Chapter 8 – Results and Discussion

The results obtained by applying the methods to the experimental material described in the previous chapter will be described here. This chapter will first endeavour to explore the extent to which bone density varies in the experimental material. Particular attention will be given to the ways in which bone density changes with age. From this exploration it will become apparent that it is inappropriate to examine the experimental material as a whole. The second section will propose a more closely controlled analytical method and will define some of the terms to be used in the execution of this method. Only then will it be possible to address and discuss any other causes of density variability. This will be achieved by focussing on one aspect of the material at a time (its preparation method, breed, sex, month at death and age.). Each aspect will be examined and discussed in turn.

This project has produced a large amount of data and these are presented in their raw form in appendix C. Only the data appropriate for each of the following analyses are presented in this chapter.

8.1: Bone Density and Bone Survival: A Note on the Aims of This Chapter

It has already been noted that bone density might be partially dependent on a number of different factors (see chapter 5). It has also been demonstrated that bone density is one of the primary factors that mediate the ability for a skeletal element (or part of element) to survive destructive taphonomic processes (see chapters 3 and 4). The explicit aim of this chapter is to explore the effects on bone density of a number of variables (eg age, sex and breed). No attempt will be made in this chapter to establish exactly how these effects are reflected in terms of differential bone destruction in the archaeological record. The archaeological application of the results presented below will be discussed in chapter 9.

8.2: Bone Density Variation with Age, Examining the Experimental Material as a Whole

8.2.1: Graphically assessing the bone density of non-identical animals

In this section it will become apparent that scatter plots are an inappropriate means of analysing the data produced by this project. It will also be demonstrated that, although line graphs are able to show broad trends within the data, a different analytical method is required in order to explore the data more thoroughly.

8.2.1.1: *Scatter plots*

It might be expected that the aims of this chapter might be most effectively achieved by plotting the data and examining them graphically. By attempting to understand some of the data produced by this project by means of a scatter plot (figure 8.1), it will become apparent that this analytical method is not suitable for this project.

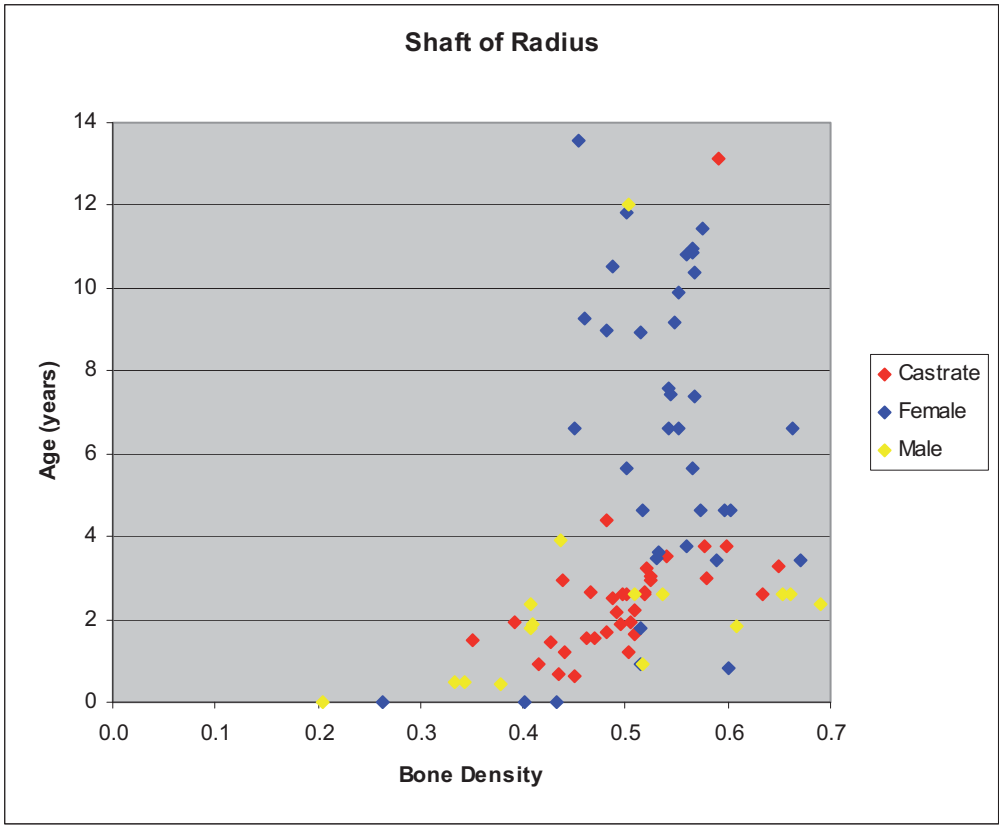

Figure 8.1: Scatter plot showing the relationship between the age at death and bone density for the shaft of the radius for male, female and castrated individuals.

Figure 8.1 refers to only two variables (age and sex) and a single scan-site (the shaft of the radius). It will be demonstrated below that this type of graph is unsuitable for the analysis of the data produced by this project. However, for the sake of completeness and so that all of the data can be examined graphically, scatter plots that relate to the full range of variables and scan-sites are presented in appendix D.

Some clear clusters are visible in figure 8.1. It is clear that, in the experimental material, female animals tend to be older than either males or castrates. A tendency for females to have a slightly higher bone density is also apparent. From figure 8.1 it might be concluded that the density of the radius shaft of females is comparatively high. Alternatively, it might be inferred that it is older animals that have a comparatively high bone density. Since there is a correlation in the experimental material between sex and age, it is impossible to be certain which of these two conclusions is correct.

This picture is further complicated by the fact that the individuals displayed in figure 8.1 are of different breeds. They have also been classified as having different months of death and have been defleshed using a variety of different preparation methods (all of which can potentially affect the density of a bone). Since figure 8.1 does not enable the impact of these additional factors to be assessed, interpretation of the patterns with reference to the full range of possible variables becomes impossible.

It can be seen that the graphical representation of the data presented above is potentially flawed, because correlations exist between the variables being examined by this project and because it is not practically possible to incorporate all of the variables into a single graph. It is for these reasons that an alternative analytical method must be sought. Such a method is outlined below, but first another graphical means of displaying and analysing the data must be discussed.

