HUNTER/FARMER MOBILITY IN SOUTHEASTERN NEW MEXICO: AN OSTEOLOGICAL PERSPECTIVE

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Abstract

From the 12th through 14th centuries A.D., an economic strategy developed in the American Southwest characterized by the trade of bison products from the Southern Plains for corn and other items from the Pueblo communities to the west. This thesis addresses the role in this trade relationship of the people who lived at two quasi-contemporary Pueblo-like villages located near the modern city of Roswell in southeastern New Mexico - Henderson and Bloom Mound. Faunal and lithic raw material studies suggest that the inhabitants of these villages may have been highly mobile, traveling hundreds of miles annually into the Southern Plains of central Texas and the Texas Panhandle to procure bison products such as dried meat and hides. They then transported these items long distances to the west to trade among the large, sedentary Pueblo communities of the Rio Grande Valley and adjacent areas for pottery, blankets, turquoise, and other items. At present, the high mobility of these Roswell-area inhabitants remains a hypothesis in need of further evaluation. This study takes a comparative osteological approach to investigate the level of mobility of these bison hunters and traders by evaluating the cross-sectional geometric properties of human femora. These data were compared with cross-sectional data from Pecos Pueblo, New Mexico - the mobility of whose population is better understood. The results of this comparison show significant differences in the skeletons of people from Pecos Pueblo and the Roswell area villages, but not in an expected way. Interestingly, these data also counter previously-documented trends in decreased femoral strength and sexual dimorphism with increased dependence on agriculture.

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1. INTRODUCTION

When people imagine living on the Great Plains before the arrival of Europeans, they imagine traveling across the open prairie in search of the enormous herds of bison which lived in the region. In contrast, when they imagine life in a Pueblo community, images of adobe architecture, farming and ceramic production come to mind. But as we move east from the Puebloan heartland, descending through the mountains into eastern New Mexico but before we reach the plains of Texas, is the landscape empty? Just as the popular imagination has not spent much time with these people, neither have archaeologists.

Historically, archaeologists have focused their resources and effort on the traditional Pueblo and Plains areas of the United States. Through extensive research into the material culture of these people and through first-hand written accounts by early Spanish explorers, an understanding of their experiences and the interaction between the two has been established (Kidder 1916; Spielmann 1991; see Hammond and Rey 1940, 1963, 1966). Pueblo people lived in permanent communities, grew maize and produced ceramics to trade for the bison products brought by Plains groups (Boyd 2001). These Plains groups traveled on foot across the landscape during the warmer months, hunting groups of bison - products from which they later brought to the Pueblo communities to trade during the winter (Speth 1991).

What about the people who lived in between these spheres of interaction? Archaeological inquiry conducted at Henderson (LA 1549) and Bloom Mound (LA 2528), two quasi-contemporary late prehistoric village sites located near Roswell, New Mexico has begun to answer this question. Research conducted at these sites by John D. Speth of the University of Michigan revealed communities occupied between the mid-1200s and mid-1400s A.D. These settlements were laid out in a Pueblo style consisting of room blocks with shared walls organized around plaza areas. Paleoethnobotanical evidence suggests that a significant amount of corn was produced nearby, and yet thousands of bison bones (and hundreds of arrowheads which may have been used in hunting these bovids) suggests that bison hunting may have been a large part of the community's subsistence activities (Speth and Rautman 2003; Adler and Speth 2003; Dunavan 2003).

Based on historic accounts by early Spanish explorers to the area as well as archaeological evidence, it appears that those living at Pecos Pueblo were much less mobile than their Plains neighbors. That settlement invested heavily in maize agriculture, which required a significant proportion of the population to remain within a few kilometers of the pueblo for most of the year (Spielmann et al. 1990). From historic accounts it appears that the males from Pecos Pueblo did engage in short hunting trips, but they involved only a small group which travelled for a few days in search of mid-size game like deer and antelope (Spielmann 1982).

Mobility is best thought of as a spectrum, and the people near Roswell seem to have engaged in a subsistence system which is in-between that of semi-sedentary or sedentary Pueblo farmers and nomadic Plains hunter-gatherers, which suggests that their overall mobility would also be in between that of traditional Plains and Pueblo communities (Eder 1984).

In order to corroborate this expectation, it is useful to look beyond indirect measures of mobility and examine the most direct evidence available - the human body. Examining osteological evidence of lifetime mobility is invaluable because it not only provides information about the experiences and activities of individuals but by averaging the sample one can gain a better understanding of the level of mobility in the community as a whole.

As put forth by Julius Wolff in the late 1800s (1982; cited in Ruff and Hayes 1983), the human body rebuilds its bones in order to better sustain forces exerted upon it during locomotion by the muscles attached to it. Combined with research by civil engineers on the physics of beams, it has been found experimentally that this bone adaptation occurs in a predictable way according to the types of movement and stress which occur during a person's life. This remodeling takes place in the ring of compact cortical bone which surrounds the medullary cavity (see Figure 1[1]) and can be characterized by its density, total area, and distribution about a central axis. The femur is the most useful bone to examine when researching mobility because of its importance in bipedal locomotion as well as the fact that femoral remodeling is well-researched (Ruff et al. 2006).

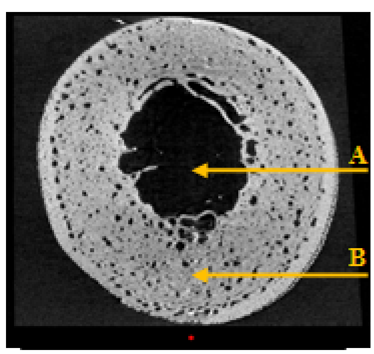


Figure 1: Osteological cross-section.
(a) Medullary cavity
(b) Compact cortical bone

[1]Image from `https://www.cs.drexel.edu/~david/geom_biomed_comp.html` (December 18, 2011)

Through observations of athletes and experimentation on animals, researchers have established that cross-sectional remodeling can both begin after adulthood and be observed when engaging in a wide range of physical activities (Burr et al. 2002; Kannus et al. 1995; Lieberman et al. 2002). Research using femoral cross-sectional morphology has addressed questions about human evolution, issues of sex and gender, the effects of agriculture on the human body, and the effects of colonialism on health and behavior (see Bridges 1989; Brock and Ruff 1988; Larsen 2000; Ruff and Brock 1988; Ruff et al. 1993; Ruff and Hayes 1983b; Stock and Pfeiffer 2001; Trinkhaus and Ruff 1998).

By conducting Computed Tomography (CT) scans on a sample of human femora (n=12), cross-sectional characteristics were measured from Henderson and Bloom Mound and then compared with data from Pecos Pueblo, a large Pueblo settlement near Santa Fe, New Mexico (about 280 km from Roswell) which was occupied between A.D. 600 and 1838. These data are useful because of their large number (n=76) and the extensive research already done with regard to mobility and subsistence at Pecos Pueblo which indicates that the community engaged in intensive agriculture and was not known to travel long distances in order to trade or hunt (Ruff and Hayes 1983, Kidder 1916; Spielmann 1983; Spielmann et al. 1990). By comparing these values to the data from Henderson and Bloom Mound, I am able to expand upon what previous research has suggested about mobility near Roswell and therefore understand more fully the subsistence strategies in use in the area and how these communities fit into the interactions between Plains and Pueblo people.

2. MOBILITY

Sedentism and mobility are two separate concepts which are problematically conflated with each other in much of the archaeological literature. As defined by Eder in 1984, sedentism is a threshold property of communities defined by the fact that at least part of the population lives at a settlement for nearly year-round. In contrast, mobility is a spectral quality of individual spatial movement that exists distinctly from sedentism.

Contrary to what we might expect, one cannot assume that a sedentary community with permanent residences is less mobile than a community which moves its primary residences multiple times per year. Notably, the Batak of the Philippines transitioned from a non-sedentary hunter/gatherer mode of subsistence to a sedentary settlement pattern which relied also on trade, agriculture, and wage labor but without an accompanying decrease in mobility. In fact, it appears that for the Batak mobility actually increased with the appearance of sedentism because it was accompanied by an expansion of their subsistence and economic activities.

By the 1900s, the Batak had permanent residences (mandated and allocated by the government) in which there was nearly always some portion of the population present. However, smaller groups or individuals left these residential bases of operations frequently to hunt and gather forest resources, to work for wages on distant plantations, and to stay for periods of time in small, temporary houses near their agricultural fields. Sedentism was forced upon this community by the government, and as a result of this policy along with the introduction of agriculture, trade and wage labor, individual mobility increased over time. This counter-intuitive relationship between sedentism and increased mobility is not entirely unknown. In fact, using cross-cultural ethnographic data, Binford has suggested that when people cease to move their towns and villages as often, their individual mobility increases to compensate (Binford 1980).

Eder also describes different levels and modes of mobility. It is important to understand these levels and how they relate to each other when examining issues of mobility in the archaeological record. The first and widest level of mobility that Eder defines concerns the settlement level, in which the entire community moves its residence. The second includes seasonal residential changes at the group level; third is the establishment of a "base of operations" from which smaller trips are made. Last is the level of individual mobility, which includes daily travel within the settlement to visit friends and complete chores as well as the distances covered during community-level moves (Eder 1984).

Because characterizing a whole community's mobility patterns is so complicated, it is important to delineate variables of mobility in order to understand which can be addressed through this analysis. In this capacity, it is beneficial to use Robert L.

Kelly's (1995) five variables of mobility: 1) number of residential moves per year, 2) average distance covered in a residential move, 3) total distance moved per year, 4) total area covered per year, and 5) average lengths of logistical forays. Combining these delineations with Eder's characterization of levels of mobility while keeping in mind the difference between mobility and sedentism provides a framework with which we can understand information regarding mobility made available by femoral-cross sectional analysis.

2.1. **MOBILITY AND FEMORAL CROSS-SECTIONAL MORPHOLOGY.**

In the 1980s, Christopher Ruff and colleagues pioneered a method of examining mobility by studying the human femur in cross-section. This method is based on the assumption (supported by experimental evidence) that bones in the human body remodel themselves in predictable ways in response to the muscle strain and load imposed upon them. By examining cross-sections of human bones, particularly of the femur, it is possible to determine a set of basic geometric properties which are affected by lifetime mobility (i.e. the frequency and magnitude of physical activity). These values can then be compared with values obtained from a data set whose level of mobility is better understood (see Ruff et al. 2006; Ruff and Hayes 1983).

Femoral cross-sectional morphology has the most direct bearing on Kelly's third variable of mobility - the total distance traveled overall by individuals (total distance moved per year). However, the concept of "total distance" must be taken somewhat liberally in this situation. Bone does not deposit in the way that tree rings do - in other words, each millimeter of cortical bone deposition does not correspond to another 50 km of average distance travelled per year (Ruff et al. 2006). The sensitivity and magnitude of this response likely differs from population to population and according to other factors as yet unknown (Bertram and Swartz 1991). Because of this, the examination of bone functional adaptation is necessarily relative and comparative; we are restricted to characterizing one population as more or less mobile than another. For this reason, a population whose mobility pattern is better understood must be included as a comparison when examining mobility at the community level.

Unfortunately, these averaged values can hide important behavioral distinctions within the community. It is likely, for example, that men consistently traveled long distances in search of game while women typically stayed closer to the village in order to gather wild plant resources, tend gardens and care for nursing infants. However, as with any proposed dichotomy, some counterexamples exist - most famously the Agta of the Philippines, in whose communities women often hunt game while carrying their young children on their backs (Eder 1984; Szuter 2000). While it is important to note that such an arrangement is possible, these cases are dwarfed by the number of ethnographic and archaeological communities which exhibit the more mobile men/less mobile women pattern (MacDonald and Hewlett 1999).

Additionally, even if the actual act of hunting were a gendered activity, there is much more to do on a hunting trip than simply kill animals. Depending on the hunting activities in which the community is engaged, weapons, traps and nets must be made and repaired, and after the hunt the animals must be processed and possibly cooked or preserved in some way. All of this work could be performed by women even in a community where hunting was done mostly by men (Fish 2000).

