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6

Aspects of human osteology and skeletal biology

Chris A. Deter, Patrick Mahoney, Sarah E. Johns and Sandra Thomas

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This chapter presents the results of three studies that were undertaken as part of the *Beaker People Project (BPP)*, and which complemented the osteological work undertaken for the *Beakers and Bodies Project* as reported in Chapter 5. The first study examined the age and sex of 201 individuals that had been deemed suitable for isotopic analysis of dental enamel. The second examined tooth enamel defects in 12 juvenile skeletons, as an indicator of non-specific infant stress. The third was a craniometric study of skulls from the Peak District, designed to assess the validity of previous claims for a change in skull shape from dolichocephalic (long-headed) during the Neolithic, to brachycephalic (round-headed) from the Chalcolithic onwards, and to explore the possible reasons for the observed differences. The chapter ends by considering the results of the craniometric study in the light of isotopic evidence suggesting a high incidence of non-local individuals within the Peak District dataset.

Determination of age and sex

Chris A. Deter and Patrick Mahoney

The aim of this study was to analyse and describe the age and sex profile of 201 skeletons for the *BPP*. Each skeleton had been deemed suitable for isotopic analysis of dental enamel, and the skeleton record numbers from the *BPP* Database are given in Table 6.1.[1] Of these, 127 have been radiocarbon-dated to the core, Chalcolithic–Early Bronze Age period, between 2500 BC and 1500 BC, with a further 68 undated individuals being attributable to this period on the basis of grave goods and/or grave form. One radiocarbon-dated individual (SK132) is of Neolithic date, one (SK249) is of Iron Age date, and four undated individuals (SK78, 117 118 and 285) are believed to be of Neolithic date (as discussed in Appendix 1). Given that the criterion for selection was suitability for isotopic analysis of dental enamel, there was a deliberate bias in the avoidance of sub-adults and of old adults (whose molars were missing or severely worn).

Standard methods were used to estimate biological sex and age at death. Results are presented for Scotland, England, and Wales; for England, the results are then further subdivided into northern, central and southern England (Table 6.1 and see also Appendix 4).

Estimation of biological sex

Biological sex estimation depends on the reliable detection of sexually dimorphic characteristics in the human skeleton (eg, Krogman 1955; Brothwell 1981; Krogman & İşcan 1986; Cox & Mays 2000). When data from the cranium and pelvis are combined, the accuracy of the sex estimation is increased (Mays & Cox 2000). Sex-based characteristics are partially age-related, appearing or becoming more pronounced after puberty, and some are affected by old age (Krogman & İşcan 1986; Buikstra & Ubelaker 1994; Schwartz 1995). Twenty-four sex-diagnostic characters of the skull and 25 sex-diagnostic characters of the pelvic bones were used to distinguish between the male and female skeletons (eg, Phenice 1969; Krogman & İşcan 1986; Ferembach *et al.* 1980; Schwartz 1995; Loth & Henneberg 1996). In very fragmented individuals where cranial and pelvic morphological analysis could not be assessed, metric analysis of the femur was used.

Biological sex classifications of the pelvis were scored on a 1–5 scale, following Buikstra and Ubelaker (1994) , where stage 1 = definitely female, stage 2 = probably female, stage 3 = indeterminate, stage 4 = probably male, stage 5 = definitely male. All biological sex estimation methods were scored independently, and then combined to create a final composite score.

Os coxae assessment

The morphological features assessment was based upon Phenice (1969), Ferembach *et al.* (1980), Krogman and İşcan (1986), and Schwartz (1995), and focused on the following (with the asterisks indicating where the characteristics were scored as presence = female and absence = male):

- Ventral arch
- Greater sciatic notch
- Width of sacral ala
- Anterior sacral curvature
- Sacral auricular surface
- Iliac tuberosity
- Iliac blade
- Iliac crest
- Auricular surface
- Pubic tubercle
- Preauricular sulcus
- Pubic rami
- Sub-pubic concavity*
- Sub-pubic angle
- Inferior pubic ramus

Table 6.1: Age and sex distribution of the 201 individuals examined, by country/region; also shows ceramic associations (where present)

Country or region	*n*	*Sex*[1]			*Age*[2]				*Pot*[3]			
		Female	*?*	*Male*	*Sub-adult*	*Young adult*	*Middle adult*	*Old adult*	*Beaker*	*Food Vessel*	*No pot*	*Other*
Scotland	39	13	6	20	3	12	20	4	24	4	11	0
England	157	42	36	79	10	33	90	24	54	21	79	3
Wales	5	0	1	4	0	2	3	0	5	0	0	0
Total Britain	*201*[4]	*55*	*43*	*103*	*13*	*47*	*113*	*28*	*83*	*25*	*90*	*3*
Northern England	85	25	17	43	3	25	45	12	23	17	42	3
Central England	23	5	4	14	2	2	16	3	5	1	17	0
Southern England	49	12	15	22	5	6	29	9	26	3	20	0

1. Female group includes possible females; male group includes possible males
2. For nine individuals (SK13, 26, 28, 101, 104, 140, 142, 244, and 288) the estimated age at death was 'adult unknown age' and these have been incorporated into the 'Middle Adult' group
3. Five individuals (SK137, 138, 266, 279 and 286) have uncertain associations with pottery and have been incorporated into the 'No pot' group. One individual (SK64) was recorded as 'other non-descript vessel' and incorporated into the 'Other' group
4.The skeletal database numbers (SK) for these individuals are 1, 2, 4, 6, 8–10, 12–15, 17–20, 23, 25–28, 30, 32–42, 45–47, 49–51, 53–54, 56, 58, 61–62, 64–66, 68–73, 77–83, 85, 88–89, 91–94, 96–99, 101–104, 107–111, 115, 117–122, 125–128, 130–144, 146–152, 154–155, 162–171, 176–177, 188, 190, 192, 195–202, 204–213, 215, 217–219, 221–223, 242–246, 249–250, 252–258, 260–282, 284–291. Of these, SK 132 has been radiocarbon-dated to the Neolithic, and SK78, 117 118 and 285 are believed to be of Neolithic date, while SK249 is of Iron Age date

- Ventral arc*
- Obturator foramen
- Ischial tuberosity
- Ischial spine
- Medial ischio-pubic ridge*
- Acetabulum

Skull assessment

The morphological assessment was based upon Ferembach *et al.* (1980), Krogman and İşcan (1986), Loth and Henneburg (1996) and Schwartz (1995), and focused on the following characteristics, with the asterisk indicating once more how male and female were scored):

- Overall shape/structure
- Glabellar profile
- Frontal slope
- Frontal and parietal tuberosities*
- Zygomatic process of frontal
- Supraorbital ridges
- Orbital outline
- Nasal bones
- Zygomatic bones
- Temporal ridges
- Suprameatal crests
- Mastoid process
- Nuchal area
- External occipital protuberance
- Mandibular condyles
- Pterygoid plates
- Canine eminence
- Palate
- Mandibular ramus
- Depth from incisors to mentum
- Lower margin of mandibular corpus
- Mental protuberance
- Angle of mandible
- Lower first molar

Metric assessment

When morphological features of the pelvis and cranium could not be assessed, metric analysis was used to assess biological sex. The measurements used were the vertical diameter of the femoral head (Stewart 1979), the circumference of the femoral mid-shaft (Black 1978) and femoral bicondylar width (İşcan & Miller-Shaivitz 1986). When used separately, the femoral head diameter and bicondylar width can provide an accuracy of 87–90% and, when used together, they can be 94% accurate (Krogman & İşcan 1986).

Estimation of age at death

Methods used to estimate the age at death were based upon the pubic symphysis, auricular surface, cranial sutures, and dental wear. Four sub-adult age categories were created to estimate age (infant = 1 week to 13 months; early childhood = 14 months to 5 years; late childhood = 6 to 12 years; adolescence = 13 to 17 years), and these were then grouped as 'sub-adults' in the analysis. Three adult age categories (young adult = 17–25 years; middle adult = 26–45 years; and old adult = 45+ years) were created.

Pubic symphysis

The morphological degeneration of the pubic symphysis (Brooks & Suchey 1990) is considered to be one of the most reliable criteria for estimating age at death in adult human remains (Buikstra & Ubelaker 1994).

Auricular surface

Changes in the sacro-iliac joint are often independent of osteoarthritic change (Buckberry & Chamberlain 2002; Schwartz 1995). Estimation of age at death from the auricular surface can, however, be more difficult to assess compared to using the pubic symphysis as a measure. However, in archaeological remains, the auricular surface is often very well preserved (Buikstra & Ubelaker 1994; Krogman & İşcan 1986; Schwartz 1995). For this study, the left auricular surface was assigned one of the eight phases described by Ubelaker (1989), based upon earlier work by Lovejoy *et al.* (1985) and Meindl and Lovejoy (1989). If the left surface was not present or could not be assessed, the right side was used.

