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RECONSTRUCTION OF DIET AND STATUS IN A PREHISTORIC HOHOKAM POPULATION FROM THE PHOENIX BASIN

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This research was undertaken to reconstruct the diet of a prehistoric population through analysis of trace element concentrations in skeletal material. Dietary differences were determined between males and females, as well as between various age groups. The sample group consisted of 49 individuals from the Hohokam population of Pueblo Grande, Arizona. Femoral samples were analyzed using Inductively Coupled Plasma-Atomic Emission Spectroscopy.

The elements chromium, magnesium, barium, strontium, and vanadium were found to vary significantly between males and females. With the exception of chromium, for which there is little information about dietary sources, these elements are found in greater concentrations in plant foods than in meats. Females had higher concentrations of all five elements, suggesting a significantly greater consumption of plants by women than men in this population. Conversely, while not statistically significant, zinc levels showed a strong trend towards higher meat consumption by males. Principle components analysis not only supports these assumptions about dietary differentiation between males and females, but also shows which elements are most susceptible to diagenetic change. The correlation between the t-test data and the principle components analysis presents a strong case for the reliability of trace element analysis in reconstruction of prehistoric diet. [Ascent, 4(1):31-39].

INTRODUCTION

In biology, trace elements are defined as those which occur in animal tissue in concentrations less than 0.01 ppm. According to Curzon (1983), trace elements act primarily as catalysts and perform functions essential for life, growth, and reproduction. Elements such as arsenic, chromium, cobalt, copper, iodine, iron, manganese, molybdenum, nickel, selenium, silicon, vanadium, and zinc have been termed essential in sustaining life (Mertz, 1986). Listed as possibly essential are barium, bromine, cadmium, flourine, strontium, and tin.

According to Schroeder (1965), the most important factor in human trace element uptake is diet. Trace elements are first taken up from the soil by plants, then passed on to herbivores, and eventually ingested by carnivores who prey on the herbivores. Omnivores, including humans, acquire trace elements from both plants and animals (Curzon et al., 1983). Once they have been ingested, trace elements are stored throughout an organism's lifetime in the inorganic portion of bone. The inorganic fraction of bone thus provides a record both of the trace elements incorporated into bone during growth and those which diffuse into the tissue following growth and development (Curzon, 1983). One can analyze the skeletal material of an individual in order to obtain an accurate record of trace element intake throughout that person's life. To some degree, the concentrations of trace elements found in an organism may be a result of the concentrations of these elements in the organism's environment (ie--pollutants). However, trace element analysis has proven to be a useful indicator of the types and amounts of food which an organism eats.
Dietary Reconstructions

Trace element analysis of human skeletal material has provided evidence concerning prehistoric diet, ancient subsistence strategies, as well as information about sex, age and social differentiation. One advantage of chemical analysis of bone, as opposed to archaeological studies of floral and faunal remains, is that trace elements are less dependent on highly variable levels of archaeological preservation. In addition, chemical analysis avoids biases introduced by short-term seasonal occupation of sites, as well as by native food processing techniques (Connor and Slaughter, 1984). Bumsed (1985) presents an interesting explanation of the advantages of chemical analysis of bone. Archaeology, she says, is the "menu" - the preserved record of the edible products available in a given population. Trace element analysis, on the other hand, is the actual "meal" selected from all the available items on the menu.

Several trace elements have proven useful in reconstructions of prehistoric diet and social status. Among these are strontium, barium, zinc, magnesium, and vanadium. The first analysis of trace elements in prehistoric human bone was an evaluation of bone strontium content conducted by A. B. Brown (1973). Strontium is discriminated against by animals in favor of calcium (Price et al., 1986). Carnivores have a lower bone strontium content than herbivores, while omnivores are intermediate between the two (Lambert et al., 1984). In regard to humans, strontium levels in bone have been used to estimate the relative amounts of plant and animal foods in prehistoric diets (Runia, 1987). Both strontium and barium have been used as indicators of trophic position (Burton and Price, 1990 in press). In addition, Burton and Price have determined that barium can be used as a possible indicator of utilization of desert resources.