Complicating this matter further is the fact that by looking at the human skeleton, we can only address sex, which is entirely biological. Activities during life are most often segregated by gender, which is a performative social identity, and is difficult to see archaeologically (Geller 2009). It is not unheard of for a person with female genitalia to live his life entirely as a man, or vice versa, but it is highly unusual - it is extremely unlikely that one of the individuals included in this study falls into this category. Assignations of gender based on a one-to-one correspondence with biological sex is, therefore, an estimation, but one which is well-founded.

2.2. **MOBILITY AT HENDERSON AND BLOOM MOUND.** Located between the traditional Pueblo and Plains areas, Henderson and Bloom Mound offer an important opportunity to examine mobility in the context of Plains-Pueblo interaction. Henderson, the site from which some individuals included in this study come, was occupied slightly earlier than Bloom Mound. It was a pueblo-like village consisting of some 75-100 rectangular rooms arranged in a block E shape which enclosed two plaza areas (see Figure 2[2]). Ceramic seriation and radiocarbon dates, indicate that the site was occupied between A.D. 1275 and 1325/1350. Two arbitrary chronological phases are recognized at Henderson - an Early Phase dating between approximately AD 1275 and 1300 and a Late Phase dating between AD1300 and 1325/1350 (Speth 2004; Speth and LeDuc 2007).

Bloom Mound, from which the remaining three individuals come, was located a few kilometers east of Henderson. The village itself was organized as pueblo-like rooms (but set a few centimeters into the ground) and arranged around a central semi-subterranean plaza (see Figure 3[3]). Evidence from ceramic seriation suggests that this site was occupied between A.D.1300/1350 into the first half of the 15th century A.D. - only two or three generations after Henderson's Late Phase ended. Excavation at Bloom Mound revealed a sharp increase in trade goods such as non-local ceramics, turquoise, and other exotic items but a sharp decline in the frequency of bison remains in comparison with

[2]Image courtesy of John D. Speth, University of Michigan
[3]Image courtesy of John D. Speth, University of Michigan.

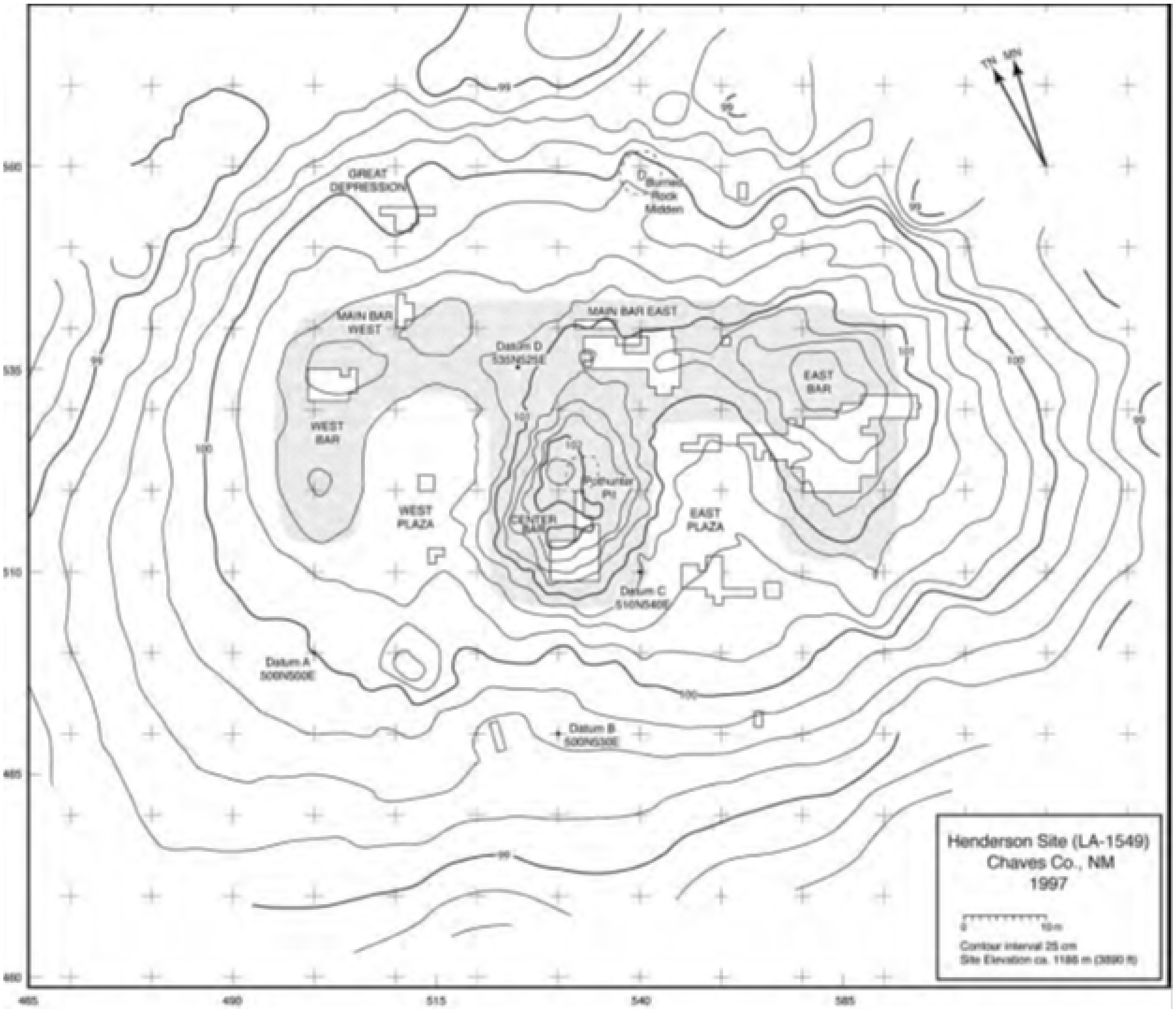


Figure 2: Map of the Henderson site.

Henderson, which may indicate a general reduction of mobility related to long-distance hunting (Newlander and Speth 2009).

Previous research which has bearing on mobility at Henderson has included faunal studies, lithic sourcing, frequency of non-local ceramics and other exotic items and examination of architecture and storage. When combined, these lines of evidence have been used to argue that the people at Henderson and perhaps Bloom Mound were significantly more mobile than one would expect in a traditional Pueblo community due to their participation in seasonal hunting trips into the Texas panhandle.

Most of the bison remains found at Henderson were high-utility parts of the upper limbs, with notably fewer pelves and skulls. When evaluated using a Modified General Utility Index, it becomes clear that this patterning is a result of decisions regarding

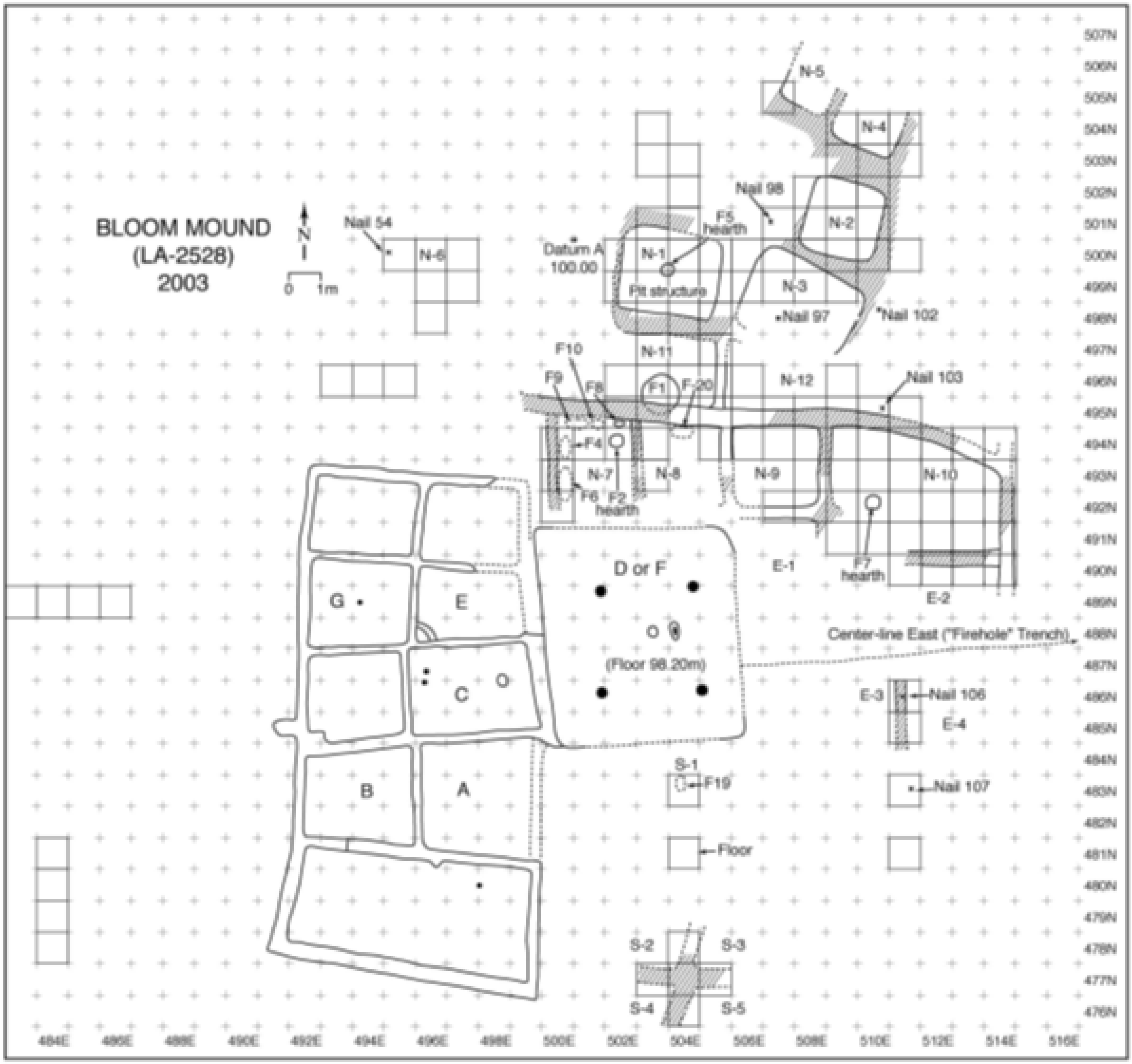


Figure 3: Map of Bloom Mound.

which skeletal elements to transport from a kill site located far from home. The General Utility Index is a composite of three different Utility Indices developed by Lewis Binford based on the relative fat, marrow and grease content of individual body parts. By combining these three factors, each body part is given a numerical value according to how nutritionally useful it is (Binford 1978).

Given the weight of adult bison, it is not surprising that the farther away from the community a kill is made, the more decisions about which parts should be left and which should be transported back home for processing must be made. For example, it is better to transport a haunch which provides a large amount of meat, marrow and grease rather than the forelimbs, which provide comparatively little of each. By using a near-by contemporaneous bison kill site as an analog, the frequencies of body parts at Henderson indicate that the locations at which these animals were killed must have been far away (Speth and Rautman 2004).

A significant amount of projectile points recovered from Henderson and Bloom Mound seem to have their origins in the Texas Panhandle or in central Texas. Appearance (i.e. color, texture, and patterning) has been used to identify sources of chert, although different sources can often resemble each other quite closely. At Henderson and Bloom Mound, another method has been used to help distinguish cherts which look similar under ordinary light. This method relies on the color that the material produces under short- and longwave ultraviolet (UV) light. Using this technique, three main kinds of non-local chert seem to be present at Henderson - Alibates and Tecovas from the Texas Panhandle, which both fluoresce bright green under UV light, and Edwards Plateau chert which fluoresces bright yellow to orange (Newlander and Speth 2009).

Approximately 40% of the projectile points found at Henderson were made with non-local materials - 20% from the Tecovas/Alibates area and the remaining 20% from the Edwards Plateau (Newlander and Speth 2009). Their sources are remarkably far away from Roswell - the Tecovas/Alibates sources are located around 320 kilometers from Roswell, and the Edwards Plateau chert could have come from over 650 kilometers away, the entire distance of which would have been travelled on foot - an indication of a highly mobile population (Newlander and Speth 2009). It is assumed that these points recovered from Henderson and Bloom Mound were made during the hunt to replace broken equipment and not traded into the community. This is supported by the fact that the points found at Henderson and Bloom Mound which were made with non-local chert do not differ in style or size from points made with obviously local chert (Speth 2011 pers. comm.).