Cranial assessment

Suture closure is associated with more advanced age than the previous two age-estimation methods. While suture closure does not appear to be sexually or racially biased, using it to assess age at death produces broad age ranges (Key *et al.* 1994). Thus, age estimates based on suture closure are only useful when other methods cannot be used, or else when utilised in conjunction with other methods (Meindl & Lovejoy 1985; Buikstra & Ubelaker 1994; Key *et al.* 1994).

A composite score was taken for the vault sites (mid-lambdoid, lambda, obelion, anterior sagittal and bregma) and the lateral-anterior sites (pterion, midcoronal, spheno-frontal, inferior spheno-temporal, superior spheno-temporal). Compiled scores from these vault landmark sites were compared to Meindl and Lovejoy (1985) to estimate the age at death. This method was not used on cranial fragments.

Dental attrition wear

Dental wear can be used to estimate age at death. Miles (1963) devised a scheme that relates the wear of the lower molar teeth to the age of the individual. In order to use this method, one must ensure that the skeleton has a normal pattern of dental eruption and occlusion, and that the wear gradient along the

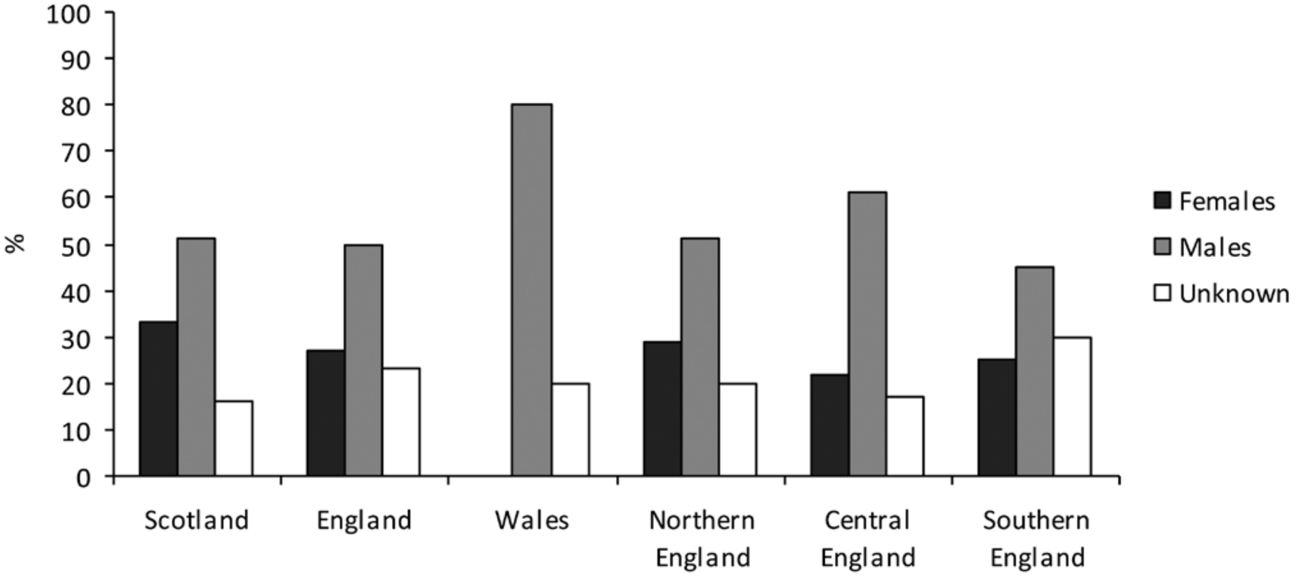

Figure 6.1: Distribution of biological sex for the 201 individuals in the study, by country and (in England) region (Illustration: Patrick Mahoney)

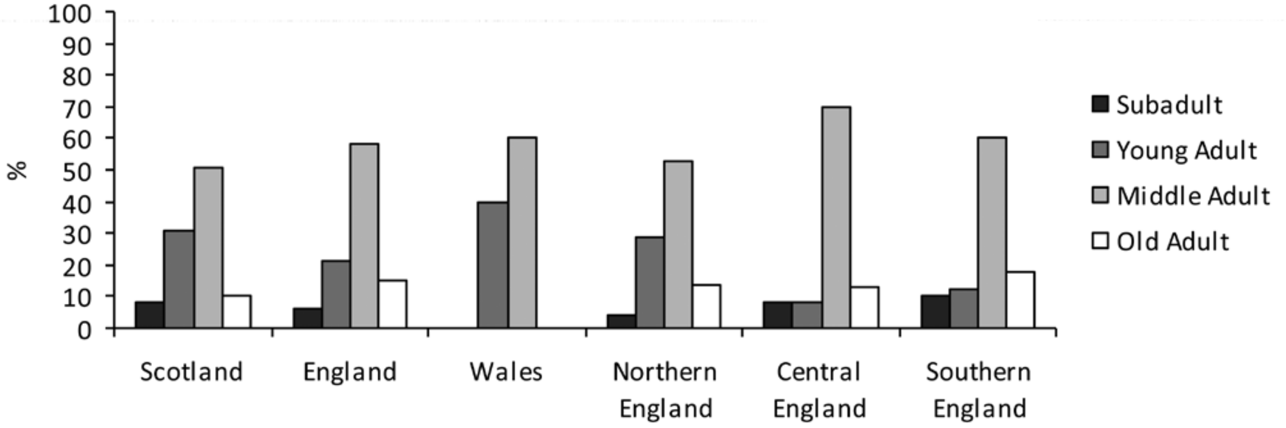

Figure 6.2: Age distribution of the 201 individuals studied, by country and (in England) region (Illustration: Patrick Mahoney)

molar row is similar to that established by Miles: in other words, M1, M2 and M3 should give roughly similar age estimates. Dental attrition wear can give a reliable age range if all three molars are present.

Sub-adult estimation of age at death

Long bone length, dental development and ossification and fusion of bones were used to estimate the age of sub-adults. Methods of calculating age from foetal long bone growth were taken from regression lines calculated by Scheuer *et al.* (1980) and Scheuer and Black (2000); for children up to 15 years, profiles by Hoppa (1992) were used.

The most accurate method for estimating juvenile age is dental development. Several different methods were used on this project: B.H. Smith's (1991) tables of mean age of attainment for dental developmental stages of permanent mandibular teeth, Mahoney's (2011; 2012) stages for developing deciduous dentition for children under 13 months, and Moorees *et al.* (1963) for stages of root resorption in deciduous mandibular canines and molars. Ossification and epiphyseal fusion centres were also used (Scheuer & Black 2000). Methods used to estimate age at death were conducted independently. After a composite was determined, each skeleton was assigned to an age group.

Results

Descriptive statistics are reported first, followed by Spearman's Rho test which was used to search for significant associations between biological sex, age at death, and the type of vessel in the burial. Data normality was tested using a Kolmogorov–Smirnov test. All analysis was undertaken in SPSS 17.0.

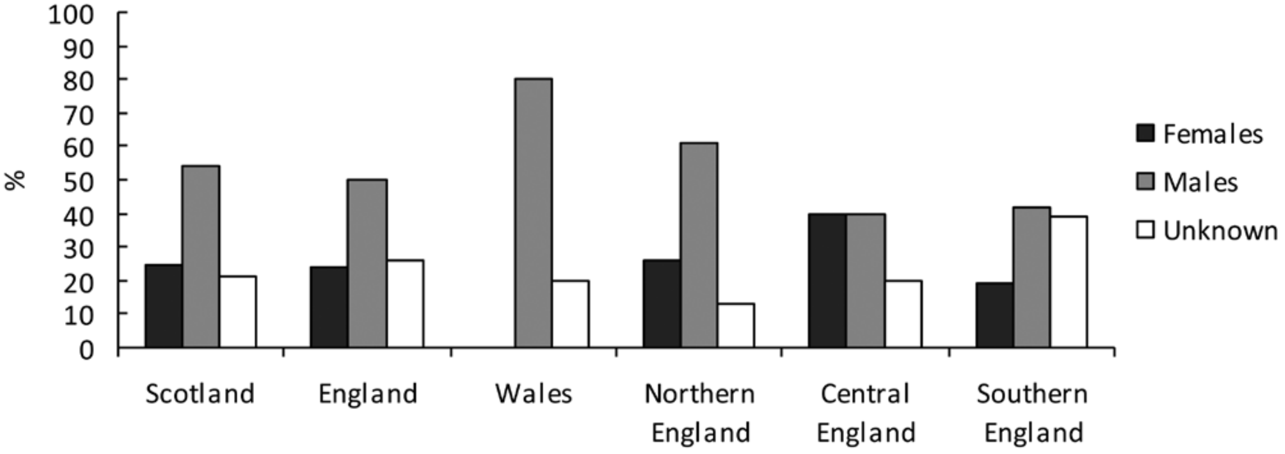

Figure 6.3: Sex of Beaker-associated individuals, by country and (in England) region (Illustration: Patrick Mahoney)