8.2.1.2: *Line graphs*

An effective method of establishing how the density of an animal's bones changes throughout its life is to compare the density of the bones from animals of a variety of ages. This can be achieved graphically by plotting the density values as a line graph in which the *y*-axis represents bone density, the *x*-axis represents the ages of the animals being examined (in order of increasing age), and each scan-site is represented by a separate line on the graph. Such a graph might reveal, for example, that the older animals have significantly higher or lower density values than younger animals. It might also be possible to observe different trends for different scan-sites.

Figure 8.2 is a line graph showing the bone density of all of the scan-sites from all of the individuals studied in this project. Each line in the figure represents a different scan-site. Displaying all of the data produced by this project in a single figure produces a very complex and confusing graph. Using figure 8.2 to track changes in density for a particular scan-site is clearly impracticable. However, it is possible to observe general trends in the data. A discussion of these general trends is presented below.

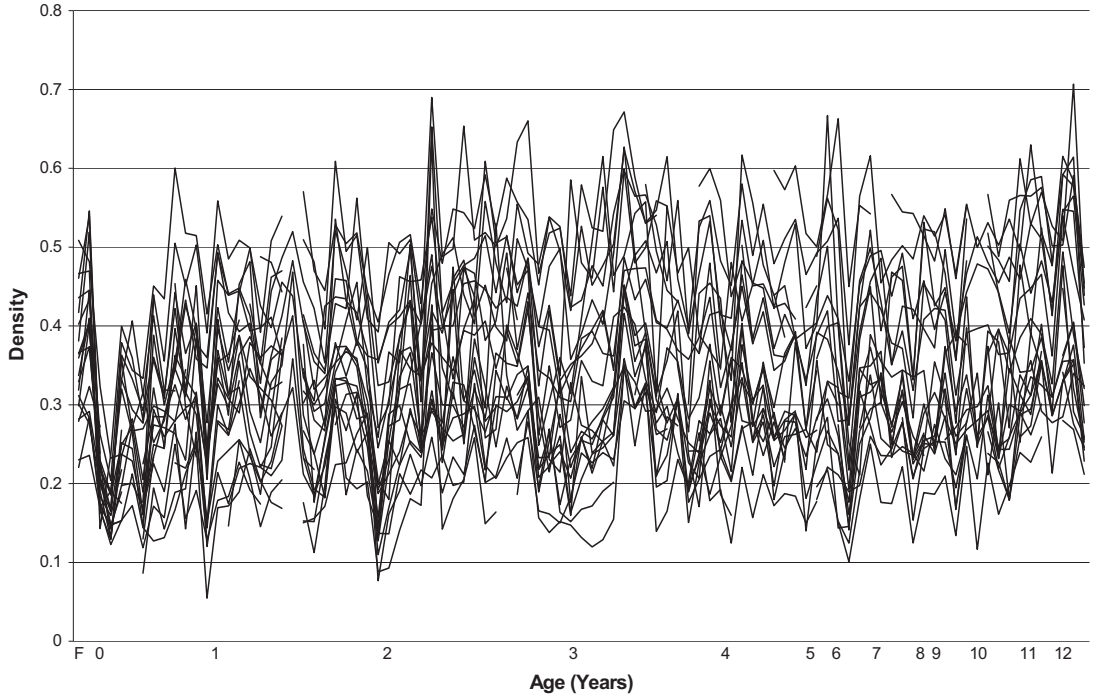

Figure 8.2: Showing the bone density of all of the scan-sites for all of the animals that were examined. The picture that is presented is a complex one and figure 8.3 aims to provide a simplified picture from which conclusions can be more readily drawn. The approximate ages of some of the animals are given in years along the* x*-axis. "0" refers to stillbirths and "F" refers to fetal animals. Note that the increase in age along the* x*-axis is irregular. The data points are joined for clarity: this does not imply that real* y*-values exist intermediate to those plotted.

Figure 8.2 clearly demonstrates that there is an enormous potential for bone density to vary between animals of similar ages. Drawing conclusions from such a complex figure is unlikely to be a straightforward process. Instead, the discussion below will mainly refer to figure 8.3**,** which displays the data from just 25 individuals that have been deliberately selected to span the full range of ages available to this study. Again, for the sake of clarity, only five scan-sites (scapula, distal humerus, distal radius, proximal metatarsal and the shaft of the femur) will be examined. These scan-sites represent the full range of skeletal locations measured in this project (bones from upper, middle and lower fore and hind limb are represented). Both trabecular and cortical bone

are also represented. Within these constraints, both the scan-sites and individuals displayed were selected arbitrarily. The patterns apparent in figure 8.2 (that are discussed below) are also visible in figure 8.3. Consequently, the latter merely represents a simplified version of the former.