The architecture present at Henderson and Bloom Mound suggests that both communities were sedentary - at least a portion of the community was present at the village at any given time. This is indicated by the fact that no clandestine storage has been found at either site. Instead, based on the fact that some sections of the room blocks contained no hearths whatsoever, it appears that whole rooms were dedicated to storage of surplus goods and food. If the entire populations at Henderson and Bloom Mound left the village in order to hunt bison in Texas, such obvious storage would leave their resources extremely vulnerable to theft (Speth 2011 pers. comm.). Using this schema, it is reasonable to assume that the entire community participated in planting the fields in the early spring. Then, later in the summer, the majority of the prime adult population left to hunt in the east, leaving a small subsection of the community that could not travel (such as the young, the elderly, and recent mothers). It is likely that these people who remained at the village looked after the crops but because they did not rely as heavily on that particular resource as the people at Pecos Pueblo, a smaller workforce was needed. This would have allowed the rest of the community to travel long distances into the planes of Texas during the hunt. In contrast to the mobility strategies occurring at Henderson and Bloom Mound, based on architecture, subsistence strategy and Spanish descriptions, it appears that the people at Pecos Pueblo were much less mobile and that it was probably males more so than females who were the most mobile.

2.3. **MOBILITY AT PECOS PUEBLO.** Pecos Pueblo itself (LA 625) began to be occupied at this time and was home to up to 1,100 sedentary maize agriculturalists during its Classic Period (A.D. 1325-1600) until their forced relocation in A.D. 1838 (Capone 2011). Contemporary with Late Phase Henderson and Bloom Mound's occupation, morphological data from the large skeletal sample at Pecos Pueblo are indicative of the osteological characteristics of the Puebloan communities with which those living at Henderson and Bloom Mound might have traded.

Large-scale permanent architecture employed at Pecos Pueblo as an indication of lower mobility is supported by the fact that the production of maize was a primary concern in the community (Speilmann 1982). In order to have a successful harvest, a farmer cannot simply plant his seeds and walk away until the fall harvest. Constant attention must be paid to the plants - they must be provided with water and protected from weeds, wild animals and raiding neighbors. This investment in the production of maize required residents of Pecos Pueblo to reduce the time they invested in other activities such as hunting and gathering wild plant foods, which require more movement across the landscape (Speth 1991; Spielmann et al. 1990).

Perhaps most telling with regard to Pecos pueblo's lower mobility, Spanish chronicles indicate that in order to trade for products from the plains such as bison meat and hide products which they did not procure themselves, the people at Pecos did not travel far. Members of the Coronado expedition from 1540-1542 described Plains groups traveling to the Pueblos of western New Mexico to trade ; one chronicle specifically mentioned nomadic traders spending the entire winter at Pecos (Creel 1991; Speth 1991).

Combined, evidence from architecture, subsistence strategy and Spanish chronicles describes a community which was so highly invested in maize agriculture that mobility in the community dropped and people began to procure meat and hides through trade. While there is no indication that the people living at Henderson and Bloom Mound traveled to Pecos Pueblo itself to trade, the subsistence and mobility strategies employed there broadly characterize the type of community with which they might have traded. This arrangement, in which Plains and Pueblo periphery groups traveled long distances to procure and trade bison products to Pueblo communities, has been termed Plains-Pueblo Interaction, and helps to frame the expected differences in mobility at Pecos Pueblo in contrast with Henderson and Bloom Mound.

3. PLAINS-PUEBLO INTERACTION

The trade of bison products by Plains groups for items such as maize and ceramics from Pueblo communities is well-documented and was an immensely important aspect of subsistence strategies for both groups. The primacy of Plains-Pueblo interaction has been described ethnographically, examined ecologically, and analyzed economically (Boyd 2001; Creel 1991; Speth and Scott 1989; Spielmann 1991).

There is evidence from accounts of Spanish explorers at Pecos Pueblo that bison hide clothing was ubiquitous there - nearly every person had shoes whose soles were made of bison hide and a buffalo robe to keep warm, though there is no mention of direct procurement of these bison hide products. This importance of bison hide products is also evident archaeologically - in his early excavations at Pecos Pueblo, A.V. Kidder found masses of bison hair and skin fragments in many burials - likely placed there as some kind of shroud or other grave good (Creel 1991).

In return for these products as well as jerked bison meat, Plains groups received ceramics, maize and certain raw materials and decorative items. Pueblo ceramics, turquoise, and obsidian have been found during excavation of sites in the Texas Panhandle and at other Plains sites the remains of bison kills made with Plains-style projectile points have been found in association with Pueblo ceramics (Boyd 2001; Spielmann 1991). These exotic goods have been found throughout the Plains in small quantities which are indicative of trade.

Intensive bison hunting in the Plains seems to appear suddenly in the archaeological record around A.D. 1300, as evidenced by a sudden increase in the overall frequency of bison bones found at sites in the Texas Panhandle and southern Plains (Creel 1991). This increase in bison remains was accompanied by a dramatic increase in the appearance of tools related to bison hunting and processing (projectile points, endscrapers, etc.) (Creel 1991).

Some researchers have suggested that this increase in bison hunting reflects a sudden increase in the population of bison in the area, as it appears to have fluctuated a number of times during the Holocene (Creel 1991). However, Speth and Scott (1989) suggest that this sudden increase could instead mark the beginning of the Plains-Pueblo trade system. The authors argue that Plains people increased their hunting of bison in order to obtain Pueblo products such as maize and ceramics in larger and larger quantities. The appearance of this economic relationship provided Pueblo groups with the much-needed protein that became more and more difficult to obtain once maize production began in earnest (Speth and Scott 1989).

This and other evidence provides support for Spielmann's (1986) view of the Plains-Pueblo system as a mutualistic relationship - one in which each party provides the other with complementary resources. Spielmann contrasts mutualism with buffering, in which trade occurs only when one party has found a resource scarce and must trade for another's surplus. This does not appear to characterize the Plains-Pueblo relationship, since each group specialized in producing different resources. This mutualism may even have been reinforced by raids on Pueblo communities by Plains groups (Spielmann 1986).

Spanish expeditions that entered Pecos Pueblo were told that the community had recently been attacked by raiding Plains groups, and it is unlikely that this type of raiding was done in order to procure the resources for which they traded. Pueblo communities are well fortified and have superior numbers in comparison with Plains raiding parties; additionally, maize would be difficult to carry away on foot in sufficient quantities to make such a raid profitable. Because of this, Spielmann (1991) thinks it likely that such raids were carried out only at times when Pueblo groups had a surplus of food and goods and were therefore less likely to trade with Plains groups. These raids helped ensure the mutualistic nature of their trade relationship - if Pueblo groups had no need for Plains products, there would be little impetus for them to trade.

Mutualism was also ensured by Plains groups on their own territory. From Spanish accounts, it appears that Pueblo groups did not often travel into the plains to hunt bison. One would-be guide of a Spanish expedition refused to accompany them into the plains because the groups there were known to attack Pueblo parties that attempted to hunt bison in their territory (Spielmann 1991). Plains groups might have sought to secure their position as providers of meat and bison products to Pueblo communities and to ensure the steady flow of maize and other products in the opposite direction.

An important impetus for this trade relationship is based in the specific nutritional needs of each group. While Plains groups had access to large amounts of high-quality protein in addition to carbohydrates available from some wild plant foods, Pueblo groups had access to large amounts of carbohydrates in the form of maize, but relied on local game to provide fat and protein. These complementary needs seem to have driven Plains-Pueblo trade.

Pueblo groups had access to large amounts of calories and carbohydrates from maize but found high-quality protein and fat harder to come by. Fat provides nearly twice as many calories per gram as carbohydrates or protein, so fatty cuts of meat were in high demand - two resources which the Plains bison products could sufficiently provide (Frisancho 2000).

Each of these nutritional resources (protein, fat and carbohydrates) is scarce for Plains and Pueblo groups at different times of the year. For Plains populations, the most dificult time of the year is in early spring, before wild plant sources become available and wild animals are lean and do not provide enough fat calories to off-set protein intake. In contrast, because Pueblo groups were able to store surplus grain from year to year, they often had enough maize to take them through this tough time and into the planting season. However, this in turn meant that Pueblo people needed to survive until the maize was ready to be harvested before they could cease to rely on stored foods. This time of scarcity occurred in mid-late summer, when Plains groups were spoiled for choice with regard to wild plant and animal sources (Speth 1991).

If Plains-Pueblo interaction truly was mutualistic in nature, we would expect it only to have occurred when Plains and Pueblo times of need overlapped, and indeed this is the case. Ethnographic accounts specifically refer to Plains groups travelling west to trade only in the winter, when both groups have lowered access to calories and protein, respectively.

3.1. **PLAINS-PUEBLO INTERACTION AT HENDERSON AND PECOS PUEBLO.** As discussed above, the Henderson site and Bloom Mound are located in between the traditional Plains and Puebloan areas. This unique geography begs a question - did they engage in this Plains-Pueblo system? If so, did their involvement most closely resemble agricultural Pueblo communities or mobile bison hunters and traders? Both of these subsistence strategies result in unique chemical traces preserved in human bone.

Stable isotope analysis was performed on a small sample (n=13) of human bone from the Henderson site. By comparing the C4 plant signatures of these human samples with a sample of bison, it can be estimated that the people at Henderson consumed approximately 85% of their calories in C4 foods, of which maize is only one example. This is about 10% less than has been observed in traditional Pueblo communities and significantly more than more mobile Plains populations in the Texas Panhandle. Evidence from tooth wear, frequencies of caries and groundstone studies indicates that the subsistence strategy employed at Henderson was somewhat in-between these two groups' (Schoeninger 2004).

It is likely that bison meat and other by-products such as fat and marrow contributed a significant proportion of the remaining 15% of the diet at Henderson, and examination of the timing of bison hunting at Henderson can help to characterize Henderson's role in Plains-Pueblo interaction. In reality, this percentage was probably much higher; because bison subsist largely on wild C4 plants, some of the C4 signature in the human bone analyzed would have come from consuming animal products.

As discussed above, Pueblo groups often needed to supplement their diet with animal products during the late summer into fall and winter, while Plains groups hunted most intensely in the spring and early summer. From the age and sex ratio of the bison remains found at Henderson, it is clear that bison hunting was, in fact, occurring in the spring, as expected (Speth and Rautman 2004).

The timing of this bison hunt would make sense if the people at Henderson endeavored to supply bison products to Pueblo communities much like more traditional Plains groups did. The importance of the spring bison hunt to the community would have taken a significant amount of useful agricultural labor away from Henderson at a time in which many people were needed to plant the fields and protect the delicate seedlings. The fact that some residents living at the Henderson site left its fields at such a formative time in maize growth is indicative of the comparatively low emphasis on maize production at Henderson and Bloom Mound.

This reasoning has been supported by analysis of the types and frequencies of bison remains at Henderson. Speth and Rautman (2004) found that certain elements (which according to the Binford's (1978) Modified General Utility Index (or MGUI) should have been transported from the kill site) were not present in domestic contexts in the expected quantities - notably ribs and thoracic vertebrae.

It has been suggested by others that the absence of ribs at the site might be due to taphonomic processes - specifically to foraging village dogs that destroyed the ribs in the search for grease and marrow, but Speth and Rautman (2004) disagree. To address this possibility, the authors examined frequencies of medium ungulate rib elements. Since the ribs from these animals are much more gracile and easier for village dogs to destroy, even fewer ribs from these animals should be present if this were indeed the case. However, the opposite was found - higher frequencies of the more delicate ungulate ribs occurred than the more robust bison elements. This indicates that the absence of ribs and thoracic vertebrae must be due to another reason - likely trade.

Trade in bison ribs has been documented ethnographically. Often, the animal was killed, then large portions of the ribcage were left intact (with most of the thoracic vertebrae still attached), and then dried in the sun. Thus prepared, the bison meat was easy to transport long distances and well-preserved for the journey (Speth and Rautman 2004). The paucity of ribs and thoracic vertebrae at Henderson provides further evidence that the people at Henderson participated in the trade of bison products out of the plains and into Pueblo communities.