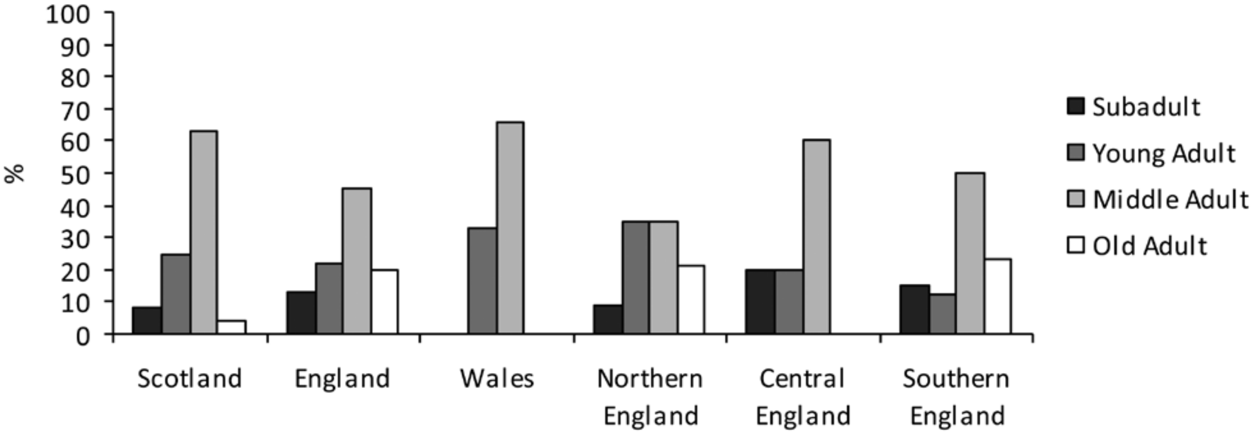

Figure 6.4: Age of Beaker-associated individuals, by country and (in England) region (Illustration: Patrick Mahoney)

Table 6.1 shows the age and sex distribution of the 201 studied individuals sub-divided by region and associated vessel (where present). Figures 6.1 and 6.2 show the percentage of individuals of each biological sex and the age-at-death distribution for each region. Figures 6.3 and 6.4 show the sex profile and the age-at-death distribution by region for the individuals associated with Beakers.

Discussion and conclusion

Within the sample, England has the largest number of individuals associated with Beakers (*n* = 54), followed by Scotland (*n* = 24) and then Wales (*n* = 5). There is a slightly higher concentration of individuals associated with Beakers in the north (namely 47 in northern England and Scotland combined) compared to the south (36 in central and southern England and Wales combined).

Overall, there were more males than females in Scotland, Wales and England, and also in all regions within England. In all regions, the number of middle-adult burials is greatest compared to the other age-at-death groups. However, associations between biological sex and age-at-death were not statistically significant.

Generally, a slightly higher percentage of the skeletons recovered with Beakers were male compared with females and those of unknown sex, and a higher percentage were middle-aged adults when compared with other age-at-death groups. Food Vessel-associated individuals were more abundant in England, specifically northern England (east Yorkshire), as were individuals buried with no vessels. In this sample Food Vessels were more often found with females in the middle-adult group but this is not representative of the larger picture in which they are buried equally with men and women (Wilkin 2013, 234). Individuals who were not buried with a vessel were most commonly males in middle adulthood. In all regions, there is no statistically significant association between age at death, biological sex, and vessel type.

Tooth enamel defects and infant stress

Patrick Mahoney and Sarah E. Johns

Twelve erupted but unworn permanent lower first mandibular molars were selected from juvenile skeletons within the *BPP* Database (namely SK11, SK14, SK31, SK36, SK57, SK59, SK60, SK75, SK80, SK82, SK100, and SK105) in order to explore tooth enamel defect evidence for infant stress. All the sampled individuals fall within the core 2500–1500 BC period.

Disruptions to enamel-forming cells during childhood development can produce hypoplastic defects that are visible on the outer tooth surface as a localised thinning of enamel (eg, Boyde 1989; Goodman & Rose 1990). These developmental defects are non-specific age-related episodes of stress that develop in response to several causes, such as dietary deficiencies, infectious disease (eg, Sarnat & Schour 1941; Sweeney *et al.* 1971; May *et al.* 1993; see Guatelli-Steinberg 2001 for a review), and psychological trauma (Schwartz *et al.* 2006). Thus, aspects of systemic stress are often inferred from the prevalence of enamel hypoplasia in archaeological samples of modern humans and fossil hominoids (eg, Lacruz *et al.* 2005; Guatelli-Steinberg *et al.* 2004).

Studies of enamel defects usually assess the outer tooth surface, yet developmental defects can also be contained within enamel. These 'sub-surface' defects are known as accentuated growth lines (also called Wilson bands and accentuated Retzius lines in the literature). The first one, the neonatal line, marks a period of enamel disruption at birth (Rushton 1933) that lasts for three to eight days (Mahoney 2011;2012). Approximately one year after birth, accentuated lines may start to emerge on the outermost enamel surface of permanent first molars as a type of hypoplasia (eg, Mahoney 2008). Before then, the lines in this tooth type are contained within the enamel and are not normally visible to the naked eye. They become visible in thin sections when viewed at magnification under a polarising microscope, where they appear as dark bands. Because enamel also contains other markings that represent daily and near-weekly growth increments (eg, Risnes 1990; Bromage 1991; Lacruz *et al.* 2012), the timing of accentuated lines can be accurately calculated. Thus, chronological patterns of infant stress can be reconstructed from adult permanent enamel.

Previous histological studies have examined accentuated growth lines in human deciduous teeth (eg, FitzGerald & Saunders 2005) and in non-human fossil and extant primate teeth (eg, Macho *et al.* 1996; Dirks *et al.* 2002; 2010). The aim of this study is to calculate the timing of accentuated lines in a sample of permanent human teeth to reconstruct the chronology of stress events in the first post-natal year. The *timing* and the *cause* of the lines will be discussed.

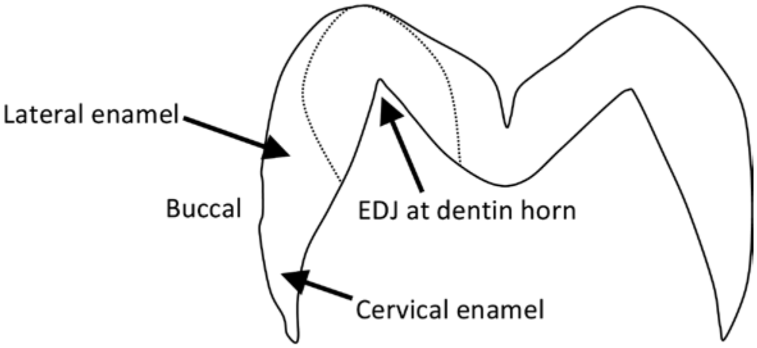

Figure 6.5: First mandibular molar enamel crown section with protoconid cuspal region highlighted (Illustration: Patrick Mahoney)

Materials

As indicated above, 12 erupted but unworn permanent lower first mandibular molars were selected from juvenile skeletons for examination. First molars were chosen rather than canines (eg, Rose *et al.* 1978) because, of the permanent teeth, only first molar enamel initiates before birth and thus contains a neonatal line. For the skeletons numbered SK60, SK75, SK80, and SK82, the cuspal enamel was complete before the end of the first post-natal year; thus accentuated lines were recorded in the cuspal continuing into the lateral enamel (Fig. 6.5).

Methods

The molars had been sectioned previously for a study of human molar enamel growth (Mahoney 2008). Each molar was embedded in polyester resin to reduce the risk of splintering while sectioning. Using a diamond-wafering blade (Buehler® IsoMet 1000) buccal–lingual sections were taken through the tip of the protoconid cusp enamel and the tip of the enamel–dentine junction (EDJ). Section obliquity was minimised following methods discussed by Mahoney (2010). Each section was mounted on a microscope slide, lapped using a graded series of grinding pads (Buehler® IsoMet 1000) to reveal the accentuated and other incremental lines, polished with a 0.3 mm aluminium oxide powder, placed in an ultrasonic bath to remove surface debris, dehydrated through a series of alcohol baths, cleared (Histoclear®), and mounted with a cover slip using a xylene-based mounting medium (DPX®). Sections were examined under a high-powered microscope (Olympus BX51) using transmitted and polarised light. Images were captured (Olympus DP25) and analysed (Olympus Cell D).