Gilbert (1975) examined changes in subsistence strategies in Late Woodland, Transitional, and Middle Mississippian populations at Dickson Mounds, Illinois. His results showed large differences in zinc content of bone between all three populations, which he concluded might indicate greater consumption of meat or nuts in the populations with higher concentrations of zinc. Lambert et al. (1979, 1982) compared the two populations of the Gibson Middle Woodland and Ledders Late Woodland sites in Illinois. This study provided information about the shift in subsistence practices from a hunter/gatherer society, represented by the Gibson site, to one based on maize cultivation, represented by the Ledders site. The comparison of trace elements between sites showed differences for only three elements: strontium, magnesium, and zinc. The researchers concluded that higher magnesium and strontium content in the Gibson site may have been due to dependence on locally gathered plants rather than protein. In addition, the lower strontium content in males of the Ledders site indicated a higher protein diet, which suggested differentiation of sexual roles consistent with a shift in subsistence practices. In their study of a Middle Woodland population at Abbott Farm, New Jersey, Byrne and Parris (1987) found evidence for substantial consumption of meat. They also concluded that low levels of zinc were indicative of high grain intake and that high levels of magnesium in skeletal material may indicate consumption of nuts and berries.

In a 1982 study of the Dallas and Hixon sites in Eastern Tennessee, Geidel concluded that dietary differences existed between status groups in the Dallas population. Members of the elite, especially subadults, apparently had a better balanced diet. In addition, higher zinc levels in male skeletons may indicate greater nut consumption rather than greater meat consumption because high vanadium levels, an indicator of less meat consumption, were also present.

The Role of Diagenesis

Diagenesis includes the postmortem processes of dissolution, precipitation, mineral replacement, and recrystallization (Pate and Brown, 1985), and can present a major problem in trace element analysis. Temperature, moisture, pH, and oxidation-reduction all contribute to the process of diagenesis (Hare, 1980; Ortner et al., 1972; Parker and Toots, 1980). According to Lambert et al. (1979; 1984), Price (1988), Parker and Toots (1980), Badone and Farquhar (1982; in Price,1989), Henderson et al. (1989; in Price,1989), and Buikstra et al.
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(1989), strontium is affected very little by diagenesis. Also considered representative of bone at the time of burial is zinc (Lambert et al., 1979, 1983, 1985). Elements which are likely to enrich bone are iron, manganese, potassium, and barium (Lambert et al., 1979, 1984, 1985; Buikstra et al., 1989). Magnesium and vanadium probably fall somewhere between these two extremes, as mixed results have been obtained for them in diagenetic studies (Lambert et al., 1983, 1984, 1985; Buikstra et al., 1989; Price, 1989).

MATERIALS AND METHODS

The Study Population

The population analyzed consisted of over 700 human skeletons from the Pueblo Grande site in Arizona’s Phoenix Basin. These remains represent a population which spanned the entire Hohokam Classic period from approximately A.D. 1050 through ca. A.D. 1350 - 1400. The Hohokam were agriculturalists who occupied settlements in the southern Basin and Range in much of what is now Arizona. As indicated by the archaeological record, their diet consisted largely of maize, legumes such as beans and mesquite, and pinon nuts. No evidence of cereal consumption has been found (Mike Foster, personal communication). It is assumed that wild plants and meats also constituted some component of Hohokam diet.

Hohokam society is believed to have been stratified. Marked differences in Hohokam burial goods indicate that some individuals were of higher status than others, suggesting a chiefdom level of socio-political organization (Lipe, 1978). One would therefore expect to find differences in access to food resources between males and females, as well as between individuals of different social classes.

The sample utilized for this study consisted of 49 adults (18-51+ yrs) representing both sexes. Sexes and ages were determined by Sheridan and Van Gerven (1991).

Method of Analysis

Inductively Coupled Plasma-Atomic Emission Spectroscopy was the chosen method of analysis. ICP-AES is based on emission spectra, that is, the amount of energy released at certain wavelengths by excited atoms (Moore, 1989). Each element emits light at a characteristic wavelength, and the intensity of light measured for a given element is directly proportional to its concentration in the sample. ICP-AES is an ideal method of analysis due to its high sensitivity (Boumans, 1987), accuracy and precision (Lee, 1984), and ability to analyze small samples (Klepinger et al., 1986). Samples were analyzed by the second author at Trace Minerals International of Boulder on an ARL 3560 ICP-AES (Figure 1).