As noted above, bison clothing and robes appear to have been ubiquitous at Pecos Pueblo (Creel 1991). It is clear ethnographically that the community at Pecos relied heavily on resources traded in during the winter from Plains groups (Spielmann 1991), and stable isotope analysis of human remains found at Pecos indicates the importance of traded animal products into the settlement.

These studies indicate that people at Pecos Pueblo obtained around 75% of their diet directly from maize, and up to 95% from C4 plants in general, suggesting a very high reliance on maize produced in the community itself in addition to some wild plant sources (Schoeninger 2004; Spielmann 1990). However, a person cannot subsist entirely on carbohydrates - fat and the full complement of proteins and vitamins required for normal functioning of the human body are very hard to come by in plant sources.

Maize lacks one nutrient in particular- niacin. Historically, people who relied heavily on maize had to develop cultural adaptations to address this. Some groups cooked maize in lime, while others added wood ash. Mediating this nutritional deficit was extremely important - if a person goes too long without a reliable source of niacin, a disease called pellagra can develop, which causes diarrhea, dermatitis, depression and eventually death (Frisancho 2000). Because Plains groups like those living at Pecos Pueblo relied so heavily on maize, it became essential that these groups continued to trade their agricultural products for bison products not only in the form of hides for clothing but in the form of the protein and other nutrients present in bison meat.

The way in which communities use the resources available to them has enormous bearing on the ways in which they move about the landscape. Faunal and stable isotope evidence from Henderson and Bloom Mound along with the presence of trade items has supported the argument that these communities procured bison products for trade with Pueblo settlements much like Plains groups did. It is important to further evaluate this hypothesis using more direct evidence of the ways these people utilized the landscape in their subsistence activities; analysis of femoral cross-sectional morphology allows archaeologists to access osteological evidence of mobility.

4. BONE FUNCTIONAL ADAPTATION

In 1892, Julius Wolff published a paper in which he theorized that human bones deposit or resorb cortical bone in response to increased or decreased in vivo physical activity, respectively. Beginning in the 1980s, biological anthropologists Christopher Ruff and Erik Trinkhaus combined this model of bone remodeling with a set of paradigms and geometric properties borrowed from civil engineering in order to infer past levels of physical activity from archaeological samples of human bones. Their previous work establishing the applicability of these techniques to archaeological samples was the basis for this paper.

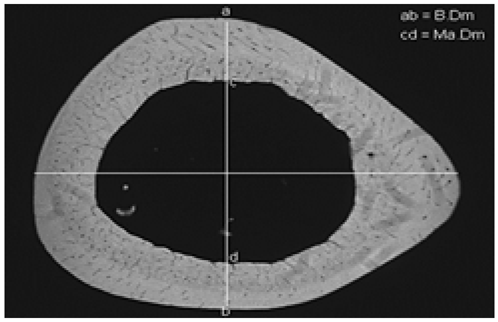
According to Wolff's Law, the human body rebuilds compact cortical bone in order to better withstand the forces exerted upon it by the muscles attached to it. For example, it has been found that in tennis players, one arm is always more robust in cross-section than the other (Ruff et al. 2006).

This type of bone rebuilding has been corroborated by historic and separate osteological evidence. Clark Spencer Larsen (2000) conducted a study on the humeral and femoral cross-sectional morphology of a Caribbean population which experienced a substantial increase in physical labor with the arrival of Spanish conquistadors. More traditional signs of increased physical stress and overall poor health were present in the skeletons studied - including an increased presence of caries, enamel hypoplasia, anemia, osteoporosis, and infection. These data as well as first-hand accounts from the period were supported when cross-sectional geometric studies were conducted on the humeri and femora from that site. In both bones, there was a dramatic increase seen in nearly all cross-sectional properties (see below) between pre-Columbian and Spanish contact time periods (Larsen 2000).

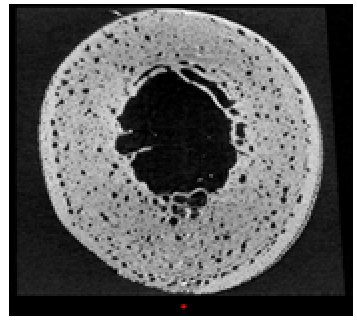
By imagining human bones as hollow beams (much like those that support buildings and bridges), the way that bone remodels itself according to prolonged or repeated stress and strain can be predicted by first understanding the physics of beams themselves. Structural beams are designed and shaped differently according to the type of stresses which they must withstand. A beam which must withstand bending pressure perpendicular to its longitudinal axis would be stronger if it were positioned so that its thickest part took the brunt of that force. In contrast, if the beam must withstand more torque than bending, the most stable shape is perfectly round. Both of these concepts hold true for human long bones, and the body remodels itself according to these expectations (see Figure 4[4]).

The type and extent of this bone remodeling can be identified by examining cross-

[4] Images from `http://www.springerimages.com/Images/MedicineAndPublicHealth/1-10.1007_s00198-009-0941-y-1` and `https://www.cs.drexel.edu/~david/geom_biomed_comp.html` (December 18, 2011)



(a) Cross-section of bone adapted to Medio-lateral bending



(b) Cross-section of bone adapted to torsional bending

Figure 4: Cross-sections of bone adapted to withstand different types of forces.

sections of human bone and computing certain geometric properties which can be compared between data sets. In their original work at Pecos Pueblo, Ruff and Hayes physically cross-sectioned a large sample (n=119) of human femora and calculated properties such as Cortical Area (CA), Medullary Area (MA), Total Area (TA), density, Second Moment of Inertia (I), Polar Moment of Inertia (J) and Polar Section Modulus (Zp). The Second Moment of Inertia is a dimensionless quantity that relies not only on the area of cortical bone but its distribution about a central axis, and is indicative of the bone's strength against bending stress. The Polar Section Modulus relates the Second Moment of Inertia to the radius of the bone and is indicative of the bone's strength against torsional bending. The Polar Section Modulus (Zp), Second Moment of Inertia (I) and the Polar Moment of Inertia (J - a measure of the average bending strength of the bone) allow researchers to discern structural differences between two sections of bone which may have the same CA but very different MA - the one with a smaller medullary cavity will have a lower bending rigidity than the one with a large medullary cavity (Ruff and Hayes 1983).

Both the tibia and the femur have been singled out by previous researchers in examining lifetime mobility because of their obvious involvement in bipedal locomotion (Ruff and Hayes 1983a). However, Ruff and Brock (1988) found experimentally that the femur exhibits the most predictable remodeling. In addition, it has been established by Ruff (1987) that the most useful place to conduct these cross-sections is at 50% of the length of the bone measured from the distal end (followed closely by 80% of the bone length), and has been shown to be little affected by the sex and genetics of the individual.

Some have criticized Ruff and Brock's view of bone remodeling as too ideal (i.e. Bertram and Swartz 1991). In response, Ruff et al. (2006) have shown that while there may be a multitude of complicating factors which make the result of prolonged and repeated stress and strain harder to predict in an exact way, the values obtained from this type of research are still indicative of relative mobility strategies, as evidenced by experiments on both animals and humans (Ruff et al. 2006).

Lovejoy et al. (2002, 2003) point out that age may be a significant complicating factor in the study of bone functional adaptation. They suggest that, though bone remodeling may be a significant process during adolescence, it ceases in adulthood and any difference in bone morphology seen archaeologically only reflects activity which occurred during that formative period. In order to refute this view, Ruff et al. (2006) point to experiments which followed tennis players who began participating in the sport at different times in their lives. These studies convincingly showed that the body adapts bone shape to stresses which begin even in adult life, although in a different way (adolescents tended to add periosteal bone, while adults added bone endosteally). In addition, the authors cite Pearson and Lieberman (2000) in pointing out that in many societies, community members begin adult activities at a much younger age than one might assume today - well within the period of adolescence when bone adaptation to in vivo stress has the greatest effect (Ruff et al. 2006:494).

Using the techniques and concepts put forth by these researchers, I examined bone remodeling as an indicator of mobility related to subsistence strategy at Henderson and Bloom Mound and compared these data with previously-published values from Pecos Pueblo. These results assist in assessing the hypothesis put forth by Speth (2010 per. comm.) that the residents of Henderson (and to some extent Bloom Mound) were more mobile than their Puebloan neighbors as a result of their direct involvement in the procurement of bison.

My analysis focused on the most informative cross-sectional variables - Percent Cortical Area (%CA), Polar Moment of Inertia (J), Polar Section Modulus (Zp), and Maximum Moment of Inertia/Minimum Moment of Inertia (Imax/Imin). These parameters reflect the compressional strength, bending strength, torsional strength of the bone, and provide an estimate of shape, respectively. When combined, they provide an estimate of the overall strength of a bone (see Ruff and Hayes 1983a; Ruff 1987; Ruff 1999; Larsen 2000; Stock and Pfeiffer 2001).

5. THE HENDERSON AND BLOOM MOUND BURIALS

Thirteen of the 27 burials excavated from Henderson and Bloom Mound were included in this study[5]. Only adult individuals (ranging from 17-50+ years of age) whose femora were reasonably intact were analyzed. During excavation, each burial was given an identifying feature number in sequence with other features (including hearths, post holes and storage pits) in the site - i.e. because the last burial at Henderson is Feature 67, this does not mean that there were, in fact, 66 other burials found at that site. The Bloom Mound feature numbers began again with Feature 1 when excavation of that site began.

Burial data have been summarized elsewhere (see Rocek and Speth 1986; Clark and Speth unpublished). In brief, the individuals included in this study range in age from 16 to 40+ years of age and include five females and eight males. Age and sex information regarding the individuals included in this study are summarized in the Index along with their femoral cross-sectional properties.

All human remains were excavated by John D. Speth under a series of annual permits to excavate human burials located in any unmarked burial ground within the State of New Mexico. These permits were issued by the Cultural Properties Review Committee, Historic Preservation Division, Department of Cultural Affairs, Santa Fe, NM.

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6. METHODS

In their previous work with cross-sectional properties at Pecos Pueblo, Ruff and Hayes (1983a) physically cut the femora included in their study in order to attain the values needed. Due to obvious ethical and curatorial issues, the femora included in this study were instead examined using Computed Tomography (CT) technology. Sumner et al. (1985) established through experimentation that cross-sectional values obtained through CT scans are accurate enough to be compared with values obtained from direct cross-sectioning.

In order to prepare the femora for CT scans the biomechanical length of each bone was determined, which Ruff and Hayes (1983a:363) defined as "the average distance parallel to the longitudinal axis between the two condyle articulation surface centers and the intersection of the longitudinal axis with the proximal end of the diaphysis (usually falling at about the junction of the femoral neck with the greater trochanter, just medial to the insertion area for obturator internus)." Length was measured by positioning the distal condyles of each bone perpendicular to the end of a standard osteological board. The positions of the 50% and 80% values were then marked using cloth medical tape, which is visible on X-Ray[6]. In the event that both the right and left femora were intact, the better-preserved element was used.

Because certain femora from both Henderson and Bloom Mound were incomplete, some of these locations were estimated. Henderson Feature 21 was missing the distal end of the right femur and the proximal end of the left femur. By examining the two fragments side-by-side and comparing osteological landmarks, it was possible to estimate an approximate length as well as locate the 50% and 80% positions on the right femur. Henderson Feature 29 was a male whose left femur was missing its proximal end. The length of this bone was estimated using a tibia to femur ratio obtained from Feature 25, another male from the Henderson sample who had a similar estimated stature. Henderson Feature 66 had to be landmarked using another female femur from Henderson with a similar estimated stature (Feature 40). Similarly, Bloom Mound Feature 40 consisted of only a section of midshaft. The 50% and 80% locations for this individual were estimated using the right femur from Bloom Feature 4.

Each femur was scanned using a GE Specimen MicroCT Scanner. This particular machine produces a series of images along the long axis of the bone, which resulted in a few centimeters of bone included in each scan (which were each made up of over 100 slices). Using a program called MicroView 2.1, these slices were compiled to create a cross-sectional view of the bone. I then rotated each image such that the Ateroposterior

[6]While the 80% location was included in the CT scans, the cross-sectional properties of that location were not included in this study because these data were not available from the Pecos Pueblo sample. Cross-sectional properties for the 80% location are available in the Index

dimension corresponded with the y-axis and the Mediolateral dimension corresponded with the x-axis. I then cropped the image such that only a 10 mm length of bone remained, as this particular program does not allow for the analysis of a dimensionless cross-section (it is unlikely that geometric properties would change significantly within this small section selected).