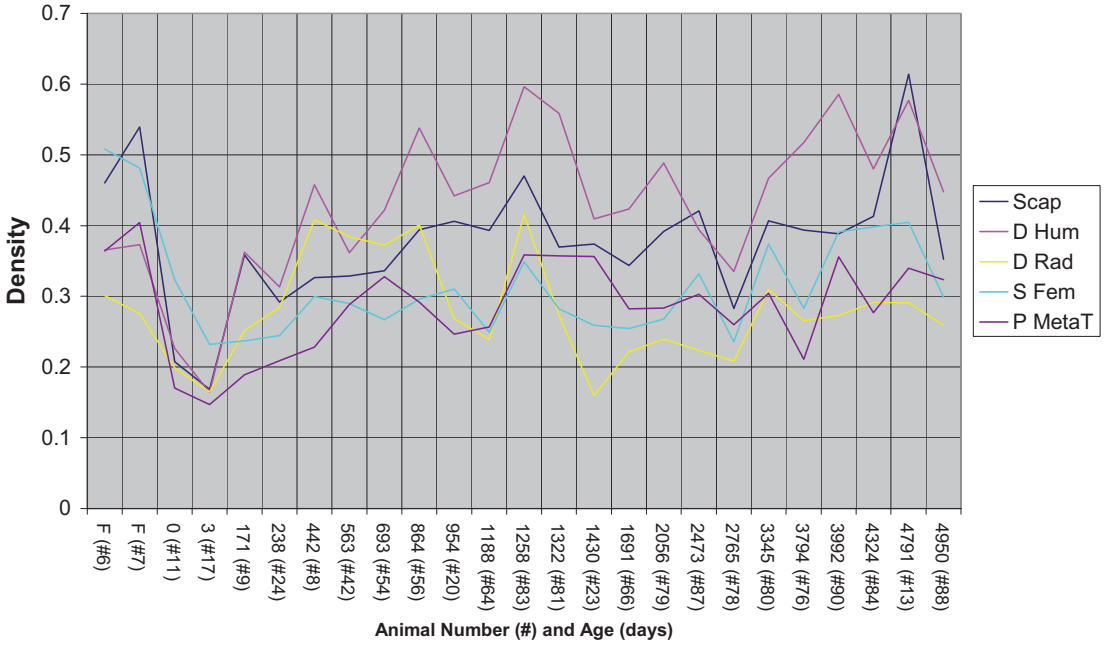

Figure 8.3: Showing the variation of bone density between 25 animals of different ages. The elements examined are the scapula, distal humerus, distal radius, proximal metatarsal and shaft of the femur. The approximate ages of some of the animals are given in years along the x-axis. "0" refers to stillbirths and "F" refers to fetal animals. Note that the increase in age along the x-axis is irregular. The data points are joined for clarity: this does not imply that real y-values exist intermediate to those plotted.

8.2.2: The nature of the data and the two types of variation

It can be seen from figure 8.3 that the density values range between approximately 0.05 and 0.7. Considerable variation is apparent, which means that, across the graph, each scan-site is capable of occupying a wide variety of density values. This variation means that both the actual and relative densities of each scan-site are not constant between each individual. It is not unusual for a scan-site to alter by as much as 0.1 between two individuals that may differ in age by only 100 days. The variation can be split into two types. First, there is an erratic combination of peaks and troughs in bone density, often occurring between animals of very similar ages and this feature of the data will be returned to below. Second, there is another type of variation

that can be seen in both figure 8.2 and 8.3. This is a more general and subtler form of variation that contributes to long-term trends across the graph.

8.2.3: General trends: results and discussion

Of particular interest here is that the bone density of the fetal animals is comparatively high. At or around birth (by the age of the stillborn animal), this density drops dramatically and then climbs steeply at first and then less so until around 1258 days (about 3.5 years – animal number 83) when it levels off. Even though it is based on data from relatively few animals, the sudden drop and recovery of bone density in very early life is consistent with what has been predicted in the literature. As has been mentioned previously (section 5.2.2), Trotter and Hixon (1974) have observed such a pattern in humans that they attributed to an early rapid increase in the size of a bone, while the mineral level remained comparatively stable. Similar observations have been made for the bones of dogs (Burns and Henderson 1936 p1208), pigs (Dickerson 1962a p49), rabbits (Weidmann and Rogers 1958 p339) and cats (Burns and Henderson 1936 p1208, Weidmann and Rogers 1958 p339). The exact timing of this feature in the sheep being examined here is not clear. This is because the exact ages at death of the fetal and stillborn animals is unknown.

It has frequently been assumed that the bones of immature animals are less dense (and so, less durable) than those of mature animals. The slight overall increase in bone density of animals aged between 171 and 1258 days (apparent in figures 8.2 and 8.3) supports this assumption. However, these figures also demonstrate that the situation is considerably more complex. In the next chapter, the pattern that has been noted here will be addressed further, by assessing how bone density differences relate to bone fusion, thus making it more archaeologically applicable. What is important to stress here is that previous taphonomic interpretations have not accounted for the fact that fetal or neonatal bone might be *more* durable than that of comparatively young animals. If the relatively high density of the very young bones is translated into increased durability, then the taphonomic implications are considerable. If this is the case, then frequencies of fused, unfused and neonatal/fetal bones should be calculated separately. If frequencies of bones that are known to have different durability are combined, then any interpretations based on such data are open to criticism. This point will be revisited in chapter 9.

8.2.4: Erratic variation: results and discussion

It would now be worthwhile to return to the more erratic variations that are superimposed on the general trend that has just been discussed. First, it is necessary to address whether or not these erratic variations relate to age, or not. No previous research has ever suggested that the bone density of a single individual is liable to fluctuate so dramatically throughout its life and so it seems highly unlikely that this is the case here. A much more convincing explanation is that these peaks and troughs are the result of differences in factors other than age between the individuals concerned. Chapter 5 described some of the factors that are known to have an effect on the density of an animal's skeleton. It is reasonable to assume that a significant part of the variability observed here is the result of factors other than age since the individuals used to produce figure 8.3 came from a wide range of sexes, breeds, months of death etc. Before the effects of age on an animal's bone density can be properly addressed, it will therefore be necessary to assess and account for the effects of these other factors. This is the aim of the following sections.

8.2.5: Understanding erratic variation

The approach chosen to try to isolate and understand the factors which potentially affect bone density is to compare animals that are similar in every possible respect, but that differ in terms either of their sex, breed, month of death, or other relevant factor. Any difference in bone density between animals that have been matched in this way is likely to be the result of the single factor that has been varied in each case. The factors that can be tested in this manner are limited by the amount of information regarding the experimental material that is available. These are:

Preparation method (how an animal was defleshed following its death)
Breed
Sex
Month of death
Age

Chapter 5 has demonstrated that each of these factors is capable of influencing the skeletal density of an animal.

Naturally, numerous other factors exist (such as health, diet or levels of exercise) that are no doubt equally capable of affecting bone density, but these factors cannot be tested because data are not available. The combined impact of all of these factors can be

assessed by comparing animals that are similar in all known respects. Bone density differences observed in such comparisons can be said to be the result of one or more of these factors, although a lack of relevant information regarding the material means that the determination of precisely *which* factors will be impossible.

Because this type of analysis involved the comparison of pairs of matched animals, the sample size will be necessarily small (two animals for each comparison). However, a small sample size is a small sacrifice in order to achieve such a closely controlled sample. More details of how this type of analysis will be carried out will be provided in the next section.

By looking at a limited number of scan-sites from 25 individuals, this section has established the range of variation in bone density. It has also been able to identify general trends in the data that are consistent with observations made by other researchers who were concerned with the effects of age on bone density.

However, the density values used in this analysis were being influenced by a broad range of variables (age as well as sex, breed, health etc.). By examining smaller numbers of carefully selected animals, it will be possible to control the factors that are influencing bone density. This course of action aims to produce data that are more easily interpreted and understood, although these data will be based on more reduced samples.