The distance in microns between the neonatal line in cuspal enamel and the next accentuated line was measured along the long axis of a prism (Fig. 6.6; and see FitzGerald *et al.* 2006 for a discussion of accentuated marking identification). This distance was divided by a local daily enamel secretion rate (DSR) – see Mahoney *et al.* 2007 for a methodology – to give the amount of time in days elapsed from birth. The procedure was repeated on subsequent markings to establish a chronology of stress events (eg, Macho *et al.* 1996). Daily enamel secretion rates were calculated by measuring a distance corresponding to five days of enamel secretion along a prism, which was then divided by five to yield a mean daily rate (eg, Mahoney 2008, figs 3–4). The procedure was repeated a minimum of six times, which allowed a mean DSR value to be calculated. Prism lengths divided by DSRs were used to estimate the time elapsed between accentuated markings in lateral enamel (see Mahoney *et al.* 2007 for a description). The frequency of accentuated markings from birth was recalculated into monthly intervals. The prevalence of the markings was recalculated following Waldron (1994):

> Prevalence = *n* individuals with condition/ total population (expressed as a percentage)

Results

The greatest frequency and prevalence (and also proportion) of accentuated markings occurred in the ninth and tenth post-natal months. Table 6.2 shows the timing of the first accentuated line after birth. Table 6.3 shows the frequency of accentuated lines in months through the first post-natal year. Figure 6.6 shows accentuated lines in SK14. Figures 6.7–6.8 are bar charts of frequency and prevalence of the condition during the first post-natal year subdivided by monthly intervals.

Discussion

The *timing* of accentuated lines was calculated in permanent first molar enamel, thus reconstructing the age at which stress events

Table 6.2: Timing of first accentuated line after birth

SK No.	*DSR*[1]	*Distance in µm*[2]	*Age in days (months)*[3]
11	3.91	401	103 (3.4)
14	3.72	130	35 (1.2)
31	3.61	448	124 (4.1)
36	4.41	696	158 (5.2)
57	3.29	532	162 (5.3)
59	4.20	498	118 (3.9)
60	4.34	960	221 (7.3)
75	4.27	349	82 (2.7)
80	4.40	642	146 (4.8)
82	3.94	414	105 (3.5)
100	4.03	605	150 (4.9)
105	4.17	713	171 (5.6)

1. DSR – Mean Daily enamel Secretion Rate.
2. Distance between neonatal and subsequent accentuated line – see Fig. 6.6
3. Distance/DSR

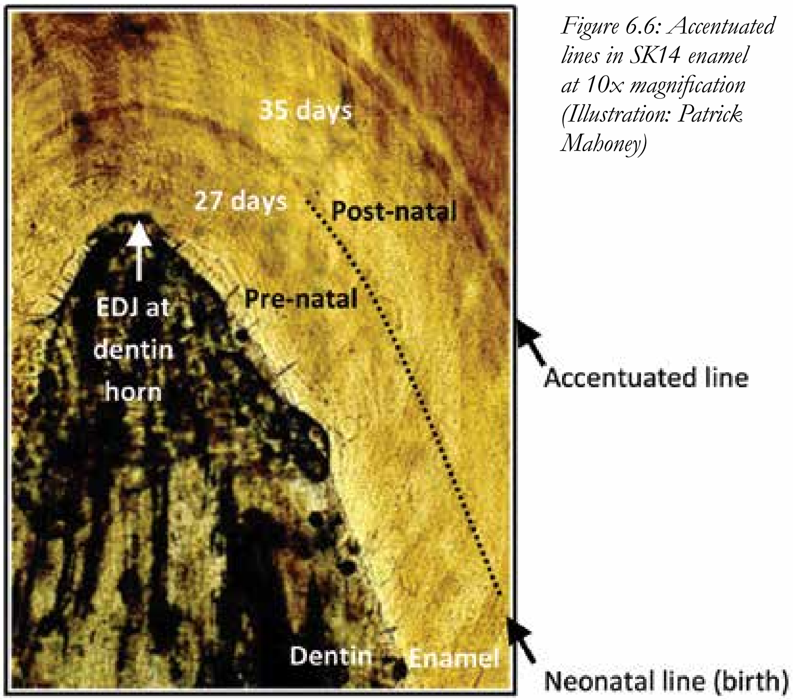

Figure 6.6: Accentuated lines in SK14 enamel at 10x magnification (Illustration: Patrick Mahoney)

Table 6.3: Frequency of accentuated lines during the first postnatal year

	Month after birth											
SK No.	*1st*	*2nd*	*3rd*	*4th*	*5th*	*6th*	*7th*	*8th*	*9th*	*10th*	*11th*	*12th*
11	–	–	–	1	–	–	–	1	1	–	–	3
14	–	1	1	1	–	–	1	1	–	2	1	4
31	–	–	–	–	1	–	1	–	1	–	1	3
36	–	–	–	–	–	1	1	1	2	2	–	1
57	–	–	–	–	–	1	–	1	–	3	1	2
59	–	–	–	1	–	–	–	–	2	3	4	3
60	–	–	–	–	–	–	–	2	5	2	–	1
75	–	–	2	–	1	–	1	4	4	2	2	–
80	–	–	–	–	1	1	1	–	2	1	2	–
82	–	–	–	1	1	–	1	–	1	4	3	1
100	–	–	–	–	1	–	2	1	2	2	1	–
105	–	–	–	–	–	1	–	–	1	3	2	2

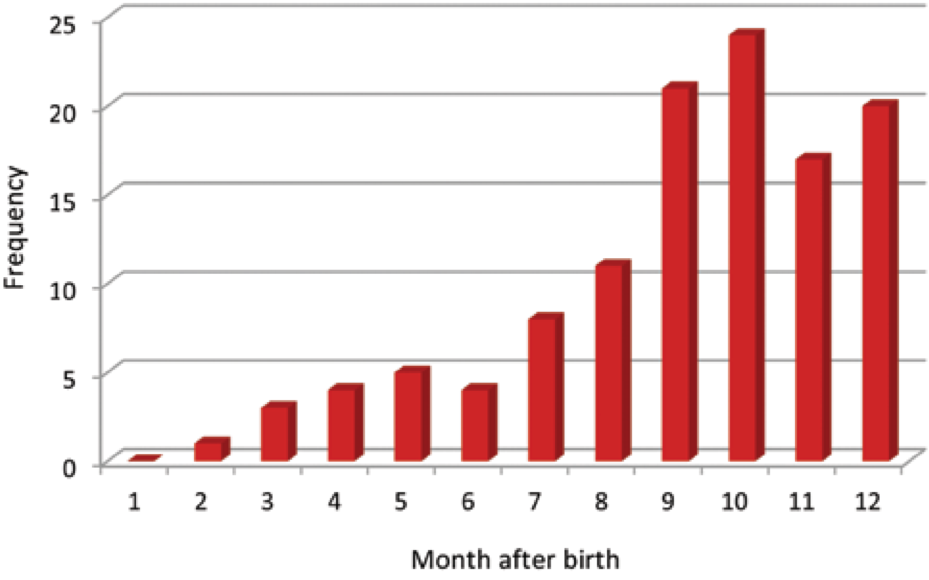

Figure 6.7: Total frequency of accentuated markings after birth, using data from Table 6.2 (Illustration: Patrick Mahoney)

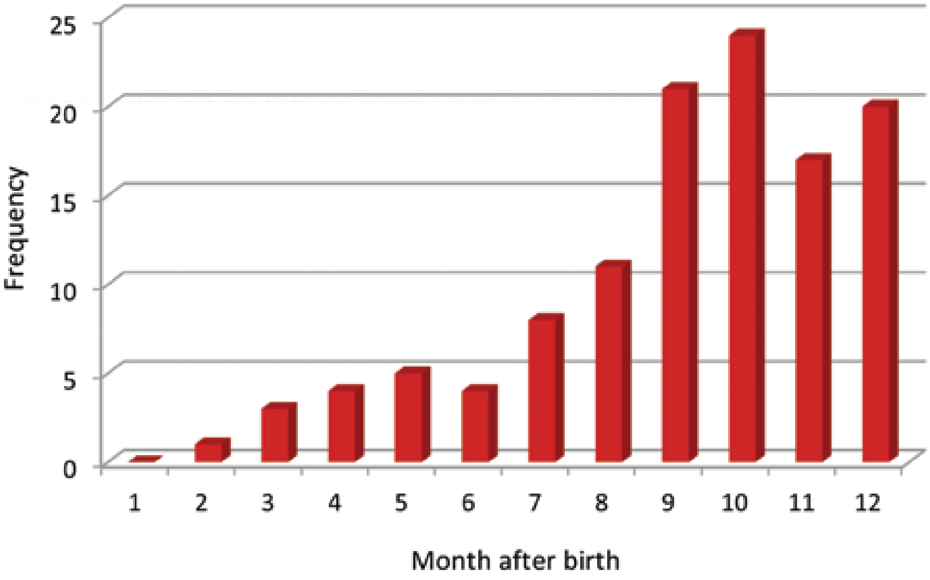

Figure 6.8: Prevalence of accentuated markings after birth; data recalculated from Table 6.2 (Illustration: Patrick Mahoney)

occurred during the first post-natal year in this sample. From adult permanent tooth enamel, this has provided a record of infant health that is not normally visible to the naked eye. Thus, histological examination of permanent first molars provides an alternative methodological approach to be used when deciduous teeth are either not present or the enamel is too worn for this type of analysis.