Using a Hounsfield Unit threshold (an arbitrary unit which the computer uses to distinguish bone tissue from other materials) of 2,000, I ran a Cortical Analysis which provided Total Area, Cortical Area, Medullary Area, Ix, Iy and J and a Bone Mineral Density Analysis on each of these rotated scans in MicroView 2.1, resulting in average values for this 10 mm section. I then used a macro for a free JavaScript program called ImageJ provided by Christopher Ruff (Moment Macro[7]), which determined the angle (theta) made between Ix and Imax (see Figure 5[8]). Using that angle, I again rotated each of the cropped images in MicroView such that the major axis corresponded with the y-axis and the minor axis corresponded with the x-axis. I again ran the Cortical Analysis, which provided values for Imax and Imin. The major radius (Cmaj) of each scan was determined by using the centroid (center of mass) provided by the Cortical Analysis run in MicroView 2.1 and then measuring the distance to the outer edge of the bone in the direction of the major axis. By dividing the Polar Moment of Inertia for each element by this value r, I determined the Polar Section Modulus (Zp).

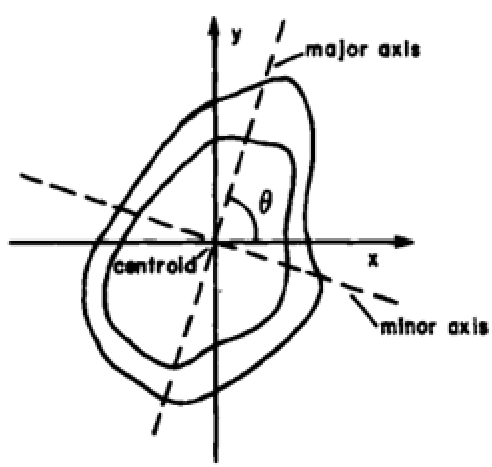

Figure 5: Diagram of major and minor axes

Because differences in leg length and body mass can affect cross-sectional geometric properties, some of these values described above were standardized. Previous research by Auerbach and Ruff has suggested that standardization by estimated body mass

[7]Available for download at `http://www.hopkinsmedicine.org/fae/mmacro.htm`
[8]From Ruff and Hayes 1983a

is best. However, the two best methods for achieving this estimation require well-preserved pelves or femoral heads, respectively - neither of which were consistently preserved in the Henderson or Bloom Mound sample (see Auerbach and Ruff 2004; Ruff et al. 2004). In lieu of body mass estimations, Ruff suggested (pers. comm. 2011) standardizing area measures by femoral length3, second moments of area by femoral length5.33, and section moduli by femoral length4 (see Ruff et al. 1993). I was concerned that standardizing these values by such high powers of bone length might result in differences which reflected not true population differences in cross-sectional properties but differences in leg length between and within populations. Therefore, in this study, J and Zp were standardized simply by dividing by femoral length. Because %CA and Imax/Imin are ratios, these values were not standardized at all (see Shaw and Stock 2011).

Because not all femora included in this study were complete, all femoral lengths used in standardization were derived from estimated statures reported by Rocek and Speth (1986) and Clark and Speth (unpublished) based on tibial lengths. Figure 6 plots the measured femoral length of eight individuals whose femora were intact against the derived length from stature estimates based on tibial length. These measured and derived lengths match well - there are two notable outliers, one of which is an individual who has previously been identified as "unusually small" (John D. Speth, personal communication, 2011).

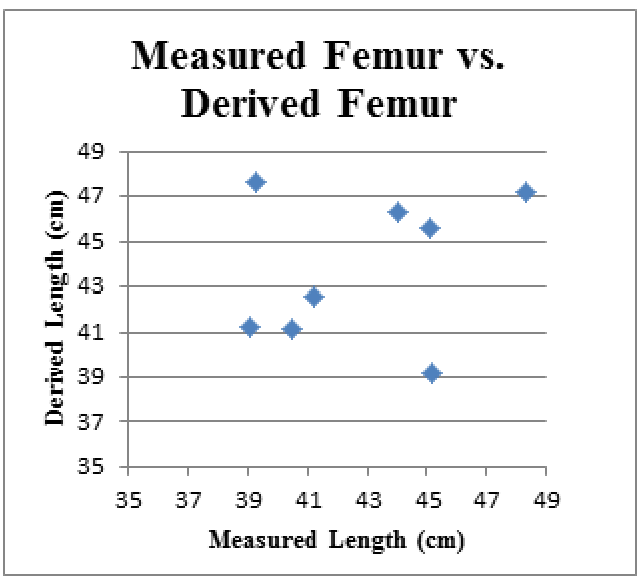

Figure 6

Feature 66, a male, included neither a well-preserve femur nor tibia. While the femur was landmarked and included in the CT scans, it was excluded from this study because it was not possible to derive a Feature 66 femur length. This resulted in a final sample size of twelve.

Stature estimates for the Henderson and Bloom Mound sample were determined by Rocek and Speth (1986) using the Genovs formula as outlined by Steele and McKern (1969). Two and one half centimeters were subtracted from the estimated height in order to approximate living stature (Clark and Speth unpublished).

Cross-sectional properties from Pecos Pueblo published by Ruff (2011) were used for comparison. These published data formed only a subset of the 119 individuals from Pecos Pueblo included in Ruff and Hayes' 1983 analysis. Once the juvenile values were excluded from the 2011 publication, 76 individuals remained for use in this study. I divided the cross-sectional values from Pecos Pueblo by a measured femur length provided by Ruff (2010) for standardization since no tibial lengths were available from which to derive estimated heights (as I did for the Roswell-area individuals). While these two methods differ, the way each population was standardized is internally consistent.

7. RESULTS

Using the statistics program SPSS (available through IBM), the femoral data from Roswell and Pecos Pueblo were analyzed both between and within sites which revealed complex relationships between cross-sectional robusticity, archaeological site origin and sex. These analyses focused primarily on three measures of cross-sectional robusticity and one measure of cross-sectional shape - J (Polar Moment of Inertia - a measure of average strength against bending forces across the cross-sectional plane); Zp (Polar Section Modulus - a measure of the torsional strength of the cross-sectional plane,); %CA (a measure of the compression strength of the cross-sectional plane); and Imax/Imin (a measure of the circularity of the bone and indicative of torsional strength)[9].

In general, higher values of J, Zp and %CA are indicative of higher strength of the bone. However, there is somewhat of an inverse relationship between some of these variables. For instance, by expanding the cortical ring of bone farther away from the centroid, the bone becomes stronger against torsional forces (Zp), but the %CA will decrease (there is less cortical bone relative to total area of the cross-section). Because of this, it is very unlikely that all three of these values would be significantly greater in one population over another. The closer that the ratio of Maximum Moment of Inertia to Minimum Moment of Inertia (Imax/Imin) is to 1, the more circular the bone, which allows this value to function as a rough shape estimate. Because a bone becomes stronger against torsional forces the more circular it is, Imax/Imin also functions as an indication of torsional strength much like Zp.

7.1. **BY POPULATION.** Table 1 illustrates differences between the sites in mean values of J, Zp, %CA and Imax/Imin by demonstrating that the mean values from the Roswell data fall outside of the 95% confidence interval at Pecos Pueblo (derived from a one-sample t-test). These minimum and maximum values define a range between which the true populational mean at Pecos Pueblo most likely falls. The fact that the Roswell-area mean values fall outside of that range indicates that there is a significant difference in the two populations' 50% femoral cross-sectional geometric properties. Contrary to expectations, however, three of the four mean values from the Roswell-area sites (barring Imax/Imin) fall below the lower boundary. Initial expectations of higher mobility at Roswell would predict the opposite - larger mean values in the more mobile population.

A Mann-Whitney U test was conducted to compare these means between geographic area, which determined statistical significance in a different way than standard t-tests (Table 2). The Mann-Whitney U test is non-parametric in that it does not assume

[9]While J is measured in mm^4 and Zp is measured in mm^3, each of these values was standardized by dividing by femoral length, resulting in values reported in mm^3 and mm^2, respectively

Standardized Variable	Roswell Mean	Pecos 95% Min	Pecos 95% Max
J (mm^3)	636.35	669	756.4
Zp (mm^2)	45.2	55.2	60.7
%CA	64.1	69.4	72.7
Imax/Imin	1.82	1.31	1.42

Table 1: Roswell means compared with Pecos Pueblo 95% confidence intervals

a normal distribution in either of the populations and is not as greatly affected by sample size as traditional analyses, which makes it ideal to use with these data. The null hypothesis which was tested in each of these analyses was that there is no difference in each of these variables between the two populations (at Henderson/Bloom mound or Pecos Pueblo). As indicated by Table 2, this null hypothesis was rejected (at a very high significance) for three of the four variables - Zp, %CA and Imax/Imin, but was retained for J. The fact that both the standard t-test and Mann-Whitney U indicated a difference between the two populations in Zp, %CA and Imax/Imin is strong support for a difference in true population means. For J, however, because the results of these two methods are inconsistent we cannot draw firm conclusions about population-level differences.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of J is the same across categories of Group.	Independent-Samples Mann-Whitney U Test	.151	Retain the null hypothesis.
2	The distribution of Zp is the same across categories of Group.	Independent-Samples Mann-Whitney U Test	.001	Reject the null hypothesis.
3	The distribution of PercCA is the same across categories of Group.	Independent-Samples Mann-Whitney U Test	.033	Reject the null hypothesis.
4	The distribution of ImaxByImin is the same across categories of Group.	Independent-Samples Mann-Whitney U Test	.001	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Table 2: Mann-Whitney U test between Roswell and Pecos Pueblo whole populations

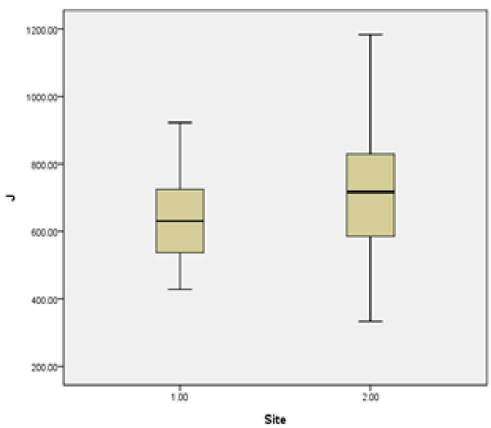

Figure 7: Side-by-side box plot by site (J)

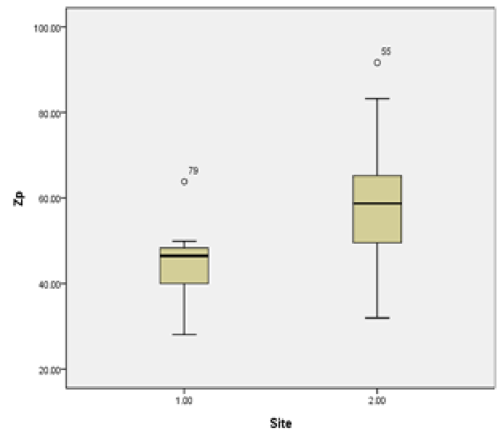

Figure 8: Side-by-side box plot by site (Zp)

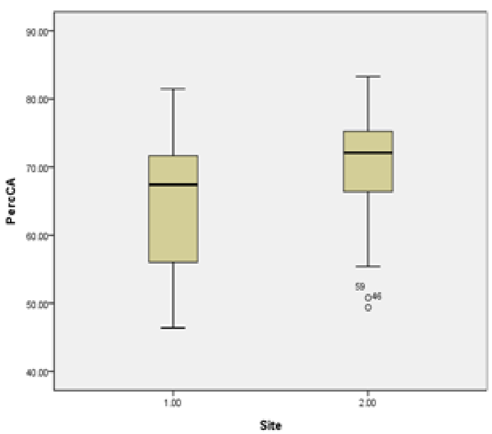

Figure 9: Side-by-side box plot by site (%CA)

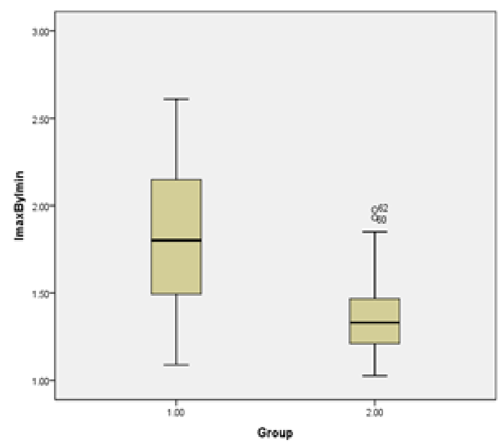

Figure 10: Side-by-side box plot by site (Imax/Imin)

It is also useful to compare the distribution of data points by variable across the two geographic origins. Figures 7–10 present side-by-side box plots for each of the four variables in question. Outliers are indicated with open circles; the two T-brackets indicate the maximum and minimum data points, while each box is bounded by the 25th percentile and the 75th percentile (the Inter-Quartile Range). The bold line within that box represents the median data point.