8.3: Research Methods, Definitions and Presentation of Results

8.3.1: Research methods and "*Background Variation*"

It has been proposed above that comparing groups of animals that differ only in terms of their preparation method, breed, sex, month of death or age will enable the impact of each of these attributes on bone density to be addressed. For the purposes of this project, these variables will be referred to as the "*five main attributes*". Any variation within such groups may be likely to be the result of the attribute that has been varied.

Even if a pair of animals is matched in terms of all of its five main attributes, variation in other factors (for which data are not available – eg nutritional status, heredity, levels of exercise, parity etc.) will potentially result in density variation. This type of variation can reasonably be assumed to exist no matter which animals are being compared. Consequently, in order to enable effective interpretation of the analyses in

this chapter, the impact of this type of variation on bone density must first be established and accounted for. For the purposes of this project, variation caused by factors other than the five main attributes will be termed "*background variation*" and will be attributable to "*background factors*". Occasionally, data may be available that suggest the causes of the background variation. Such data will be referred to as "*background information*". It must be stressed that this terminology is peculiar to this project and might not reflect the use of these terms elsewhere. However, their use in the subsequent sections has been closely defined and they are intended to simplify the text.

Few of the individuals examined by this project had exactly the same age at death. It should therefore be noted at this stage that animals that had ages within two months of one another were deemed to be similar. This policy had the effect of greatly increasing the number of matched groups that were available for study. This assumption is reasonable for all animals above approximately 200 days of age. However, it has been demonstrated (above) that considerable fluctuations in age occur in the first few days of life. Consequently, animals younger than 200 days will only be deemed similar if their ages are *exactly* the same. In order to increase the sample size still further, animals that had a month of death within two months of each other were also deemed to be similar. First, the background variation in the material will be explored and then the absolute and relative variability of each of the five main attributes will be described and discussed in turn.

8.3.2: Presentation of the results

All of the following analyses will involve the comparison of pairs of animals. In each case, the bone densities of one animal will be subtracted from those of the other. The resulting differences will be displayed in tabular form. This is possible because it is the *differences* between the individuals that are of importance here, and not their absolute values. Generally, the animals with an overall higher bone density will be intentionally subtracted from the animal with the overall lower bone density. This will produce predominantly negative values. When positive values are produced, these will be highlighted in red. When the difference between the two animals is lower than that resulting from intra-observer error tests (0.24 – see section 7.4.2) the cell will be greyed-out – regardless of whether it is positive or negative. Figure 8.4 and table 8.1 will elucidate this technique.

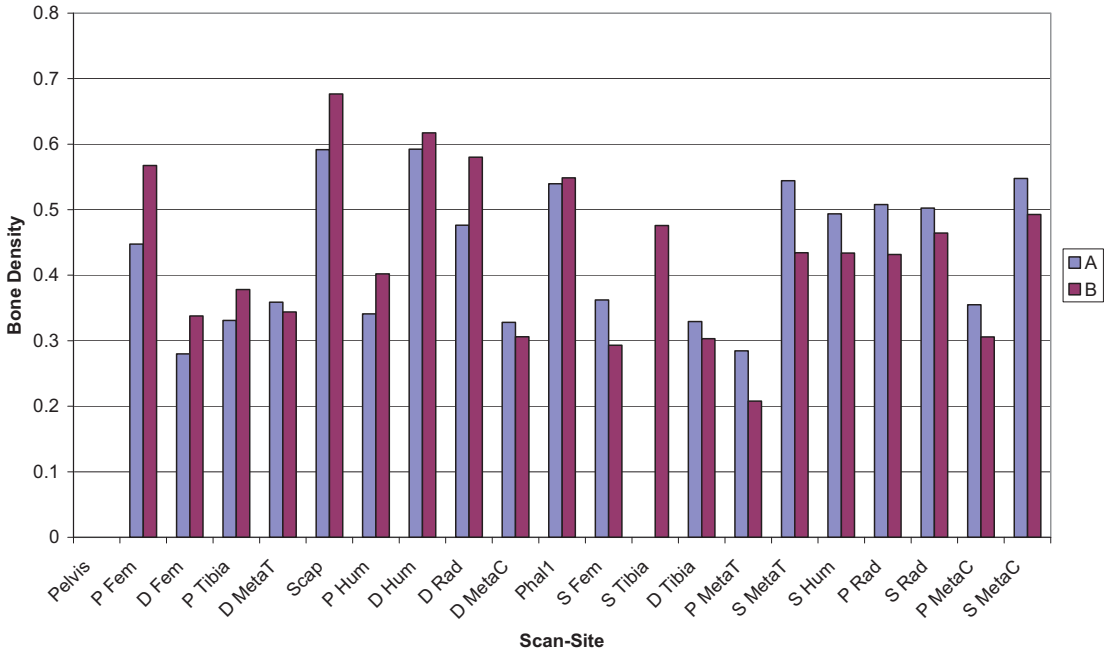

Figure 8.4: Showing the bone density values that might be obtained from two animals. The values are presented so that the two animals can be compared. The differences in the column heights that are shown graphically here are incorporated into table 8.1, below. The data presented here do not relate to any actual animals studied by this project.

	A	B	A-B
Pelvis			
P Fem	0.448	0.568	-0.120
D Fem	0.280	0.338	-0.058
P Tibia	0.331	0.378	-0.047
D MetaT	0.359	0.344	0.015
Scap	0.592	0.677	-0.085
P Hum	0.341	0.402	-0.061
D Hum	0.592	0.617	-0.025
D Rad	0.476	0.580	-0.104
D MetaC	0.328	0.306	0.022
Phal1	0.540	0.549	-0.009
S Fem	0.362	0.293	0.069
S Tibia		0.476	
D Tibia	0.329	0.303	0.026
P MetaT	0.285	0.208	0.077
S MetaT	0.544	0.434	0.110
S Hum	0.494	0.434	0.060
P Rad	0.508	0.432	0.076
S Rad	0.502	0.464	0.038
P MetaC	0.355	0.306	0.049
S MetaC	0.548	0.493	0.055

Table 8.1: Showing the differences (A-B) between the bone densities of animals A and B. It is readily apparent that some of these differences are lower than the intra-observer error. It can also be seen that for some scan-sites, A is denser than B and in others, the converse is true.