Sampling Procedure

Samples were cut with a fine-toothed band saw from near mid-shaft of the femur. This location was chosen based on its documented resistance to diagenesis (Lambert et al., 1984). Each sample was then cleaned ultrasonically in triple-distilled, deionized (18 megohm) water. Excess soil and possible contaminants from the band saw blade were removed by scraping with teflon blade. After cleaning, bone samples were dried to a constant weight for approximately 48 hours at 85 C. Five gram samples were then weighed out, transferred to porcelain crucibles, and ashed in a muffle furnace at 900 C for eight hours. Ashed samples were crushed in a porcelain mortar and pestle, and 0.1 g of powdered bone was transferred to acid-cleaned polypropylene test tubes for digestion. Samples were digested with 2 ml Tracepur ® (70%) nitric acid and heated on high for 1 hour in a dry bath to facilitate digestion. The digested samples were diluted to 37 ml with ultrapure water.

Quality Control Methods

In order to minimize contamination and insure the best possible results, several quality control measures were employed. All polypropylene containers and test tubes were cleaned with 20% nitric acid, and plastic gloves were used to handle samples. Preparation of bone samples was done in a Class 100 Clean Hood. Trace analysis grade chemicals and ultrapure triple-distilled, deionized (18 megohm) water were used. Samples from each batch of water used to prepare the samples were analyzed by ICP-AES to check for contaminants. In addition, quality controls (samples with known values) were periodically

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analyzed to check for consistency with the machine itself. These included in-house quality controls, 2 developmental archaeological bone Standard Reference Materials (SRMs) from the University of Wisconsin-Madison, and an animal bone SRM from the International Atomic Energy Agency (IAEA H-5).

Controls for Diagenesis

Cortical bone is considered to be less subject to diagenesis than is cancellous bone. For this reason, cortical bone was used in this study. Comparison between the two tissue types often provides valuable insights into the diagenetic processes at work on bone material. Unfortunately, such a comparison was not possible for this population because additional bone samples were not available. However, soil samples are available for many of the individuals, and their trace element concentrations could be compared to the values obtained for bone.

<table>
<thead>
<tr>
<th></th>
<th>MEAN</th>
<th>CV</th>
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<tbody>
<tr>
<td>Ba</td>
<td>164.40 ± 154.74</td>
<td>94.12</td>
</tr>
<tr>
<td>Cr</td>
<td>12.93 ± 2.67</td>
<td>20.63</td>
</tr>
<tr>
<td>Fe</td>
<td>159.57 ± 102.20</td>
<td>64.04</td>
</tr>
<tr>
<td>K</td>
<td>348.01 ± 148.47</td>
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</tr>
<tr>
<td>Mg</td>
<td>2055.92 ± 949.52</td>
<td>46.18</td>
</tr>
<tr>
<td>Mn</td>
<td>28.75 ± 28.25</td>
<td>98.27</td>
</tr>
<tr>
<td>P</td>
<td>170754.21 ± 11113.89</td>
<td>6.51</td>
</tr>
<tr>
<td>Sr</td>
<td>1846.15 ± 742.43</td>
<td>40.21</td>
</tr>
<tr>
<td>V</td>
<td>31.48 ± 29.13</td>
<td>92.53</td>
</tr>
<tr>
<td>Zn</td>
<td>148.14 ± 48.83</td>
<td>32.96</td>
</tr>
<tr>
<td>Sr/Zn</td>
<td>14.64 ± 10.52</td>
<td>71.82</td>
</tr>
</tbody>
</table>

Table 1. Descriptive statistics for the elements analyzed in this study.
### RESULTS

The elements analyzed in this study were barium, chromium, iron, potassium, magnesium, manganese, phosphorous, strontium, vanadium, and zinc. Table 1 shows means, standard deviations, and coefficients of variation for ten elements and the ratio of strontium/zinc.

Table 2 shows significance of variation for the eleven variables in Table 1 between males and females, age groups, and sex and age considered together. The 46 individuals chosen for this study were divided into three age categories: 15-35 yrs, 36-45 yrs, and 46 yrs and older. Elements in the table are listed in order of decreasing significance. Chromium, magnesium, barium, strontium/zinc, vanadium, and strontium alone were determined to vary significantly (p<0.05) by sex. Only chromium was found to vary significantly by age, with the highest values for females in the second age category. None of the elements were found to vary significantly when both age and sex were considered. This is consistent with the results obtained by Lambert et al. (1982), who could draw no conclusions from age correlations in their study.