By comparing these side-by-side box plots it is possible to understand the differences in distribution of data points within each population. Figure 7, which examines Polar Moment of Inertia (J) by site, does not indicate the presence of outliers in either population. While the spread of data points is much wider at Pecos Pueblo, neither the Roswell-area nor the Pecos Pueblo data seem skewed in either a positive or negative direction. The markedly larger distribution of values at Pecos Pueblo may be a result of differences by sex (discussed below).

In contrast, Figure 8, which presents side-by-side box plots of the Polar Section Modulus (Zp), does indicate distributional differences between the two populations. Both the Henderson/Bloom Mound and Pecos Pueblo samples exhibit one outlying data point. Taking into account those outliers, the distribution of data points from the Roswell-area sites is markedly different from Pecos Pueblo. While both populations have a similar minimum value, the Pecos Pueblo sample exhibits a much wider spread of data which appears to approach a normal distribution. In contrast, the distribution of data from the Roswell area has a much smaller spread and is skewed left, as the median value, 75th percentile and maximum values are clustered much closer together than the 25th percentile and minimum values.

The fact that the Roswell-area data do not appear to be distributed normally may be an error related to small sample size or may, in fact, represent the true distribution of values in the population. However, because both the Mann-Whitney U test - which does not assume a normal distribution - and the t-test indicated statistical significance, we can be confident in stating that there is a difference between these two populations with regard to Polar Section Modulus (Zp).

Figure 9 illustrates the distribution of %CA by population. As with Zp, distribution of %CA varies between the populations at Roswell and Pecos Pueblo. Pecos Pueblo exhibits a number of outliers, while Roswell exhibits none. Taking these outliers into account, the spread of data at Roswell is much greater than that at Pecos Pueblo (contrary to what was seen in the distributions of Zp). The distribution of %CA at Pecos Pueblo appears to exhibit a normal distribution, while the distribution at Roswell appears to be skewed. However, because the Mann-Whitney U test does not assume a standard normal distribution, the conclusion of the presence of a significant difference between the two populations in %CA is still valid.

Figure 10 shows the distribution at Henderson/Bloom Mound and Pecos Pueblo of Imax/Imin - the greatest moment of area over the lowest moment of area in each cross-sectional plane. This gives a general idea of the circularity of the bone - the closer to 1 Imax/Imin is, the more circular the bone. As discussed above, circularity in bone structure is ideal if the bone often undergoes torsional stress, or could be a result of equal amounts of directional bending along perpendicular axes. The side-by-side box plots in Figure 8 show a few high outliers at Pecos Pueblo, but none in the Roswell area. Roswell's distribution is much larger than is seen at Pecos Pueblo. This observation can be helpful in putting the difference seen in Zp (another measure of torsional strength) into context. It appears that the lower Zp value reported above is a consequence of the more circular nature of the Pecos Pueblo femoral sample, which could be the result of more generalized femoral loading at Pecos Pueblo.

7.2. **BY SEX.** Tables 3 and 4 show the results of a Mann-Whitney U test for significance in each geographic region by sex. The null hypothesis tested in each instance was that there is no difference by sex in each of these populations. At Pecos Pueblo, three of the four hypotheses tested were rejected, indicating the presence of significant differences by sex at Pecos Pueblo in values of J, Zp, and Imax/ Imin, but not in %CA. At Roswell, all four hypotheses tested were retained, indicating no differences present between the cross-sectional values in males and females of the population. Importantly, this indicates that the communities at Roswell and Pecos Pueblo participated in very different gendered labor structures (see below for discussion).

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of J is the same across categories of Sex.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
2	The distribution of Zp is the same across categories of Sex.	Independent-Samples Mann-Whitney U Test	.001	Reject the null hypothesis.
3	The distribution of PercCA is the same across categories of Sex.	Independent-Samples Mann-Whitney U Test	.377	Retain the null hypothesis.
4	The distribution of ImaxByImin is the same across categories of Sex.	Independent-Samples Mann-Whitney U Test	.004	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Table 3: Mann-Whitney U test by sex at Pecos Pueblo

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of J is the same across categories of Sex.	Independent-Samples Mann-Whitney U Test	.062	Retain the null hypothesis.
2	The distribution of Zp is the same across categories of Sex.	Independent-Samples Mann-Whitney U Test	.123	Retain the null hypothesis.
3	The distribution of PercCA is the same across categories of Sex.	Independent-Samples Mann-Whitney U Test	.223	Retain the null hypothesis.
4	The distribution of ImaxByImin is the same across categories of Sex.	Independent-Samples Mann-Whitney U Test	.167	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Table 4: Mann-Whitney U test by sex at Roswell

To further investigate differences in cross-sectional properties, the data were broken down by geographic origin and by sex; each group was then compared against every other group (Roswell males with Roswell females, Pecos males, and Pecos females, etc.) The results of these comparisons are reported in Table 5. Each pairing which introduced two variables (both sex and site) was excluded from this figure (i.e. Pecos males vs. Roswell females). Significant results ($p \leq 0.05$) are bold and highlighted.

The results for the analysis of J by site and sex follow the results of the Mann-Whitney U test by sex discussed above. No statistical significance was found between sites (Roswell males vs. Pecos males or Roswell females vs. Pecos females), or by sex at Roswell. However, as anticipated from previous studies and the abovementioned Mann-Whitney U test (Figure 3), there is a difference by sex at Pecos Pueblo ($p = 0.000$).

Analysis of Zp also follows expectations given previous analyses in this paper and by Ruff and Hayes (1983b). As indicated by traditional t-test and Mann-Whitney U (see above), there is a difference between the populations at Pecos Pueblo and Roswell even broken down by sex (Roswell males vs. Pecos males and Roswell females vs. Pecos females). In addition, examination by sex echoes the results of the Mann-Whitney U

Value Tested	Variable 1	Variable 2	Sig ($p \leq 0.05$)
J	Roswell Male	Roswell Female	0.069
	Roswell Male	Pecos Male	0.194
	Roswell Female	Pecos Female	0.263
	Pecos Male	Pecos Female	**0.000**
Zp	Roswell Male	Roswell Female	0.195
	Roswell Male	Pecos Male	**0.002**
	Roswell Female	Pecos Female	**0.017**
	Pecos Male	Pecos Female	**0.000**
%CA	Roswell Male	Roswell Female	0.101
	Roswell Male	Pecos Male	0.264
	Roswell Female	Pecos Female	**0.002**
	Pecos Male	Pecos Female	0.805
Imax/Imin	Roswell Male	Roswell Female	**0.002**
	Roswell Male	Pecos Male	**0.000**
	Roswell Female	Pecos Female	**0.0354**
	Pecos Male	Pecos Female	**0.016**

Table 5: One-way ANOVA by site and by sex

tests for significance by sex; there is a significant difference found at Pecos Pueblo (p=0.000), but none exhibited at Roswell ($p = 0.195$).

Comparing %CA by sex and by site introduces some complexities. Both the Mann-Whitney U and t-test analyses for significance in %CA by site (discussed above) produced significant results (although the Roswell-area values were smaller than those at Pecos Pueblo, contrary to expectations). Keeping this in mind, because the Mann-Whitney U tests conducted for sex differences in each geographic region indicated no significance, we would expect significance between the two sites (i.e. Roswell males vs. Pecos males) but none between the sexes at each site (i.e. Pecos males vs. Pecos females). Following this expectation, no significant difference emerges between Roswell males and Pecos Pueblo males ($p = 0.264$). However, statistical significance is demonstrated between Roswell females and Pecos Pueblo females ($p = 0.002$).

In considering this, a question arises: if %CA in Roswell females is equal to Roswell males, which is equal to Pecos males, which in turn is equal to the values for Pecos females, how can a difference between Pecos females and Roswell females emerge? Posed another way, if Roswell F = Roswell M = Pecos F = Pecos M, how can it be that Roswell F $\neq$ Pecos F (if $a = b = c = d$, how can $a \neq d$?)? This problematic logic is the result of small differences compounded at each step. For instance, if we took a large lecture class of, say, 100 students and lined them up by height, we would observe a smooth transition from the shortest to the tallest student, but compare the shortest quarter with the tallest quarter, and a very real difference becomes apparent. Combined with a small sample size - there are only five females from Roswell, while the Pecos Pueblo female sample consists of 37 individuals - this difference can be explained.

Statistically significant differences are exhibited in Imax/Imin in every permutation of site and sex, which is contrary to what was seen in the Mann-Whitney U test in Figure 4. This Mann-Whitney U test suggested that there was no difference by sex at Roswell in Imax/Imin, while the one-way ANOVA presented in Table 5 does indicate a difference by sex at Roswell ($p=0.002$). When evaluating the results of these two tests, it must be kept in mind that the Mann-Whitney U test does not assume equal variances and attempts to account for small sample size, while the one-way ANOVA does not - its results can therefore be seen as more cautious.

Just as this analysis has indicated differences at Pecos Pueblo by sex, Ruff and Hayes (1983b) also noted significant differences in femoral cross-sectional geometries by sex. The authors found that males had higher mean cross-sectional values (except, notably, in later investigations of %CA, in which females exhibited a larger mean value) and were more adapted to bending in the anteroposterior direction, while females were more adapted for mediolateral bending strength (see Ruff and Hayes 1983b; Ruff 2010). Ruff and Hayes concluded that these differences reflected adaptation to different types of activity; males traveled longer distances in pursuit of game and by participating in long-distance running while women covered a smaller distance in the course of their farming-dominated activities (Ruff and Hayes 1983b). Keeping in mind the behavioral implications of the sex differences observed at Pecos Pueblo, a question emerges: are the cross-sectional values at Roswell more similar to Pecos Pueblo males or females?

Table 6 shows the 95% confidence intervals for the true populational means by sex at Pecos Pueblo with the mean values observed at Roswell. This configuration was used because the results of the Mann-Whitney U tests by sex above indicated a difference in nearly all variables by sex at Pecos Pueblo but none at Roswell —therefore Roswell was treated as one population while Pecos Pueblo was separated by sex. The 95% confidence intervals which do not include the Roswell mean are bold and highlighted — these indicate statistical significance. This chart reveals differences in the mean values between the population at Roswell and each of the sexes at Pecos Pueblo except in one instance — the mean value for J at Roswell falls within the 95% confidence interval for *females* at Pecos Pueblo.

A Mann-Whitney U test was again used to corroborate these results. The results of the Mann-Whitney U tests for significance between the whole Roswell sample and Pecos Pueblo males is presented in Table 8 and tests for significance between the whole Roswell sample and Pecos Pueblo females is presented in Table 7. The null hypothesis tested in each case is that there is no difference in cross-sectional values by sex at each site.

Variable	Roswell Mean	Pecos Male 95% Interval	Pecos Female 95% Interval
J (mm^3)	636.35	**740.01 - 858.79**	569.66 - 672.99
Zp (mm^2)	45.2	**58.85 - 66.50**	**68.42 - 74.07**
%CA	64.1	**68.97 - 72.64**	**68.43 - 74.07**
Imax/Imin	1.82	**1.36 - 1.50**	**1.23 - 1.36**

Table 6: Roswell means compared with Pecos Pueblo 95% confidence intervals by sex

The results of these Mann-Whitney U tests for significance mirrors the results of the t-test reported in Table 5. There is a significant difference shown between the pooled male and female sample from Roswell and Pecos Pueblo males in every variable. Likewise, the Mann-Whitney U test for significance between pooled males and females at Roswell vs. Pecos Pueblo females indicated significant differences in Zp, %CA and Imax/Imin. However, just as the t-test showed, there is no difference seen between the pooled Roswell sample and Pecos Pueblo females in Polar Moment of Inertia (J).