Table 8.1 shows the bone densities of two fictitious animals ("A" and "B") and the difference between them ("A-B"). Figure 8.4 shows the densities of these two animals graphically. For both table 8.1 and figure 8.4 the trabecular scan-sites are listed first, followed by the cortical scan-sites. Within this, hind limbs are listed before the forelimbs and then the most proximal scan-sites are listed before the more distal ones. This will make it easier to see patterns in the data that relate to skeletal location. Due to missing data for the shaft of the tibia and the pelvis, both these cells for A-B are left blank.

Figure 8.4 shows that the density differences between the distal metatarsal, distal metacarpal and first phalanx are small. These differences are in fact smaller than the intra-observer error and so in column "A-B" they are greyed-out. This implies that for these three scan-sites, the two animals have essentially similar densities.

Figure 8.4 also shows that the trabecular scan-sites of animal "A" are invariably lower than those of animal "B" (and so negative values for A-B are produced).

Conversely, the cortical scan-sites of "A" are *higher* than those of "B" (and so positive values for A-B are produced). This is apparent in column "A-B" of table 8.1 because the trabecular scan-sites are printed in black, while the cortical scan-sites are shown in red.

This technique means that a reasonably brief examination of column "A-B" reveals that the trabecular skeleton of animal "A" is less dense than that of "B" and the reverse is true for the cortical skeleton. It is also apparent that the foot bones of these two animals have essentially the same densities.

In the following analyses, only the difference between the animals from any one pair will be displayed. Now that the research methods and data presentation have been described, the impact of background variation on bone density can be addressed.

8.4: The Impact of Background Variation on Bone Density

Establishing the background variation of bone density within the experimental material is an essential first step in the analysis. This will indicate the degree to which factors other than the five main attributes can affect bone density. If the variation of bone density between essentially similar animals is slight, then it will be possible to assume that the five main attributes are the main factors that potentially affect bone density. Consequently, variation noted in subsequent analyses is most likely to be the product of the main attribute in question. However, if background variation is considerable, then in subsequent analyses, the impact of the five main attributes may be reduced, masked, or mimicked.

Whichever is the case, it will be possible to speculate on the causes of background variation as well as exploring the way in which it affects the skeleton according to bone type, or skeletal location.

8.4.1: Materials

The groups of animals that were compared in order to establish the background variation of bone density were similar in terms of each of their five main attributes, although they occasionally differed in other factors. The skeleton numbers of each of the animals used in this analysis are displayed in table 8.2 along with the information concerning them that was available. It should be noted that the background information provided is almost certainly not exhaustive.

The animals are displayed in table 8.2 in their matched groups. Where a matched group of more than two animals was available, as many pairs as possible were created from the matched group.

Skeleton Number	Age (days)	Preparation Method	Breed	Sex	Month of Death	Month of Birth	Locality	Accession Number	Mode of Death	Condition at Death	Comments
6	0	Bu	Manx	F	2	2	Norfolk	1020	Stillborn	U/K	Twin = 1021
7	0	Bu	Manx	F	2	2	Norfolk	1021	Stillborn	U/K	Twin = 1020
25	541	Bo	S X B	C	10	4	Edinburgh	2852	U/K	U/K	
27	531	Bo	S X B	C	10	5	Edinburgh	2851	U/K	U/K	
22	950	Bo	Shet	C	11	4	Hoy	3218	U/K	U/K	
20	954	Bu	Shet	C	11	4	Hoy	2944	U/K	U/K	
55	950	Bo	Shet	M	12	4	Hoy	3281	U/K	U/K	
52	954	Bo	Shet	M	12	5	Hoy	3289	U/K	U/K	
49	960	Bo	Shet	M	12	4	Hoy	3288	U/K	U/K	
83	1258	Bu	Soay	F	9	4	Bedford	2229	U/K	U/K	
82	1277	Bu	Soay	F	9	3	Bedford	2224	U/K	U/K	
67	1259	Bu	Soay	F	9	4	Bedford	2228	U/K	U/K	
72	1691	Ma	Shet	F	12	4	Hoy	1488	U/K	Av	
91	1691	Ma	Shet	F	12	4	Hoy	1495	U/K	U/K	
66	1691	Ma	Shet	F	12	4	Hoy	1491	U/K	Gd	
95	2056	Ma	Shet	F	12	4	Hoy	1496	U/K	Av	
79	2056	Ma	Shet	F	12	4	Hoy	1493	U/K	Av	
92	2421	Ma	Shet	F	12	4	Hoy	1492	U/K	U/K	
94	2421	Ma	Shet	F	12	4	Hoy	1497	U/K	Av	
4	2421	Ma	Shet	F	12	4	Hoy	1489	U/K	Poor	
68	2421	Ma	Shet	F	12	4	Hoy	1490	U/K	Av	Poor feet

Table 8.2: Showing all of the five main attributes and the background information of the 21 animals that were compared in order to establish the background variation. Where more than two matched animals were available, they were split into as many pairs as possible. Bu = Buried; Bo = Boiled; Ma = Macerated; F = Female; M = Male; C = Castrate; U/K = Unknown; Av = Average; Gd = Good.

8.4.2: Results

The bone densities for each of the scan-sites of the animals described above were calculated.

The differences between the densities for each pair are displayed in table 8.3 according to the methods described above. The actual density values themselves can be viewed in appendix C. For each pair, the density values of the animal with an overall higher skeletal density are subtracted from those of the overall lower density animal (therefore the majority of the differences are negative). Differences that do not exceed

the intra-observer error are greyed-out. To aid interpretation, positive differences are shown in red. Each pair is displayed in order of increasing age.