Table 3 shows the correlation of each element with two components. These two components account for almost 50% of all the variation among the elements. Correlated with the first component, which accounts for 32.5% of the total variation, are the elements barium, chromium, magnesium, vanadium, and strontium/zinc. Barium, phosphorous, manganese, and iron are all correlated with the second component, which accounts for 15.3% of all the variation.

### DISCUSSION

**Analysis of Variance**

As previously indicated in Table 1, only chromium was found to vary significantly by age group, and no element was determined to vary significantly by both age and sex. However, chromium, magnesium, barium, strontium, and vanadium were determined by Student's t-test to be significantly higher in females than in males. In addition, the ratio of strontium/zinc was determined to vary significantly between the sexes. These elements are considered good indicators of greater consumption of plants relative to animal products. Thus, it can be asserted that not
Table 3. Eigenvector values for each of the elements.

<table>
<thead>
<tr>
<th>EIGEN-VECTOR 1</th>
<th>EIGEN-VECTOR 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ba</strong></td>
<td>-0.345</td>
</tr>
<tr>
<td><strong>Cr</strong></td>
<td>-0.377</td>
</tr>
<tr>
<td><strong>Fe</strong></td>
<td>-0.162</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td>0.067</td>
</tr>
<tr>
<td><strong>Mg</strong></td>
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</tr>
<tr>
<td><strong>Mn</strong></td>
<td>0.195</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>-0.039</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td>0.390</td>
</tr>
<tr>
<td><strong>Sr/Zn</strong></td>
<td>-0.396</td>
</tr>
<tr>
<td><strong>SEX</strong></td>
<td>0.362</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>32.50%</td>
</tr>
</tbody>
</table>

Magnesium

The highest concentrations of magnesium are found in whole seeds such as nuts, legumes, and unmilled grains. It is also found in relatively high concentrations in green vegetables. The poorest sources of magnesium are considered to be fish, meat, and milk (National Research Council, 1989). Thus, higher magnesium should indicate greater consumption of plants versus animal resources. Pinon nuts and numerous legumes are known to be components of the Hohokam diet. Females showed significantly higher values of magnesium compared to males.

Barium

Barium is usually associated with strontium in the food chain from plants to animals (Mertz, 1986). According to Lambert et al. (1984), barium may be discriminated against by carnivores to an even larger degree than is strontium. Primary sources of barium include grains and nuts. High barium might then indicate low meat intake and high plant consumption. Higher barium values for females in the Hohokam fit this pattern.

Strontium

As discussed earlier, strontium has been repeatedly utilized as an indicator of relative plant versus meat consumption. Foods containing the most strontium include legumes (Parker and Toots, 1980), some nuts (Lambert et al., 1984; Price, 1989), and roots and lower leaves of plants (Price, 1989). Two of these were definitely a part of the Hohokam diet, and the third was a likely component. Poor sources of strontium are meat and maize (Katzenburg, 1984). Price et al. (1986) state that pregnancy and lactation should be another cause of higher bone strontium among females in a population.

Vanadium

In general, food contains very little vanadium in relation to other elements (National Research Council, 1989). There is conflicting evidence as to which foods are good sources of vanadium. One study (Myron et al., 1977: p. 292; in Mertz, 1986) lists whole grains, seafood, meats, and dairy
products as rich in vanadium. Vanadium is apparently abundant in animal fat (Buikstra et al., 1989). According to Geidel (1981,1983; in Buikstra et al., 1989), and Hatch and Geidel (1983; in Buikstra et al., 1989), vanadium can be used to reliably differentiate between diets high in plant (greens, grains, and nuts) and those high in meats. They state that strong evidence for meat consumption would be low vanadium levels. If this data is correct, the low vanadium levels in Hohokam males indicate higher meat consumption than in Hohokam females. None of the sources listed as high in vanadium by Mertz are known to be components of the Hohokam diet.

**Strontium/Zinc**

Valcovic (1988) recommends comparing the relative values of strontium to zinc in human tissues. Zinc, in contrast to strontium, is considered to be an indicator of greater meat than plant consumption. Animal products are the major sources of zinc, with whole grain cereals and some seafood also being fairly good sources (Mertz, 1986). Hatch and Geidel (1983,1985; in Buikstra, 1989) list nuts as rich in zinc.