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of J is the same across categories of Group.	Independent-Samples Mann-Whitney U Test	.944	Retain the null hypothesis.
2	The distribution of Zp is the same across categories of Group.	Independent-Samples Mann-Whitney U Test	.029	Reject the null hypothesis.
3	The distribution of PercCA is the same across categories of Group.	Independent-Samples Mann-Whitney U Test	.048	Reject the null hypothesis.
4	The distribution of ImaxByImin is the same across categories of Group.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Table 7: Mann-Whitney U test between Roswell pooled sample and Pecos Pueblo females

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of J is the same across categories of Group.	Independent-Samples Mann-Whitney U Test	.007	Reject the null hypothesis.
2	The distribution of Zp is the same across categories of Group.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
3	The distribution of PercCA is the same across categories of Group.	Independent-Samples Mann-Whitney U Test	.046	Reject the null hypothesis.
4	The distribution of ImaxByImin is the same across categories of Group.	Independent-Samples Mann-Whitney U Test	.004	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Table 8: Mann-Whitney U test between Roswell pooled sample and Pecos Pueblo males

8. DISCUSSION

My research identified significant differences in the bone density of the people who lived near Roswell and at Pecos Pueblo during the 12th and 13th centuries A.D. - differences were observed at the population level in Zp and Imax/Imin (both measures of torsional strength) as well as in %CA (a measure of compressional strength). These differences can be explained through differences in subsistence strategy in each geographic region. The results of a t-test and Mann-Whitney U test for significance in J (a measure of average bending strength) were contradictory, although further analysis by sex will help to explain this contradiction (see below for discussion).

Research in cross-sectional morphology is based on the assumption that higher average lifetime mobility is reflected in the cross-sectional geometry of lower limb bones; the body deposits more bone in areas in which there is more frequent or more intense loading. Using previous research, I expected to find a higher level of mobility in the Roswell area than at Pecos Pueblo (see above). However, the data included in this study indicate that the populations at Henderson and Bloom Mound exhibited lower strength against bending, torsion and compression.

This does not, however, require that one entirely discount this theory of higher mobility at Roswell. Sample size is the most obvious limiting factor in this analysis - the femoral sample from Henderson and Bloom Mound together numbers only twelve, and there is some indication of change in subsistence strategy (which likely affected mobility) between the two sites (see above). While this small sample size limits the conclusions which can be drawn, I have attempted to mediate its effects through the type of statistical analyses used.

In evaluating these results, one must consider the type of movement which was likely used in each community and how it might have affected bone remodeling. Through experimentation on macaques and rats, it has been shown that more vigorous activity causes greater bone deposition than less intense physical activity does (Bertram and Swartz 1993; Ruff et al. 2006). One might expect the large distances traveled yearly by bison hunters to cause notable physical changes in the long bone structure - much greater than those experienced by Pueblo farmers whose daily activities required them to move within a much smaller physical area. However, it is possible that the hundreds of miles walked by those living at Roswell were not reflected in their femoral cross-sectional morphology in the way that the habitual long-distance running practiced by Pueblo men was (see Ruff and Hayes 1983b).

It has been shown that the type of terrain in which an individual moves affects the cross-sectional morphology of the femur. In his 1999 study, Ruff found a significant difference between groups living in the mountains versus the plains in measures of both

CA and J in a pooled Amerindian sample. The fact that the majority of the bison hunt was conducted in the strikingly level planes of eastern Texas may contribute to lower values in both %CA and J exhibited at Henderson and Bloom Mound (Ruff 1999). While it is currently unclear how terrain affects measures of Imax/Imin and Zp, it is certainly conceivable that habitual movement in mountainous terrain would subject the human femur to much higher torsional, compressional, and bending forces than when moving about a flat landscape.

Additionally, the role of loading frequency in bone deposition is not fully understood (Bertram and Swartz 1993). The community at Roswell likely participated in a few months of long-distance travel and bison procurement followed by a comparatively less mobile period of trading and residence in their permanent settlement. At Pecos Pueblo, it is possible that long-distance running may have continued throughout the year. While the growing season at Pecos Pueblo hovered around the necessary 120 days for maize growth, heavy agricultural labor may have occurred for most of the spring, summer and fall as the fields and irrigation systems were maintained (Capone 2011). Habitual heavy agricultural labor combined with year-round long-distance running may have caused the population at Pecos Pueblo to experience notably more bone deposition than the population at Roswell.

These data have indicated striking differences in the way that these two communities structured their labor with regard to sex and gender. As discussed above, gender is extremely difficult to identify in the archaeological record, and archaeologists are therefore restricted to approximating gendered divisions of labor by utilizing sex - a biological component which maps nearly 1:1 with a masculine/feminine gender binary in many societies. Basing this analysis on that admittedly large assumption, these data indicate that a gendered difference existed with regard to mobility at Pecos Pueblo. Ruff and Hayes (1983b) attributed this observed difference to a gendered division of labor - women engaged primarily in agriculture while men traveled farther distances in search of game and in pursuit of long-distance running. In contrast, no difference by sex in J, Zp, %CA or Imax/Imin was evident at Henderson or Bloom Mound. This indicates that both men and women experienced much the same level of mobility throughout their lives.

Pooling the males and females at Roswell and then comparing their cross-sectional values separately with Pecos Pueblo males and females introduced some very interesting relationships. In values of J, as discussed above, no significant difference between the two pooled populations was exhibited. However, in separating the Pecos Pueblo males and females, it became clear that the Roswell pooled mean actually fell within the 95% confidence interval for Pecos Pueblo females but not males. This does not mean that the population at Roswell was engaging in agriculture at the level that Pecos Pueblo women were - in fact, this is very unlikely given previous research in the area which does not indicate a level of maize production anywhere near that of Pecos Pueblo's (see above for discussion). It does, however, indicate that the population at Roswell experienced much the same amount of overall bending strain in the femoral midshaft that Pecos Pueblo females did.

The relationship between Roswell and Pecos Pueblo Imax/Imin values may indicate that the people living near Roswell engaged in a more specialized type of mobility than the population at Pecos Pueblo. Average Imax/Imin values in the pooled Roswell population are much higher than both males and females from Pecos Pueblo, indicating a much less circular midshaft cross-section (resulting in lower torsional strength reflected in Zp values). By examining the mean values of Imax and Imin separately between the two populations, it can be seen that this higher value is due not to a much larger Imax value but to a much smaller Imin value.

These lower Imin values at Roswell may be due in large part to the effect of terrain on femoral robusticity - it can be expected that travelling across an uneven mountainous landscape would put many different kinds of stress and strain on one's bones including significant torsion, which would cause the Imin values at Pecos Pueblo to increase. Higher Imax/Imin values at Roswell may, therefore, be an indication of the much more specialized remodeling in their adaptation to walking at a relatively slow pace (though by no means a leisurely stroll) across hundreds of miles of flat plains.

The femoral cross-sectional properties at Henderson and Bloom Mound have countered the expectations of researchers in multiple ways. Researchers have previously demonstrated a relationship between increased agricultural investment and decreased femoral robusticity (see Bridges 1989; Ruff and Brock 1988; Ruff 1999). However, this analysis has shown an opposite relationship - the heavily agriculture-dependant population at Pecos Pueblo exhibited higher levels of robusticity than in the hunter-gatherer/farming population at Roswell.

Previously recorded trends in sexual dimorphism of femoral cross-sectional morphologies also run contrary to what has been exhibited by Pecos Pueblo and the Roswell area. Studies of differences in femoral robusticity by sex indicated a general decrease in sexual dimorphism from hunter-gatherers to agriculturalists (Ruff 1997; Ruff 1999). The results of studies at both Pecos Pueblo and Roswell do not fit with this trend - Roswell strikingly so. When compared with hunter-gatherer and agricultural Amerindian populations, Pecos Pueblo exhibits a striking degree of sexual dimorphism (in measure of Ix/Iy [analogous to Imax/Imin] nearly 10%). This is a very high value when compared with other agricultural populations even within New Mexico (one population from which exhibited as little as 2% difference by sex - see Ruff 1999).

In contrast, the sex differences in Ix/Iy in hunter-gatherer populations reported in that 1999 study range from 10% to nearly 27% - a larger range than exhibited by the agricultural populations and a much larger amount of sexual dimorphism than was seen in the hunter/farmers at Roswell in any of the cross-sectional values included in this study (there is no statistically significant difference by sex in Imax/Imin - see above).

9. CONCLUSIONS AND CONTRIBUTIONS

Femoral cross-sectional geometries vary greatly between the populations at Roswell and at Pecos Pueblo, although not in the ways expected. Differences in most cross-sectional properties at Pecos Pueblo are somewhat out of the ordinary for most agricultural populations, and the complete lack of sexual dimorphism at Henderson and Bloom Mound has not been seen previously in hunter-gatherer populations.

Contrary to expectations, cross-sectional geometric values in the population at Roswell are smaller than those at Pecos Pueblo, which could be the result of complications related to sample size as well as the poorly-understood effect of terrain and loading frequency on femoral robusticity. Both the community at Roswell and Pecos Pueblo seem unique within the current milieu of skeletal samples subjected to this type of analysis.

Mobility at the level of the community has intrigued anthropologists for decades, but the studies that these researchers have published are largely based on ethnographic data from the 19th and 20th centuries. While the importance of a world-wide synchronic view of mobility in different sociopolitical and geographic environments cannot be disputed, diachronic aspects of mobility have been neglected due to obvious limitations in the ethnographic record. By examining mobility in an archaeological sample, I have provided a narrow window into mobility hundreds of years before any ethnographic data was recorded.

The study of mobility both in the ethnographic and archaeological record is a comparative one. There is no base level of mobility against which to compare each community, because the level of mobility in each society is mediated by numerous factors including differences in religion, political structure, environment, and subsistence strategy. Before any wider conclusions can be posited by researchers regarding mobility throughout time and space, a substantial data set must be accumulated. By making the cross-sectional data from Henderson and Bloom Mound available to others, I have contributed a data set against which future researchers can compare their own data.

The results of this study have been surprising and have run contrary to previously described trends related to change in subsistence strategy throughout time and in the ways in which these communities structured their labor along gendered lines. The applicability of femoral cross-sectional analyses is still unclear, and by illustrating the variation possible in these schema put forth in its early stages, these data have contributed to the development of the field.

Finally, this study has provided insight into the lives of individuals living at Henderson and Bloom Mound in a way that only direct osteological analysis can. It can be expected that levels of mobility are not constant from individual to individual within a community, and examination of femoral cross-sectional morphology can bring this expectation to the foreground as we attempt to characterize these differences by sex, age, or possibly sociopolitical status. While the small sample size included in this study has precluded much of this analysis, the potential exists (pending further research or an increase in the sample size) to greatly enrich our understanding of life in pre-Hispanic southeastern New Mexico.

