of discarded hearthstones recovered around a hearth basin is that they had been removed from the basin itself after being deemed too small to be useful as heat-retention reservoirs. Economically, the availability of hearthstones in the surrounding landscape will factor as a function of the longevity of a hearthstone’s use-life. The physical use-life of caliche nodules may provide a baseline for assessing gross economic yield, based on the estimated redundancy of individual nodules.

Hearth-basin temperatures achieved a maximum burn temperature of 673°C. This temperature was only sustained for a short period of time. Once ember beds developed, temperature ranges between 204°C and 371°C were sustained for at least 6 hours. Under laboratory conditions, significant alteration of caliche nodules occurred at temperatures above 700°C (Lintz, 1989). The results of this experiment suggest it is unlikely that mesquite-fueled basins could attain and sustain the temperature range at which Lintz (1989) observed physical signs of disintegration.

Inferences from the hearth basin temperatures should be regarded with caution. A recent study (Canti and Linford, 2000) suggests the use of a single thermocouple.
has limited potential for ascertaining useful data on the internal dynamics of fire pits during use. Variables such as thermocouple position, weather, wind down-draft, and burning embers can lead to false readings that can be in excess, or vastly underrepresentative, of the overall temperature of the hearth. Therefore, without additional data, it is not possible to assess the relationship between the hearth-basin geometry and dynamics of fuel expenditure as hypothesized by Groenendijk (1987).

The high variability associated with the results of this experiment largely stems from the actualistic research design of the experiment. These results, although not clear-cut, provide a more realistic baseline for interpreting burned caliche assemblages. Future experimental work is necessary, and current research needs to integrate a suite of analytical tools that include spatial, volumetric, statistical, paleomagnetic, environmental, fuel-source, and disturbance studies in order to facilitate a high level of interpretation of prehistoric hearthstone technologies.

CONCLUSIONS

Completion of this phase of actualistic research has generated a number of significant results pertinent to understanding the cultural use of caliche as a component of hunter-gatherer thermal-feature technology on the Southern High Plains, and more generally within a growing corpus of thermally altered stone research (e.g., Atkins, 1988; Lintz, 1989; Ellis, 1997; Jackson, 1998; Thoms, 2003; Brink and Dawe, 2003).

The main results of this experiment indicate that:

1. When exposed to sustained high temperatures (above 204°C), caliche hearthstones generally become darker and more variable in color, undergo weight loss, and fracture.
2. Shallow basin-hearth structures fueled by mesquite are capable of achieving and sustaining temperatures that result in the physical alteration of individual caliche nodules.
3. Burned caliche hearthstones generated by actualistic research are visually similar to those encountered in the archaeological record of the Southern High Plains.
4. Evidence for burning on individual hearthstones is the result of the interaction of a complex set of variables, and, therefore, cultural processes that result in the discard of spent hearthstones cannot be elucidated in a straightforward manner from the archaeological record.
5. A potentially predictable relationship appears to exist between firing temperature, coloration, fracture, and weight loss at an assemblage scale.
6. Small fractured hearthstones in the archaeological record are not necessarily related directly to secondary cultural processes (such as water boiling), but are instead a secondary result of the burning process.
7. Hot-rock technology is essentially reductive and hearthstones are a non-renewable component that may be profitably analyzed in terms of economic benefit, redundancy, and re-cycling.
The analysis of hearthstones recovered from the archaeological record has significant potential for exploring prehistoric hunter-gatherer subsistence strategies. The broader implication of this investigation is the realization that the interpretation of hearthstones, as recovered during archaeological investigation, is rarely a straightforward matter. Further experiments using a wider range of hot-rock resources and simulated structures may help to explain the relationship between the physical properties and constraints indicated by this study. Future research designs need to prioritize fine-grained data recovery, structural analysis, and actualistic study of hunter-gatherer thermal-feature technologies in order to build datasets capable of assessing the wide range of cultural variation inherent in the archaeological record. Expansion of the analytical focus to include the life-history of hearthstones and thermal features would engender the possibility of morphological variation following discard and abandonment. Actualistic experimentation indicates the potential benefits of detailed analysis and interpretation of hearthstone assemblages is currently underutilized.

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