Analysis of relative strontium/zinc has proven more useful in some studies than analysis of each element separately. In a study of Price III site, which was probably used intermittently through time by the same population, strontium concentrations were found to increase across time, while zinc values showed decreases. Price (1989) states, "...the minor increase in bone strontium contrasts with a general decrease in zinc values, as would be expected if plant and/or shellfish intake were increasing (p.149)." According to Lambert et al. (1984: p.302),"...two dimensional plots of strontium vs. zinc provide a rudimentary pattern analysis and a better approach to dietary problems than use of strontium alone.” Beck (1985) re-examined data from the Gibson, Ledders, and Etowah sites and analyzed new data from Moundville, AL using two dimensional plots of strontium versus zinc values. Hunter/gatherers were found to be associated with relatively high zinc and low strontium values, while settled agriculturalists were found to have lower zinc and higher strontium values.

**Principle Components Analysis**

Table 4 illustrates the results of the principle components analysis. The first component describes 32.5% of the total variation in individuals sampled. Barium, chromium, magnesium, vanadium, and the ratio of strontium/zinc were all correlated. These are the elements previously determined to vary significantly by sex. The fact that these elements show loading for this vector suggests that Component 1 accounts for variation between males and females.

The second component accounts for 15.3% of the total variation. Correlated elements are iron, manganese, phosphorous and, slightly less so, barium. Iron and manganese are known to be highly susceptible to enrichment, and barium has also been shown to be a contaminating element by Lambert et al. (1984, 1985). No data was found for phosphorous. The conclusion can be drawn that Component 2 indicates elements which have leached into the bone after burial.

Each of the elements examined in this study, with the exception of chromium, have been analyzed repeatedly by other researchers. The effects of diagenesis on most of these elements have not yet been fully established. Based upon the data presented in this paper and the results of other studies, strontium and the strontium/zinc ratio seem to be least susceptible to diagenesis and most reliable for recreation of prehistoric diet. Barium,

<table>
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<th>COMPONENT</th>
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<th>2</th>
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</thead>
<tbody>
<tr>
<td>Variation due to</td>
<td>Sex</td>
<td>Diagenesis</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>3.245</td>
<td>1.526</td>
</tr>
<tr>
<td>Associated %</td>
<td>32.5</td>
<td>15.3</td>
</tr>
<tr>
<td>Cumulative %</td>
<td>32.5</td>
<td>47.8</td>
</tr>
<tr>
<td>Associated Elements</td>
<td>Ba, V, Cr, Mg, Sr/Zn</td>
<td>Fe, Mn, P, Ba</td>
</tr>
</tbody>
</table>

Table 4. Principle components analysis of the variation found in this study.
vanadium, and magnesium are somewhat less reliable. Finally, those elements which are most susceptible to diagenesis are iron and magnesium.

CONCLUSIONS

Chromium was the only element found to vary significantly by age, and no element was found to vary significantly by both age and sex. Thus, no conclusions can be drawn about trace element variation between age groups in this population. However, the elements chromium, magnesium, barium, strontium, and vanadium were determined using the Student’s t to vary significantly between males and females. Many of the plant foods found to be components of the Hohokam diet are known to be good sources of these elements. The exception is chromium, for which there is little information about dietary sources. Females have higher concentrations of all five elements, suggesting greater consumption of plants by women than by men in this population. In addition, the ratio of strontium/zinc was found to vary significantly by sex. Females have higher strontium levels and lower zinc levels, while males have higher zinc and lower strontium levels. This indicates that males were consuming more meat than plants, and females were probably consuming more plants than meats. This seems reasonable, given the fact that men traditionally have greater access to animal resources and women have greater contact with plant resources.

Principle components analysis supports these assumptions about dietary differentiation between males and females, as well as providing insight into which elements might be most susceptible to diagenetic change. Over thirty-two percent (32.5%) of all the variation in trace elements concentrations in the bone material studied can be accounted for by differences between the sexes. Slightly more than fifteen percent (15.3%) can be accounted for by enrichment of the bone from the surrounding soil. The correlation between the t-test data and the principle components analysis, supported by the archaeological record for this site, suggests that trace element analysis of bone is a reliable method of reconstruction of prehistoric diet.

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