The *timing* of the stress events reported here differs compared to FitzGerald *et al.* (2006), who examined accentuated markings in a sample of human deciduous teeth from an Imperial Roman necropolis. They reported a period of high prevalence in the second through to the fifth post-natal months, and another period of greater prevalence beginning in the sixth month and continuing through to the ninth month. In the present study, line prevalence gradually increased from the second through to the fifth month, but the overall frequency in each month was low. In contrast to the evidence from the Roman necropolis, the greatest prevalence of stress events for infants of the Beaker period occurred in the ninth and tenth post-natal months.

Differences in the age-at-death profiles between these studies suggest one factor that might have contributed to the difference in the timing of the stress events. In the study by FitzGerald *et al.* (2006), most of the teeth sampled are those of children who died in their second year. For our British Chalcolithic and Early Bronze Age sample, the juveniles had survived into at least their third year because permanent first molar cervical enamel was complete (Mahoney 2008). Therefore, differences in life expectancy between the two infant populations may reflect differences in the stresses experienced during their first year.

The *cause* of the developmental defects is difficult to determine with certainty because accentuated markings form in response to multiple stressors. With this in mind, high frequencies of accentuated lines in non-human primate tooth enamel can correlate with a life-history event, weaning (Dirks *et al.* 2010), the age at which food other than breast milk is introduced into the diet (mixed feeding), or the moment at which breastfeeding eventually ceases. A shift from exclusive suckling to a mixed feeding strategy is potentially beneficial for infant brain development and growth, as it allows access to foods that are higher in protein and calories than maternal milk (Kennedy 2005), as well as the inclusion of specific key micro-nutrients in the diet (Davies & O'Hare 2004). However, as breast milk intake is reduced in favour of other foods, there is an increased risk of:

- exposure to food-borne pathogens and intestinal parasites (Black *et al.* 1981; Motarjemi *et al.* 1993),
- the infant's being unable to digest adult food efficiently (Kennedy 2005),
- tooth wear (Ayers *et al.* 2002),
- kwashiorkor, or acute protein-energy malnutrition (Walker 1990),
- conditions related to vitamin deficiency (West *et al.* 1986).

This trade-off is known as 'the weanling's dilemma' (Rowland *et al.* 1978). If the transition to a mixed feeding strategy is poorly regulated and weaning-food preparation is unhygienic, the costs of including solid food in the diet will outweigh the benefits, and will only serve to increase infant nutritional stress, sickness, and mortality.

Weaning age can correlate not only with high frequencies of accentuated lines within enamel but also with other dental defects. For example, increased frequencies of surface hypoplastic defects have been associated with the age at which infant mixed feeding commences in living human populations (Alcorn & Goodman 1985; Goodman *et al.* 1987), and in archaeological samples of modern humans dating to the historic periods, using contemporary texts as a source for weaning age (eg, Moggi-Cecchi *et al.* 1994), though this latter association is not always consistent (eg, Wood 1996). Other animals show a similar relationship between surface hypoplasia and weaning (Franz-Odendaal 2004; Dobney *et al.* 2004).

For the Chalcolithic–Early Bronze Age sample studied here, none of the children displayed indicators of stress in the month after birth, but this was followed by a gradual increase in stress until it peaked at 9–10 months of age. This suggests that the timing of these tooth enamel defects may reflect, in part, a gradual weaning process in this population, starting at approximately 7 months, or earlier, with weaning stress peaking at 9–10 months. Some traditional societies begin to supplement milk feeds with weaning foods in the second half of the first year (Kennedy 2005), and there are developmental changes of the mandible and teeth that occur at a similar time (Humphrey 2010), making a mixed feeding strategy possible.

Stable isotope findings for Iron Age Yorkshire (at Wetwang Slack: Jay *et al.* 2008) suggest a weaning strategy comparable to the one proposed here for the Beaker period. Infant milk intake at Wetwang Slack might have been supplemented by animal and/or plant foods from a very early age because $\delta^{15}N$ values through the first year were not elevated to the extent expected for exclusive breastfeeding (*ibid.*, fig. 4; see also Herring *et al.* 1998 for a similar example from the historic period).

Thus, while we cannot exclude the possibility that the tooth enamel defects reported here formed in response to infectious disease unrelated to diet, the timing of the accentuated lines in this sample are consistent with a gradual process of weaning that led to dietary deficiencies, and increased illness and disease.

Craniometry of skulls from the Peak District

Sandra Thomas

This study is based on the craniometric analysis of 41 human skulls from the Peak District dating to the Neolithic, Chalcolithic and Early Bronze Age, most of them excavated by Thomas Bateman around the mid-nineteenth century (Bateman 1848; 1855; 1861).[2] The crania were recovered from barrows in the Peak District, across two counties (Derbyshire and Staffordshire), and are major contributors to the osteological data of these periods in this area. They have been analysed by subjecting craniometric measurements to univariate and multivariate statistical analyses, the results of which have produced groupings similar to those recognised by previous typologies of cranial shape. With the 28 individuals that feature in the *BPP*, these results were compared with isotope measurements (as detailed in Chapters 7–11) to assess associations between cranial morphology, diet and patterns of movement. In addition, a number of individuals have produced evidence of deliberate deformation of the skull.

Aims of the study

The purpose of this study was to assess variability in cranial morphology over time and to investigate whether it might relate to changes in the geographical origins of the people buried in the Peak. In order to understand biological, geographical and temporal relationships, the crania making up the dataset were grouped into three time periods (Neolithic, Beaker[3] and Early Bronze Age) according to the relative chronology of their associated finds and grave type. Skull shape from the Neolithic through to the Early Bronze Age was then examined by statistically analysing 35 cranial measurements for each skull in the sample. This information was then compared with results from other countrywide studies using similar methods and with stable isotope results from the same specimens, where available.

Why craniometry?

By the time of Bateman's excavations, craniometry and the related 'discipline' of phrenology had gained a foothold in anthropological and antiquarian methods. Used as a determinant of personality and behavioural traits at this time (eg, Bateman 1848, 42 describing cranium J.93.931 as 'fine and intellectual'), craniometry subsequently acquired a poor scientific reputation and became associated with racist ideas (Renfrew 1987, 4).

Concurrent with its use by early anthropologists as what they believed to be a valid means of assessing personality and cognitive capacity, cranial shape was also used as an indicator of racial or ethnic affinity, and basic patterns of differing cranial form were recognised among prehistoric crania, with Thurnam famously observing the contrasting long-headed and round-headed individuals of Britain, and their respective association with long and round barrows, idealistically matching the head shape with the respective barrow shape (Thurnam 1863; 1871, 199).

Although metric measurements became somewhat overused, warranting the caution of Brothwell (1981), Howells' (1973) comprehensive study of cranial form and its relationship to latitude and climatic regions established craniometry as an indispensable method in the calculation of bio-distance, the quantitative assessment of divergence among individuals and groups based on morphological data (Buikstra *et al.* 1990).

Recent discussions of craniometry have

focused on the ways in which cranial shape may be influenced by climate or diet as well as by genetic and cultural factors (Beals 1972; Spencer 1997, 81–90; Mays 1998, 97–101). Mays concluded that the changing cranial index from dolichocranic to brachycranic at the transition to the Beaker period in Britain cannot adequately be explained by changes in climate or diet (Mays 1998, 98–9). Instead, he suggested that the most parsimonious explanation for the change in cranial form in Britain is immigration of continental European people, bringing Beaker material culture to Britain (*ibid.*, 100).

Craniometry's utility in characterising both individual and group diversity has resulted in craniometric methods being applied here for the right reasons: the elucidation of groups based on cranial shape (which may relate to bio-distance) and the application of an old method *sine* old biases. It has also been interesting to reapply the original anthropological methods used on this collection and to relate their current use to modern methods used for the same purpose.