Animals Compared / Scan-site	6-7	25-27	20-22	52-49	55-49	52-55	67-82	67-83	82-83
Pelvis	-0.010					-0.039			
P Fem	-0.044	-0.019	0.083	0.045	0.068	0.022	-0.037	-0.090	-0.053
D Fem	-0.010	-0.040	-0.017		-0.034		-0.079	-0.103	-0.023
P Tibia	-0.006	-0.061	-0.024	-0.021	-0.004	0.016	-0.066		
D MetaT	-0.126	-0.040	0.066	-0.068	-0.102	-0.034	-0.016	-0.064	-0.048
Scap	-0.079	-0.034	-0.033	0.051	0.025	-0.026	-0.001	0.003	0.003
P Hum	-0.064	-0.018	0.009	-0.026	0.069	0.095	-0.020	-0.010	0.011
D Hum	-0.007	0.004	-0.012	0.029	0.000	-0.029	-0.002	-0.032	-0.030
D Rad	0.025	-0.052	-0.048	0.077	0.114	0.037	-0.037	-0.080	-0.043
D MetaC	-0.103	-0.044	0.015	-0.042	-0.081	-0.038	-0.009	-0.077	-0.068
Phal1		-0.073	0.023	-0.048	-0.028	0.021	-0.026	-0.054	-0.028
S Fem	0.027	-0.033	-0.050	-0.039	-0.055	-0.015	0.037	-0.020	-0.057
S Tibia	-0.003	-0.107	-0.026	0.052	-0.011	-0.064	0.040	-0.054	-0.094
D Tibia	0.028		-0.178		0.008		0.102	0.053	-0.049
P MetaT	-0.040	-0.033	-0.007	0.001	0.061	0.060	-0.030	-0.061	-0.031
S MetaT	-0.044	-0.086	-0.032	-0.063	-0.090	-0.027	-0.020	-0.119	-0.099
S Hum	-0.138	-0.015	0.003	-0.037	-0.043	-0.006	0.070	-0.022	-0.092
P Rad	-0.129	-0.198	0.198	0.042	-0.034	-0.076	-0.015	0.053	0.068
S Rad	-0.031	-0.076	0.003	-0.124	-0.151	-0.027	0.058	-0.083	-0.142
P MetaC	-0.042	-0.005	0.016	-0.043	-0.036	0.007	-0.030	-0.051	-0.021
S MetaC	-0.073	-0.112	-0.062	-0.091	-0.060	0.031	-0.019	-0.138	-0.119

Animals Compared / Scan-site	66-72	66-91	72-91	79-95	68-4	4-92	4-94	68-92	68-94
Pelvis	0.054								
P Fem	0.048	-0.101	-0.149		-0.133	-0.072	-0.075	-0.205	-0.208
D Fem	-0.015	-0.012	0.003		-0.049	-0.030	-0.100	-0.080	-0.149
P Tibia		0.129		-0.022	-0.028	-0.064		-0.091	
D MetaT	-0.033	-0.028	0.006	0.107	-0.061	-0.088	-0.135	-0.150	-0.196
Scap	-0.012	-0.049	-0.037	0.009	-0.068	-0.082	-0.100	-0.150	-0.168
P Hum	0.063			-0.041	-0.021	0.013	-0.049	-0.008	-0.070
D Hum	-0.005	0.015	0.020	-0.073	-0.242	0.098	0.001	-0.144	-0.241
D Rad	-0.038	-0.041	-0.003	-0.090	-0.105	0.004	0.048	-0.101	-0.056
D MetaC	-0.061	-0.111	-0.050	-0.032	0.002	-0.166	-0.172	-0.164	-0.170
Phal1	0.003	-0.025	-0.028	-0.065	-0.008	-0.141	-0.182	-0.149	-0.190
S Fem	-0.013	-0.034	-0.021		-0.125	-0.028	-0.008	-0.153	-0.133
S Tibia	-0.032	-0.056	-0.024	-0.015	-0.160	-0.028	-0.079	-0.189	-0.240
D Tibia	-0.024	-0.035	-0.011	-0.048		0.029	-0.038		
P MetaT	0.038	0.012	-0.025	-0.024	-0.099	-0.006	-0.034	-0.106	-0.134
S MetaT	-0.012	0.055	0.068	-0.035	-0.079	-0.044	-0.080	-0.122	-0.159
S Hum	-0.069	-0.095	-0.026	-0.041	-0.153	0.193	0.015	0.041	-0.137
P Rad	-0.058	-0.107	-0.049	0.062	-0.175	0.017	-0.050	-0.158	-0.225
S Rad	0.024	-0.006	-0.030	-0.066	-0.213	0.110	0.121	-0.103	-0.092
P MetaC	-0.082	-0.081	0.001	-0.042	-0.091	-0.012	-0.045	-0.103	-0.135
S MetaC	-0.043	-0.012	0.031	-0.031	0.002	-0.113	-0.177	-0.111	-0.176

Animals Compared	
Scan-site	
Pelvis	92-94
P Fem	-0.003
D Fem	-0.069
P Tibia	
D MetaT	-0.047
Scap	-0.018
P Hum	-0.062
D Hum	-0.097
D Rad	0.044
D MetaC	-0.006
Phal1	-0.041
S Fem	0.020
S Tibia	-0.051
D Tibia	-0.067
P MetaT	-0.028
S MetaT	-0.037
S Hum	-0.178
P Rad	-0.067
S Rad	0.011
P MetaC	-0.032
S MetaC	-0.064

Table 8.3: Showing the differences in density values for each of the matched pairs. All of the greyed-out values are less than the intra-observer error, and so can be attributed to background variation. Values shown in red are positive while values shown in black are negative.

There are no clear patterns that immediately emerge from table 8.3. The large numbers of differences that exceed the intra-observer error demonstrate that there is undoubtedly a significant degree of background variation within each matched pair. For some of the pairs, one individual tends to have a consistently either higher or lower level of skeletal density (the difference is consistently negative, eg pair 68-94). The variation between these pairs can be described as being uni-directional. Other pairs show multi-directional differences (there is a more even mixture of positive and negative differences, eg pair 66-72). Notably, the pairs that show multi-directional differences between their densities also tend to display smaller differences, while the strongly uni-directional differences tend to be of greater magnitude.

In the case of pairs 20-22, 66-72 and 72-91, the number of differences that exceed the intra-observer error is comparatively low and the differences that do exceed the intra-observer error generally do so by a narrow margin. This implies that, in terms

of bone density, these animals were similar. Conversely, the differences recorded within pairs 68-4, 4-94, 68-92, and 68-94 not only exceed the intra-observer error, but often do so by a considerable degree. Between these two extremes exists an array of background variation that does not fall into any definable category.

8.4.3: Discussion

Perhaps the only firm conclusion that can be drawn from this analysis is that background variability does exist. The pairs examined here seem to show a wide range of variation, from the slight to the extreme. Both uni-directional and multi-directional differences are apparent.

Where the difference between the bone density of two animals is uni-directional, it implies that one of the animals has a consistently higher or lower bone density than the other. This probably means that one or more of the factors described in chapter 5 has led to variation in the bone density of one of the animals. It has been noted that pairs with uni-directional density differences tend to be of a higher magnitude. This suggests that where an environmental or genetic factor affects the bone density of an animal, it does so in a uniform direction.