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APPENDIX A. ROSWELL AREA 50% VALUES

Site	Feature	Sex	Age	Measured Length (cm)	Derived Length (cm)	Cortical Area (cm)	%Cortical Area	Ix (cm^4)	Iy (cm^4)	Imax (cm^4)	Imin (cm^4)	J (cm^4)	Zp (cm^3)
Henderson	1	Female	21-27	41.2	42.5	14.67	66.0870349	9741.2359	11853.18	12032.56	9491.226	21523.79	1702.831
Henderson	8	Female	17-20	40.5	41.1	11.98	56.7154287	9707.8835	14419.8	14490.72	9587.834	24078.55	1838.057
Henderson	21	Female	40+	XXX	45.2	11.98	48.0776948	6467.7504	13161.27	13112.97	6401.726	19514.69	1271.316
Henderson	25	Male	26-30	45.1	45.5	19.72	68.7443352	10273.6075	20372.95	21855.69	8877.187	30732.88	2165.813
Henderson	29	Female	35+	XXX	45.1	20.9	81.4846583	12393.471	19754.3	20960.01	11111.33	32071.34	2216.402
Henderson	36	Male	19-22	48.3	47.2	24.15	76.3974566	13250.7683	25452.73	26623.56	11839.22	38462.77	2358.233
Henderson	40	Female	17-23	XXX	40.3	13.04	69.7848657	9414.8157	13630.01	13625.31	9234.431	22859.74	1867.626
Henderson	41	Male	21-24	39.25	47.7	20.14	68.9466297	9510.2979	23420.04	23766.72	9109.077	32875.8	1866.882
Henderson	66	Male	Adult	XXX	XXX	11.02	60.6127276	7526.454	11678.25	11630.94	7436.332	19067.27	1453.298
Henderson	67	Male	30-40	45.2	39.2	45.2	39.1774336	8877.1198	13495.34	13822.34	8388.951	22211.29	1828.09
Bloom	4	Male	35-45	44	46.3	16.13	55.3553657	12213.3694	22194.98	22293.18	11889.48	34182.66	2173.087
Bloom	9	Female	25-30	39.1	41.3	8.84	46.4163823	8984.1444	8712.264	9201.599	8450.317	17651.92	1648.171
Bloom	20	Male	40-45	XXX	47.2	14.67	57.9315247	19947.4119	23830.84	27585.47	15952.73	43538.2	3013.024

APPENDIX B. ROSWELL AREA 80% VALUES

Site	Feature	Sex	Age	Measured Length (cm)	Derived Length (cm)	Ix (m^4)	Iy (cm^4)	Imax (cm ^4)	Imin (cm^4)	J (cm^4)	Zp (cm^3)
Henderson	1	Female	21-27	41.2	42.5	9224.27	14883.66	15152.2938	7686.407	22838.7	1575.0828
Henderson	8	Female	17-20	40.5	41.1	7760.28	18915.33	18966.9829	7637.5016	26604.48	1827.2311
Henderson	21	Female	40+	XXX	45.2	5005.409	17067.19	17359.1054	4571.2274	21930.33	1332.341
Henderson	25	Male	26-30	45.1	45.5	9819.793	18681.9	18586.0905	9790.8359	28376.93	1572.1289
Henderson	29	Female	35+	XXX	45.1	XXX	XXX	XXX	XXX	XXX	XXX
Henderson	36	Male	19-22	48.3	47.2	9368.535	16851.28	20788.9448	11580.8237	32369.77	1715.409
Henderson	40	Female	17-23	XXX	40.3	12339.47	19156.28	21152.3766	10376.2532	31528.63	2093.5345
Henderson	41	Male	21-24	39.25	47.7	8577.452	22398.4	22385.2294	8468.2269	30853.46	1918.7473
Henderson	66	Male	Adult	XXX	XXX	7636.525	10810.18	11200.6598	7110.8875	18311.55	1500.9465
Henderson	67	Male	30-40	45.2	39.2	13268.93	18744.54	19661.5391	12396.0906	32057.63	2336.5619
Bloom	4	Male	35-45	44	46.3	10142.47	19626.6	19513.8759	10548.181	30062.06	1689.8289
Bloom	9	Female	25-30	39.1	41.3	13453.05	7513.21	13377.4862	7507.8625	20885.35	1702.1474
Bloom	20	Male	40-45	XXX	47.2	16358.95	31680.16	32480.376	15776.6697	48257.05	2666.1351

APPENDIX C. PECOS PUEBLO 50% VALUES

Site	ID number	Sex	Age	Length (cm)	CA (cm^2)	%CA	Ix (cm^4)	Iy (cm^4)	Imax (cm^4)	Imin (cm^4)	J (cm^4)	Zp (cm^3)
Pecos Pueblo	59803	2	44	40.2	252	55.4	15063	12570	16354	11280	27634	2251
Pecos Pueblo	59805	1	32	43.8	371	74	20029	17932	21103	16858	37961	2960
Pecos Pueblo	59807	1	16	40.6	301	78.6	11807	11263	13726	9347	23071	1955
Pecos Pueblo	59815	2	27	39.3	343	80.1	13796	14522	15168	13150	28318	2415
Pecos Pueblo	59817	2	37	38.2	305	79	11078	11876	12054	10900	22954	2027
Pecos Pueblo	59822	1	17	41.6	281	64.8	14910	11941	15453	11398	26851	2106
Pecos Pueblo	59823	1	22	41.8	317	71.2	15951	13638	17236	12353	29589	2466
Pecos Pueblo	59845	2	32	39.8	352	79.4	14636	16364	19387	11613	31000	2490
Pecos Pueblo	59846	2	54	40.9	316	66.5	16055	16788	17276	15567	32843	2591
Pecos Pueblo	59847	2	16	38.3	194	62.6	6297	7137	8055	5379	13434	1224
Pecos Pueblo	59856	2	37	41.1	403	81	20707	19113	24927	14892	39819	3063
Pecos Pueblo	59862	1	32	42.7	363	82.1	14828	16158	19140	11846	30986	2561
Pecos Pueblo	59864	2	18	36.8	207	72	5967	6273	6556	5684	12240	1243
Pecos Pueblo	59873	1	16	44.3	298	67.7	15744	12359	16874	11229	28103	2294
Pecos Pueblo	59912	2	54	38.8	297	66.2	16380	12729	17077	12032	29109	2446
Pecos Pueblo	59918	1	27	44.5	388	71.2	21251	21998	22017	21232	43249	3252
Pecos Pueblo	59923	2	32	39.5	290	68.3	13823	12271	14290	11804	26094	2289
Pecos Pueblo	59981	1	22	41.5	297	74.7	12743	10876	12845	10774	23619	2104
Pecos Pueblo	59996	2	22	37	309	83.3	9072	12523	12630	8965	21595	1995
Pecos Pueblo	59998	1	22	42.7	367	76.7	14892	20446	21830	13508	35338	2745
Pecos Pueblo	60003	2	32	41.7	315	70.6	16637	13223	16696	13164	29860	2468
Pecos Pueblo	60005	2	44	38.3	266	70.8	10330	10492	10549	10273	20822	1893
Pecos Pueblo	60010	1	32	40.4	372	79.6	15790	18392	19737	14446	34183	2825
Pecos Pueblo	60013	2	18	38.6	264	66	10762	12005	12142	10626	22768	1976
Pecos Pueblo	60023	1	18	39.2	259	71.7	9421	10105	10773	8753	19526	1680
Pecos Pueblo	60026	1	54	44.4	310	56.3	19888	19327	21417	17797	39214	2842

Site	ID number	Sex	Age	Length (cm)	CA (cm^2)	%CA	Ix (cm^4)	Iy (cm^4)	Imax (cm^4)	Imin (cm^4)	J (cm^4)	Zp (cm^3)
Pecos Pueblo	60041	2	27	41.1	340	75.3	17745	13896	18674	12967	31641	2552
Pecos Pueblo	60044	1	22	42	317	71.6	15737	13317	15758	13296	29054	2457
Pecos Pueblo	60045	2	17	41.3	257	69.3	10127	9975	10849	9252	20101	1795
Pecos Pueblo	60049	2	54	39.3	235	61.7	10283	9710	10484	9509	19993	1793
Pecos Pueblo	60057	2	44	40.2	328	75.5	14070	14793	16329	12534	28863	2371
Pecos Pueblo	60063	2	37	40.3	281	68.4	13051	11638	13875	10813	24688	2142
Pecos Pueblo	60064	1	37	46.1	445	73.9	29463	25111	29653	24921	54574	3836
Pecos Pueblo	60075	1	54	43.4	312	61.7	19714	16366	22070	14011	36081	2754
Pecos Pueblo	60086	1	37	43.2	382	70.3	23604	20776	26501	17880	44381	3324
Pecos Pueblo	60107	1	19	42.9	300	73.1	13170	12122	13575	11718	25293	1934
Pecos Pueblo	60109	1	27	43.3	360	73	21363	15968	23565	13766	37331	2911
Pecos Pueblo	60142	1	18	41.4	232	57.1	10245	11243	11324	10164	21488	1783
Pecos Pueblo	60143	2	19	38.1	226	73.7	7071	6948	7701	6317	14018	1316
Pecos Pueblo	60157	1	16	43.2	265	72.5	11397	8900	12195	8102	20297	1897
Pecos Pueblo	60180	1	44	43.2	361	65.3	22055	21261	24362	18954	43316	3227
Pecos Pueblo	60194	1	37	42.7	296	65.6	12986	16847	18372	11461	29833	2406
Pecos Pueblo	60201	1	27	43.5	337	72.2	15917	17117	20646	12388	33034	2627
Pecos Pueblo	60212	1	44	43.4	379	73.8	22143	17841	23375	16609	39984	3088
Pecos Pueblo	60213	2	17	41.1	259	58.3	11861	14289	15198	10952	26150	2051
Pecos Pueblo	60216	2	54	41.4	247	49.4	15734	14307	16504	13536	30040	2379
Pecos Pueblo	60218	1	37	43	379	69.2	23449	20775	24988	19237	44225	3331
Pecos Pueblo	60242	1	54	43.9	368	64.9	30560	17324	31795	16089	47884	3580
Pecos Pueblo	60252	2	32	42.6	297	80.9	9895	11004	11580	9318	20898	1896
Pecos Pueblo	60259	2	27	43.4	360	80.5	20427	12761	21866	11322	33188	2743
Pecos Pueblo	60260	1	37	41.8	299	61.9	18277	14481	18638	14120	32758	2569
Pecos Pueblo	60266	1	32	40.8	344	71.5	19759	14864	20036	14587	34623	2726

Site	ID number	Sex	Age	Length (cm)	CA (cm^2)	%CA	Ix (cm^4)	Iy (cm^4)	Imax (cm^4)	Imin (cm^4)	J (cm^4)	Zp (cm^3)
Pecos Pueblo	60267	1	44	44	391	75.2	23739	17696	23993	17443	41436	3069
Pecos Pueblo	60271	2	22	41.2	309	75.5	13980	11340	14415	10905	25320	2261
Pecos Pueblo	60275	1	32	42	406	70.1	27000	21785	28143	20643	48786	3849
Pecos Pueblo	60298	2	27	39.8	269	71.6	12047	9448	12052	9443	21495	1833
Pecos Pueblo	60302	2	37	38.7	314	73	13370	14461	15743	12087	27830	2399
Pecos Pueblo	60308	2	27	37.8	333	74.6	14830	15401	17762	12470	30232	2562
Pecos Pueblo	60309	2	44	41	246	50.8	14384	14429	14642	14171	28813	2314
Pecos Pueblo	60313	1	44	46.1	391	72.5	24029	20491	28901	15620	44521	3280
Pecos Pueblo	60314	1	27	42.2	353	74.4	18370	15733	20260	13842	34102	2790
Pecos Pueblo	60316	1	44	43.9	332	66.3	16918	18932	20523	15327	35850	2731
Pecos Pueblo	60446	2	54	39.3	290	66.9	13246	13905	14035	13116	27151	2185
Pecos Pueblo	60450	2	22	37.7	277	80.7	8591	9725	10279	8036	18315	1782
Pecos Pueblo	60454	1	54	44.7	344	65.2	23586	17141	26011	14716	40727	2962
Pecos Pueblo	60458	1	27	44.4	341	74.5	17417	14726	17606	14537	32143	2556
Pecos Pueblo	60596	2	16	41.5	289	76.7	12605	9534	12985	9154	22139	1913
Pecos Pueblo	60620	2	37	43.6	352	73.2	19174	15712	19975	14912	34887	2663
Pecos Pueblo	60663	1	54	42	385	76.3	18605	20600	23306	15899	39205	3027
Pecos Pueblo	60685	2	22	37.5	231	80.6	6707	6158	7166	5699	12865	1255
Pecos Pueblo	60688	1	17	44.1	315	74	13065	14333	16229	11170	27399	2192
Pecos Pueblo	60732	1	18	40	278	71.7	13101	10431	14702	8830	23532	1945
Pecos Pueblo	60744	2	44	39.9	306	66.3	14791	15807	17061	13538	30599	2524
Pecos Pueblo	60772	2	22	38.3	245	77	8522	7114	8818	6819	15637	1526
Pecos Pueblo	60930	2	32	35.1	232	75	7052	7559	7577	7034	14611	1429
Pecos Pueblo	60935	1	22	40.5	305	75.1	16173	10234	17098	9309	26407	2272