Aside from being a cost- and time-efficient method requiring only non-destructive techniques, craniometry is a useful grouping technique that is objective, straightforward to apply, and can feasibly be utilised alongside other methods. While stable isotope and ancient DNA studies reveal respectively the environmental and genetic characteristics of biological organisms, craniometry quantifies the (partially genetically determined) physical form of individuals in a population, and provides a basis for assessing similarities among and differences between individuals and populations. These patterns of cranial variation do not of themselves indicate genetic relatedness and are best interpreted alongside the social or funerary archaeological contexts surrounding them. Craniometric methods also provide information about the particular osteological components of the cranium that underlie the overall patterns of shape difference.

The history of the Bateman Collection

The Bateman Collection is a product of antiquarian excavations and collectings between 1843 and 1860 by Thomas Bateman, a native of Derbyshire. Bateman was a prolific barrow-digger himself, and he augmented his own archive with donations from various contributors and by other means of acquisition. These were noted by assigning a letter-code in his publications: C – 'Denotes objects collected by Mr. Samuel Carrington in Staffordshire', D – 'Signifies articles that have been presented', P – 'Distinguishes purchases', R – 'Marks the discoveries of Mr. James Ruddock in Yorkshire', T – 'Is used in every instance in which the articles have been found by the author' and W – 'Characterises the collections of the late William Bateman Esq.' (Bateman 1855, xii).

The Bateman Collection originally comprised over 3,500 items of natural and archaeological interest, of various origins (Marsden 1979, 358). Yet it was the excavated human bones, in particular the crania, that formed its prized bedrock (*ibid.*, 471). Although some post-cranial material was retained (usually long bones, for stature estimates), of the human bone material in general, primarily only the skulls remain. The crania were preferentially selected for keeping according to the interests of the day in phrenology and craniometry.

In addition, associated finds and grave goods were kept (Bateman 1848; 1855; 1861). Bateman himself used these as dating tools to categorise his material typologically and they fulfil that role to this day. The collection consists of both unburnt and cremated remains, ranging in date from the Neolithic to the Medieval period. Prehistoric specimens constitute the majority of the collection, and unburnt remains from the Neolithic, Chalcolithic and Early Bronze Age form the sole focus of this present study.

The collection passed to Bateman's son after his death and the antiquarian component was given on permanent loan to Sheffield City Museum in 1876 (Marsden 1979, 485). With the exception of some small human bones and sherds, which were supposedly buried in the garden of Bateman's home, Lomberdale House (now Lomberdale Hall, in Middleton-by-Youlgrave, Derbyshire), the remainder of the collection was sold in four lots between 1893 and 1895 to allay the growing debts of the inheritor. In 1893 Sheffield City Museum – now Museums Sheffield, Weston Park – bought the loaned antiquarian component (Howarth 1899; Marsden 1979, 485–8).

From the time of discovery, the Bateman collection of skulls became a focus of research.

Bateman himself uses analogies from Wilson's 1863 publication on crania to describe some skulls as 'platy-cephalic' (flat-headed), or 'kumbe-kephalic' (boat-shaped), although these descriptions are virtually meaningless in craniometric terms today. Davis and Thurnam used some of Bateman's skulls for creating engravings for their 1865 publication, *Crania Britannica*. (Five of these skulls are included in the current study: J.93.929, Ballidon Moor, J.93.930, Long Low, J.93.939, Wetton Hill [SK191], J.93.942, near Arbor Low [SK202] and J.93.945, Parcelly Hay [SK211]).

William Boyd Dawkins, then curator of Manchester Museum, subsequently examined the skulls, providing a brief description of each, a cranial index value and a corresponding cranial shape. This was published in Howarth's 1899 catalogue of Bateman's material. The whereabouts of Boyd Dawkins' notes are unknown, but the cranial index values in his catalogue appear to have been calculated by means of the conventional formula used today (maximum cranial breadth / maximum cranial length).

In 1981 an undergraduate dissertation was completed on the craniometry of all the skulls in the Bateman Collection, from Neolithic to Medieval specimens, the aim being to illustrate the relationship between cranial shape and discrete archaeological periods (Jervis 1981). The relationship between shape and period was found to be insubstantial, although the dates assigned to the crania have been revised since then. Brodie's 1994 study of the Bateman Collection was part of his doctoral research on the Neolithic–Chalcolithic–Early Bronze Age transition, pioneering work that assembled craniometric data on specimens from all over Britain. Brodie's conclusions were primarily of a causal nature, focusing on the biological stimuli for morphological change. He interpreted the increased brachycranialism of the Early Bronze Age as a biological product alone, associated with changes in climate.

The history of the excavations

Barrow-digging emerged as something of a field sport of the upper classes broadly from the eighteenth to the early twentieth century. In keeping with the fashions of the day, Bateman excavated with speed and had agents such as Samuel Carrington working simultaneously in the next county. Bateman produced three published works (1848; 1855; 1861), one of which was a catalogue, covering the finds and excavations in slightly greater detail than was common for the time. Another catalogue was prepared by Howarth (1899) soon after the purchase of part of Bateman's collection by Sheffield City Museum, and this catalogue includes the museum registration numbers. This is an invaluable source for matching museum numbers to Bateman's often brief descriptions.

The products of Bateman's diggings, together with a cranium from the Bagshawe collection and three crania from full skeletons excavated by Barry Marsden in the 1960s (Marsden 1979; 1994), form the sample for this present study.

The craniometric procedures

A series of 35 cranial measurements were selected for assessment, covering the calvarial and facial aspects of the skull but omitting the mandible (since it is not always present). The measurements were selected with reference to two sources.

Firstly, a base of 20 measurements was chosen to correspond with the analysis of Neolithic/Chalcolithic/Early Bronze Age material conducted by Brodie (1994) in which a corpus of 249 skulls was studied, including 21 of the 41 skulls in the dataset of this study. Table 6.4 displays all measurements used by Brodie.

These measurements were abbreviated with labels introduced by Howells (1973), but correspond to definitions found in Brothwell (1981). In the current study, Brothwell's abbreviations are used for those measurements corresponding to Brodie's study, in order to avoid confusion with the second set of measurements used in the current study, which use Howells' (1973) abbreviations but which also use Howells' (1989) definitions. Measurements that are common to both series retain both abbreviations.

Secondly, a further series of measurements were adopted from the multivariate discriminant analysis and classification programme CRANID written by Richard Wright (2009). This software classifies individual specimens on the basis of existing discriminant functions, derived from a database of cranial measurements from worldwide population samples built into the programme.

This in-built database currently holds only two populations as examples from Britain, the Roman Poundbury sample (Farwell & Molleson 1993) and a Medieval London sample (Wright 2009). Consequently, the programme is unsuitable for classification of British prehistoric specimens. However, the measurements are both universal and provide additional information to Brodie’s subset, without excess, with the added advantage of conforming to an already worldwide database that is easy to access and should, one hopes, expand to include prehistoric British examples in the near future.

The CRANID subset consists of 29 measurements, all of which are based on Howells’ (1989) measurements. Table 6.5 displays the original CRANID measurements and their abbreviations.

Of the CRANID measurements, 15 overlap with Brodie’s measurements. One measurement has been discounted (nasal height, as used in the CRANID programme) as it was not an exact overlap but too similar to provide additional information. This leaves a total of 35 measurements employed in the present study.

The measurements are of three types (Wright 2009, 36):

1.`Those taken from biologically-defined landmarks;
2.`Those taken from instrumentally-defined measuring points;
3.`Those that combine (1) and (2).

The biological landmarks from which the measurements are taken are displayed in Table 6.6, using definitions taken from Howells (1973, 163–83), Buikstra and Ubelaker (1994), Wright (2009), and Brothwell (1981, 79–80). All definitions have been compared to each other in order to ensure consistency. Although prosthion and alveolare are defined as separate points, they are repeatedly within 4 mm of each other and are therefore counted as one for the purpose of this study. For measurements that are taken from instrumentally-defined points, the measurement definitions alone are sufficient to show the measurement location, as these not biologically distinct and are specific to each skull.