Horwitz and Smith (1990 p665) claim that bone loss due to dietary deficiencies will preferentially affect trabecular bone. Only in relatively extreme cases of malnutrition will cortical bone be lost. Similarly, bone density change brought on by either high or low levels of physical exercise are limited to weight-bearing regions of the skeleton (Bartosiewcz *et al* 1993 p29, Bourrin *et al* 1994 p2001, Kannus *et al* 1995 p29). In this analysis, there is no clear patterning of the variation across the skeleton according to skeletal location, bone type or bone function. This is unsurprising, since a repeatable pattern of bone loss would imply that a single process was responsible for the background variation. It is much more likely that the differences observed here are the result of multiple processes affecting the skeletons in a variety of ways.

Occasionally it is possible to offer an explanation for the observed differences. For example, an examination of table 8.3 shows that animal number 68 has consistently (and often considerably) lower bone densities than any of the other animals with which it was compared. It is possible that the observation that this animal had “poor feet” (see table 8.2) is being reflected in its bone density. If this is the case, it is rather surprising that this condition should be reflected in the entire skeleton rather than the lower limb bones alone. It is possible that the condition affected this animal’s ability to stand or eat; however, it is also arguable that further, unknown factors are also at work here.

The condition of an animal when it died might also help to explain the observation that animal number 4 has a generally lower bone density than animal number 68 or 92. The "poor" condition of animal number 4, reported in table 8.2 might account for the low bone density in this individual. However, the fact that the difference between animals 4 and 94 is not markedly uni-directional highlights the point that bone density cannot be predicted simply on the basis of whatever background information regarding the animals in question happens to be available.

An explanation for the differences between animals number 79 and 95 can also be tentatively suggested. The observed pattern here is one of number 95 having more bones that are denser than the bones of number 79. Lambing records of these two animals reveal that number 95 had not produced any lambs for the two years leading to its death, while number 79 produced one lamb in each of these equivalent years. Parity is known to cause a burden on the skeleton, eventually resulting in the reduction of bone density. This fact can be used to explain the reduced density of the skeleton of the more parous animal, especially if it was living under conditions of nutritional stress.

All of these explanations must be offered tentatively, since it is not possible to test their validity.

This analysis has also produced strongly directional patterns that cannot be explained (eg pairs 25-27 or 82-83). This is perhaps due to the quality or the quantity of the information about the animals that is available.

This analysis is primarily concerned with the *direction* of density differences within matched pairs of animals. It therefore enables animals that have relatively high or low skeletal densities to be identified. This provides some insight into the effect on bone density of the main variable being examined (in this case, background variation). The methods employed here enable the magnitude of bone density differences between matched pairs to be examined. However, it is not possible to compare these differences with the actual densities of each scan-site. Consequently, the potential for the density differences identified here to alter the ability of the bones to withstand taphonomic destruction cannot be assessed. This chapter is not concerned with the ability of bone density variation to affect element frequencies in the archaeological record. Chapter 9 will address the potential for the bone density variation identified here to be represented as bias in archaeological element frequencies.

8.4.4: Summary

Without a doubt, significant variation in bone density exists between animals that have been matched in terms of their five main attributes. Since the animals being compared were always matched, this variation must be the result of other factors and as such can be defined as "background variation". This background variation can range from slight to extreme (as much as 0.242, according to the results presented in table 8.3). The extent of the impact of background factors on skeletal density is probably dependent on the nature of these factors themselves.

Background variation is the result of a broad array of environmental and genetic factors acting independently, together, or even by interacting to alter the bone density of the animals being examined here. Consequently, the observed background variation is erratic. At best, only *possible* explanations for its behaviour can be suggested. If two criteria were fulfilled, predicting background variation might become possible. Firstly, a full understanding of the operation and interaction of the numerous variables involved in determining bone density is needed. Secondly, these variables must be recorded in the material being analysed. Until both of these requirements are fulfilled, background variation will remain unpredictable.

8.5: The Impact of Variations in Preparation Method on Bone Density

Now that the extent of background variation in bone density has been measured and discussed, it is possible to assess the impact of variation in each of the five main attributes on the bone density of the animals under analysis here. The first of the five main attributes to be addressed will be the preparation method. The potential for the preparation method to affect the density of a bone has been demonstrated by numerous authors. The removal of calcium (or collagen) from bone through chemical diagenetic processes (White and Hannus 1983 pp321 - 322) or boiling (Rosen *et al* 1994) is likely to result in a decrease in its density. Similarly, the increase in porosity associated with diagenetic microbial action (Bell 1990, Garland 1987, Hackett 1981) will be exhibited as a decrease in density.

The preparation method is the only one of these attributes to be *post mortem* in origin. If the impact of preparation method can be shown to be negligible, then any other variation in bone density observed later can be said to be *ante mortem*. Furthermore, if the bone density of animals that have been buried can be shown to be substantially different from that of animals that have been boiled or simmered, there

will be implications regarding the taphonomic behaviour of archaeological faunal assemblages that have been cooked. It is important to understand such density differences, so that bias in the archaeological record according to the ways in which food was prepared can also be appreciated.

8.5.1: Materials

Six pairs of animals that were matched in every one of their attributes except preparation method were available for study. These pairs covered a wide range of available ages, sexes and months at death. The details of these animals are shown in table 8.4.

Skeleton Number	Age (days)	Preparation Method	Breed	Sex	Month of death	Month of birth	Locality	Accession Number	Mode of Death	Condition at Death	Comments
58	668	Ma	Shet	M	2	4	Hoy	1591	U/K	U/K	
46	694	Si	Shet	M	3	5	Hoy	2583	U/K	U/K	
54	693	Si	Shet	C	3	5	Hoy	2582	U/K	U/K	
34	704	Ma	Shet	C	4	4	Hoy	2892	U/K	U/K	A "poor doer"
22	950	Bo	Shet	C	11	4	Hoy	3218	U/K	U/K	
30	970	Ma	Shet	C	12	4	Hoy	2866	U/K	U/K	
70	2703	Bo	Soay	F	8	5	Newmarket	3209	Put Down	Poor	Oral infection
75	2711	Bu	Soay	F	9	4	Bedford	2225	U/K	U/K	
78	2765	Si	Soay	F	11	4	Newmarket	2509	U/K	U/K	

Table 8.4: Showing all of the five main attributes and the background information of the nine animals that were compared in order to establish the variation attributable to preparation method. Where more than two matched animals were available, they were split into as many pairs as possible. Ma = Macerated; Si = Simmered; Bo = Boiled; Bu = Buried; Shet = Shetland; M = Male; F = Female; C = Castrate; U/K = Unknown.

For this analysis each matched pair consists of two animals that are similar in terms of four of their five main attributes, but that differ in terms of the method that was used to deflesh and clean them. Each skeleton was assigned one of five “preparation categories”. These were burial (Bu), boiling (Bo), simmering (Si), maceration (Ma) and unknown (U/K). The temperature and duration of treatment had not been recorded, so only conclusions regarding the preparation categories will be able to be drawn. It will be

impossible to assess how different duration or temperatures of treatment affect bone density.

8.5.2: Results

As in the previous section, the bone densities for each of the animals described above were calculated. An indication of the actual variation in bone density within each pair is provided by subtracting the densities from one of the animals from those of the other. Again, the densities of animals with an overall higher bone density were subtracted from those of lower density animals, with the exception of pair 58-46. In this case, the density of the generally lower density skeleton (46 - simmered) was subtracted from that of the generally higher density skeleton (58 - macerated). This was intended to provide some continuity with pair 34-54, where the density of the simmered animal (54) was subtracted from that of the macerated animal (34).

The actual density differences are presented in table 8.5. Once again, pairs with density differences that do not exceed the intra-observer error are greyed-out and positive differences are shown in red.

Animals Compared / Scan-site	58-46 (Ma-Si)	34-54 (Ma-Si)	30-22 (Ma-Bo)	70-75 (Bo-Bu)	78-70 (Si-Bo)	78-75 (Si-Bu)
Pelvis	0.031	-0.148	0.062			
P Fem	0.047	-0.138	-0.216	-0.045	-0.027	-0.072
D Fem	0.124	-0.119	-0.043	-0.047	-0.050	-0.097
P Tibia	-0.065	-0.150	0.035			-0.130
D MetaT	0.071	-0.168	-0.084	-0.040	-0.051	-0.091
Scap	0.034	-0.091	-0.105	0.007	-0.095	-0.088
P Hum	0.081	-0.049	-0.036	-0.012	0.003	-0.009
D Hum	0.008	-0.151	-0.028	-0.014	-0.127	-0.140
D Rad	0.082	-0.215	-0.079	-0.034	-0.036	-0.069
D MetaC	0.086	-0.207	-0.107	-0.069	-0.019	-0.088
Phal1	-0.003	-0.110	0.019	-0.043	-0.033	-0.075
S Fem	0.122	-0.122	-0.097	0.014	-0.019	-0.005
S Tibia	0.085	-0.100	-0.011	-0.018	0.001	-0.017
D Tibia	-0.008	-0.182	-0.251	-0.098	-0.011	-0.110
P MetaT	0.061	-0.141	-0.020	-0.039	-0.005	-0.044
S MetaT	0.022	-0.116	0.026	-0.054	-0.029	-0.083
S Hum	0.068	-0.170	0.006	-0.009	0.000	-0.009
P Rad	-0.077	-0.297	-0.004	0.010	-0.137	-0.126
S Rad	0.200	-0.102	0.020	0.022	-0.024	-0.002
P MetaC	0.033	-0.180	-0.029	-0.064	-0.041	-0.105
S MetaC	0.098	-0.101	0.016	-0.074	0.070	-0.004

Table 8.5: Showing the differences in density values for each of the pairs. The individuals from each pair are known to differ only in the methods used to deflesh them. All of the greyed-out values are lower than the intra-observer error, and so can be attributed to background variation. Red values are positive and black values are negative.

The data from table 8.5 contain a number of patterns that justify description. The animals examined by this analysis fall into one of two categories. Pairs 58-46 and 34-54 exhibit strongly directional differences. In both of these cases one animal from each pair has consistently (or in the case of pair 34-54, ubiquitously) higher or lower bone densities than the other.

This contrasts with the results of the other pairs from this analysis, which show a less clearly defined directionality. In these cases it is the trabecular bone that displays the greatest differences, while the cortical bone tends to show more differences in bone density that are within the intra-observer error. It seems, therefore, that while some unknown process has affected the density of the trabecular bone of these animals, this process has had little or no effect on the cortical skeleton.

The following discussion will attempt to assess the factors that have resulted in the two distinct patterns described above.

8.5.3: Discussion

It is possible to hypothesise that if the preparation method used to deflesh an animal were to affect the bone density of its skeleton, it would do so by affecting the mineral content of the bones and not by altering their bulk density. In order to alter the bulk density, the process in question would be required to remove bone material from the bone by thinning the trabeculae or the cortical bone. It is unlikely that this could occur in anything but the most extreme cases.

What is considerably more likely is that the preparation processes will result in the removal of mineral or other radiodense material from the bone. A study into the effects of boiling on bone demonstrated that prolonged boiling or simmering of chicken bone results in a leaching out of bone mineral into the "soup" solution (Rosen *et al* 1994 p487). Similarly, diagenetic action of organic acids and soil fauna has the effect of removing material from buried bone without affecting its external macroscopic morphology (Locock *et al* 1992 p301). Such processes will alter the radiodensity of the bone without affecting its morphology and will ultimately lead to a lower bone density value being calculated.

It follows from this that preparation processes primarily affect bone density without significantly affecting the morphology of the bone. Where differences in bone density values can be attributed to bone morphology, it would be unwise to implicate preparation method as the causative factor. In cases such as these, it would be wise to follow the lead of Horwitz and Smith (1990) who used morphological changes such as these to identify animals that were diseased or nutritionally stressed.

Figures 8.5 and 8.6 display the mid-shaft cortical thickness of each bone from the two pairs of animals under consideration here (34-54 and 58-46). In both figures, the cortical thickness of each bone shaft is compared with the density of the same scan-site. If, in each case, the element with the lower bone density also has a reduced cortical thickness (to which the reduced density can be attributed), then it is unlikely that any preparation method is responsible for the observed density difference. However, if the two bones have a similar cortical thickness, then the conclusion that the preparation method is the cause of the observed density difference is a more reasonable one.