Table 6.4: Twenty cranial measurements and their abbreviations, arranged alphabetically (after Brodie 1994, 55)

Abbreviation	*Brothwell’s*	*Measurement*
ASB	Biast. B	Bi-Asterionic Breadth
BAL	GL	Basi-Alveolar Length
BBH	H’	Basi-Bregmatic Height
BNL	LB	Basi-Nasal Length
FRC	S'_1	Frontal Chord
FRK	S_1	Frontal Arc
GOL	L	Maximum Cranial Length
NPH	G’H	Upper Facial Height
NLB	NB	Nasal Breadth
NLH	NH’	Nasal Height
OB	$0'_1$	Orbital Breadth
OCC	S'_3	Occipital Chord
OCK	S_3	Occipital Arc
OH	O_2	Orbital Height
PAB	G_2	Palatal Breadth
PAC	S'_2	Parietal Chord
PAK	S_2	Parietal Arc
PAL	G'_1	Palatal Length
WCB	B’	Minimum Frontal Breadth
XCB	B	Maximum Breadth

Table 6.5: Twenty-nine CRANID measurements and their abbreviations, in alphabetical order (Wright 2009, 39–42). Nasal height (NLH) was omitted from this study

Abbreviation	*Measurement*
ASB	Biasterionic Breadth
AUB	Biauricular Breadth
BBH	Basion-bregma Height
BNL	Basion-nasion Length
BPL	Basion-prosthion Length
DKB	Interorbital Breadth
EKB	Biorbital Breadth
FMB	Bifrontal Breadth
FRC	Nasion-bregma Chord (Frontal Chord)
FRS	Nasion-bregma Subtense (Frontal Subtense)
GOL	Glabello-occipital Length
JUB	Bijugal Breadth
MAB	Palate Breadth, External
NAS	Nasio-frontal Subtense
NLB	Nasal Breadth
NLH	Nasal Height
NOL	Nasio-occipital Length
NPH	Nasion-prosthion Height
OBB	Orbit Breadth, Left
OBH	Orbit Height, Left
OCC	Lambda-opisthion Chord (Occipital Chord)
OCS	Lambda-opisthion Subtense (Occipital Subtense)
PAC	Bregma-lambda Chord (Parietal Chord)
PAS	Bregma-lambda Subtense (Parietal Subtense)
SSS	Zygomaxillary Subtense
WMH	Cheek Height
XCB	Maximum Cranial Breadth
XFB	Maximum Frontal Breadth
ZMB	Bimaxillary Breadth

Landmark	*Definition*
Alveolare	The lowest point on the alveolar process between the sockets of two central incisor teeth. This was taken to be an almost identical point to Howells' prosthion (1973)[1]
Asterion	The common meeting-point of the temporal, parietal and occipital bones, on either side[2]
Auriculare	A point on the lateral aspect of the root of the zygomatic process at the deepest incurvature, wherever it may be[3]
Basion	On the anterior border of the foramen magnum, in the midline, at the position pointed to by the apex of the triangular surface at the base of either condyle, ie, the average position from the crests bordering this area[2]
Bregma	The posterior border of the frontal bone in the median plane, where the coronal and sagittal sutures meet[1,2]
Dacryon	The point at which the sutures between the frontal, maxillary and lacrimal bones meet[1]
Ectoconchion	The intersection of the most anterior surface of the lateral border of the orbit and a line bisecting the orbit along its long axis[2]
Frontomalare anterior	The most anterior point on the fronto-malar suture[2]
Endomolare	The mid-point on the inner margin of the socket of the second upper molar tooth[1]
Glabella	The most prominent point between the supraciliary arches, in the midline[1]
Jugalia	The deepest points in the curvature between the frontal and temporal processes of the malars[2]
Lambda	The point at which the sagittal and lambdoid sutures meet[2]
Nasion	The intersection of the fronto-nasal suture and the median plane[2]
Nasospinale	The junction of the midline and a line across the inferior anterior nasal aperture[1]
Opisthion	The inferior edge of the posterior border of the foramen magnum in the midline[2]
Orale	The midpoint of a line tangential to the posterior margins of the sockets of the two upper central incisor teeth[1]
Prosthion	The most anteriorly prominent point, in the midline, on the alveolar border, above the septum between the central incisors.[2] This was taken to be an almost identical point to Brothwell's alveolare (1981)
Staphylion	The point at which a line tangential to the two curves on the posterior border of the palate crosses the interpalatine suture[1]
Zygomaxillare anterior	The intersection of the zygomaxillary suture and the limit of the attachment of the masseter muscle, on the facial surface[2]

1. Brothwell 1981
2. Howells 1973
3. Buikstra & Ubelaker 1994

Table 6.6: Biological landmarks from which measurements are taken

The measurements and their descriptions are presented in Table 6.7, following the order in which they were taken, as some measurements are sequentially related (eg, the subtense measurements which measure the greatest height of an arc or prominence, and are taken perpendicularly to a chord). The measurements were taken using a spreading calliper, a sliding calliper, an improvised coordinate calliper and a measuring tape. A coordinate calliper is recommended for taking subtense measurements, but an improvised version was used in this case; a plastic scale ruler was adjusted to the length of sliding calliper projections, and placed perpendicularly to the calliper measures on the point of greatest projection. The reading was taken on the displaced part of the scale rule (Wright 2009).

Margins of error

In order to estimate the margins of error encountered, two procedures were followed. General errors were tested by ensuring that the results fell within the *maxima* and *minima* values found in the CRANID manual where relevant, the manual being based on a database of over 3,000 skulls (*ibid.*). Intra- and inter-observer error were estimated by taking all measurements for each guideline set, thereby ensuring that all overlapping measurements were taken twice. These were then compared to any available results found in previous works by Jervis (1981) and Brodie (1994).

A margin of 4 mm was deemed to be a reasonable difference between measurements taken. This figure was based on observed individual variations of 1 mm or 2 mm on different measuring occasions by the same observer, on slight differences in measuring equipment, and on the observer's interpretation and implementation of each measurement definition. When an error of greater than 4 mm was discovered either intra- or inter-

Table 6.7: The measurements and the descriptions used in the Peak District study, and the instrument used to obtain the measurement. Abbreviations and descriptions are adapted from Howells (1973) and Brothwell (1981)

Abbreviation	*Description*
GOL/L	Greatest length, from the glabellar region, in the median sagittal plane (spreading calliper)
NOL	Greatest cranial length in the median sagittal plane, measured from nasion (spreading calliper)
BNL/LB	Direct length between basion and nasion (spreading calliper)
BBH/H'	Distance from basion to bregma, as defined (spreading calliper)
XCB/B	The maximum cranial breadth (greatest bi-parietal breadth) perpendicular to the median sagittal plane, above the supramastoid crests, taken at right angles to the mid-sagittal plane (spreading calliper)
XFB	The maximum breadth at the coronal suture, perpendicular to the medial plane (spreading calliper)
AUB	The least exterior breadth across the roots of the zygomatic processes, wherever found (spreading calliper)
ASB/BiastB	Direct measurement from one asterion to the other (sliding calliper)
BPL/GL	The facial length from basion to prosthion, as defined (spreading calliper)
NPH/G'H	Upper facial height from nasion to prosthion, as defined (small spreading calliper)
OBH/O2	The height between the upper and lower borders of the left orbit, perpendicular to the long axis of the orbit and bisecting it (small sliding calliper)
OBB/O'1	Breadth from ectoconchion to dacryon, as defined, approximating the longitudinal axis which bisects the orbit into equal upper and lower parts (small sliding calliper)
JUB	The external breadth across the malars at the jugalia, ie, at the deepest points in the curvature between the frontal and temporal process of the malars (sliding calliper)
NLB/NB	The distance between the anterior edges of the nasal aperture at its widest extent (small sliding calliper)
MAB	The greatest breadth across the alveolar borders, wherever found, perpendicular to the median plane (small sliding calliper)
ZMB	The breadth across the maxillae, from one zygomaxillare [anterior] to the other (sliding calliper)
SSS	The projection or subtense from subspinale to the bimaxillary width [ZMB] (improvised coordinate calliper)
FMB	The breadth across the frontal bone between frontomalare anterior on each side, ie, the most anterior point on the fronto-malar suture (sliding calliper)
NAS	The subtense from nasion to the bifrontal breadth (improvised coordinate calliper)
EKB	The breadth across the orbits from ectoconchion to ectoconchion (sliding calliper)
DKB	The breadth across the nasal space fromdacryon to dacryon (sliding calliper)
WMH	The minimum distance, in any direction, from the lower border of the orbit to the lower margin of the maxilla, mesial to the masseter attachment, on the left side (sliding calliper)
FRC/S'1	The frontal chord, or direct distance from nasion to bregma, taken in the midplane and at the external surface (sliding calliper)
FRS	The maximum subtense, at the highest point on the convexity of the frontal bone in the midplane, to the nasion-bregma chord (improvised coordinate calliper)
PAC/S'2	The external parietal chord, or direct distance from bregma to lambda, taken in the midplane and at the external surface (sliding calliper)
PAS	The maximum subtense, at the highest point on the convexity of the parietal bones in the midplane, to the bregma-lambda chord (improvised coordinate calliper)
OCC/S'3	The external occipital chord, or direct distance from lambda to opisthion, taken in the midplane and at the external surface (sliding calliper)
OCS	The maximum subtense, at the most prominent point on the basic contour of the occipital one in the midplane (improvised coordinate calliper)
NH'	From nasion to nasospinale (small sliding calliper)
G1	From the staphylion to the orale (small sliding calliper)
G2	From one endomolare to another (small sliding calliper)
B'	Smallest diameter between the temporal crests on the frontal bone (sliding calliper)
S1	Minimum distance from nasion to bregma taken over the surface of the bone (tape)
S2	Surface distance from bregma to lambda (tape)
S3	Surface distance from lambda to opisthion (tape)

observer, the measurement was retaken. On two occasions, where there was still a discrepancy of >4 mm between observers, it was decided that an error had occurred on the part of the original observer.

Additional information

In many cases, the landmarks utilised for taking the measurements were not available for one reason or another. The fragmentation of the skull often did not allow for accurate measurement of particular variables. The degree of preservation also obscured some points, especially those at sutural junctions. The post-excavation reconstruction of skulls in the collection is, in some instances, biologically incorrect or has involved the use of plaster stands built into the crania, inhibiting access to certain points. In some specimens plastering of the vault prevented some points from being clearly visible, and Wormian bones (extrasutural ossicles) occasionally displaced the usual positioning of the landmark.

These latter two conditions did not, however, cause major obstruction to measurement collection; even with a plastered skull, cranial form is maintained and most points could be discerned or legitimately estimated. Also, when a Wormian bone was encountered, following Howells (1973) the alignments of the surrounding sutures were extended to a central point where they intersected and this was taken to be the landmark. For bilateral measurements, the left was preferentially selected. When the condition of the skull did not allow this, the right-hand side was used.

The skulls display two forms of deformation in a minority of cases:

- firstly, there are some that display post-mortem taphonomic distortion, resulting in the alteration of the skull form;
- secondly, there is evidence of ante-mortem modification of the parietal and occipital bones (as discussed below).

In the light of these observations, it was decided not to conduct a regression using predictor variables to estimate missing values, as these missing values would have been based on data that may already deviate from the norm, and this would have increased the associated error.

In some osteological studies it is possible to replace a missing value with the group mean. In this project, with the overall sample amounting to 41 individuals, divided into four groups (Neolithic, Beaker, Early Bronze Age, and ungrouped) and sub-divided into male and female groups, the group sizes are so small that the average values would be unrepresentative. For this reason, substitution of a missing value by group mean was deemed unsuitable.

In addition, as so many measurements were taken, there is a very sizeable suite of information available for each individual as a whole, and supplementary estimates are not as important to obtain as they would be in a study using fewer measurements. In any case, it would be more appropriate to run statistical tests on raw data separately from enhanced data and to make the results available for comparison with each other in order to understand fully the implications or potential benefits of supplementation.

Statistical procedures

The statistical package SPSS version 15 was used for all descriptive, univariate and multivariate statistics and Field (2009) was consulted for all assumptions and interpretations except where stated. The sample was divided into chronological groups according to radiocarbon dates available at the time of analysis and according to associated finds, to explore cranial shape change across time (Table 6.8).[4]

For statistical analyses, the chronological groups were divided by sex, forming categories of individuals. This was significant for biological and anthropological reasons: female skulls tend to yield smaller measurement values, and it was felt important to investigate whether patterns of population affinity varied between the sexes. Size correction procedures were applied (see below).

The Neolithic group consisted of just three individuals, all of which are males.[5] The 'Beaker'group (of individuals buried with a firmly-identified Beaker) contained an evenly balanced mix of six females and seven males. The 'Early Bronze Age' group (comprising individuals from barrow graves, not firmly associated with an incontrovertibly-identified Beaker) was male-dominated, with a ratio of 17 males to two females; this may represent either an archaeological reality or be a product of bias in the sample. In Brodie's study, males and females form a ratio of approximately 2:1 in excavated skeletons of both the Neolithic and Chalcolithic/Early Bronze Age, a ratio that is apparent all over Britain (Brodie 1994). This ratio appears to be a good representational guideline for the inclusion of members of each sex within barrows during these periods.

Only in cases where a category was formed of five individuals or more was the group selected for statistical analysis, with the exception of the Neolithic group which was also analysed even though the sample size is very small, at just three. As a result of this decision on sample

Table 6.8: The chronological groups of the Peak District samples formed for statistical assessment and the skulls assigned to each one, followed by the sex of each individual in brackets

Neolithic			*Beaker*[1]			*Early Bronze Age*			*No Group*		
SK No.	*Site Name*	*Museum Ref. No.*	*SK No.*	*Site Name*	*Museum Ref. No.*	*SK No.*	*Site Name*	*Museum Ref. No.*	*SK No.*	*Site Name*	*Museum Ref. No.*
–	Longlow	J.93.930 *(m)*	SK198	Green Low	J.93.909 *(m)*	–	Near Monsal Dale	J.93.908 *(m)*	SK202[2]	Middleton Moor, near Arbor Low	J.93.942 *(m)*
SK214	Liffs Low	J.93.931 *(m)*	SK215	Mouse Low	J.93.914 *(m)*	SK196	Hay Top	J.93.911 *(m)*	-	Bole Hill	J.93.938 *(m)*
–	Five Wells Hill	J.93.937 *(m)*	SK208	near Castern	J.93.915 *(m)*	SK197	Near Monsal Dale	J.93.912 *(m)*	SK219[2]	Hazlebadge Hills	1957.32 *(?m)*
			–	Haddon Field	J.93.921 *(m)*	SK207	Gratton Hill	J.93.913 *(m)*	SK209	Bole Hill	J.93.934 *(f)*
			SK204	Hay Top	J.93.943 *(m)*	–	near Cross Low	J.93.916 *(m)*	SK201[2]	Smerrill Moor	J.93.940 *(f)*
			SK211	Parcelly Hay	J.93.945 *(m)*	–	Rolley Low	J.93.917 *(m)*	SK203	Smerrill Moor	J.93.923 *(?f)*
			SK221	Bee Low	1981.410 *(m)*	SK206	Gotham	J.93.918 *(m)*			
			SK195	Hay Top	J.93.911A *(f)*	–	Gratton Hill	J.93.919 *(m)*			
			SK190	Stakor Hill	J.93.922 *(f)*	SK205	Galley Low	J.93.920 *(m)*			
			SK210	Bee Low	J.93.935 *(f)*	SK199	Three Lows	J.93.925 *(m)*			
			–	Blake Low	J.93.941 *(f)*	–	Ballidon Moor	J.93.929 *(m)*			
			SK216[2]	Bee Low	1981.401 *(f)*	SK192	Waggon Low	J.93.932 *(m)*			
			SK222	Bee Low	1981.412 *(f)*	SK191	Wetton Hill	J.93.939 *(m)*			
						SK200	Bee Low	J.93.944 *(m)*			
						–	Rolley Low	J.93.947 *(m)*			
						SK213	Shuttlestone	J.93.948 *(m)*			
						–	New Inns	J.93.965 *(m)*			
						–	Galley Low	J.93.926 *(f)*			
						SK212	Bailey Hill	J.93.946 *(f)*			
	3 *(m)*			7 *(m)*, 6 *(f)*			17 *(m)*, 2 *(f)*			3 *(m)*, 3 *(f)*	

1. See chapter endnote 3 regarding the author's use of the term 'Beaker [period]'
2. Although placed in the 'No group' category here, SK201, SK202 and SK219 were later radiocarbon-dated to the Early Bronze Age, after the completion of this study, and SK216 (placed here as 'Beaker') was radiocarbon-dated to the Middle Neolithic. Also note that the sex of SK202 needs to be verified through aDNA analysis

Category	*Index*	*Description*
Dolichocranic	< 75.0	Long-headed
Mesaticranic	75.0–79.9	Middle range
Brachycranic	80.0–84.9	Broad-headed
Hyperbrachycranic	85 and over	Very broad-headed

Table 6.9: Cranial shape categories, the index range for each category and the shape description (from Brothwell 1981, 87)

size, the only female group in the dataset is that from the Beaker group. It is unfortunate that there were no other female groups for comparison but the female Beaker group was compared to all three male groups nonetheless.

Descriptive and univariate statistics

The cranial index has a long history of use as a measure of head shape. This index is a ratio of maximum cranial breadth to maximum cranial length, multiplied by 100 and typically rounded to the nearest integer value. The resultant index range generally falls between 60 and 90 and the range is divided into discrete categories of shapes as presented in Table 6.9 (Brothwell 1981, 87).

Firstly, descriptive statistical analyses were conducted on the components of the cranial index (length and breadth), to examine their influence on cranial shape and groupings based on shape. Univariate tests were then carried out on cranial indices in order to determine whether traditional cranial form groupings could be associated with particular chronological groups. The cranial index was calculated for each skull and the mean and standard deviation for each category were calculated; these were then included in further tests of normality of distribution. The Kolmogorov–Smirnov and the Shapiro–Wilk tests were used to test the distribution for normality. The specimens that were not assigned to a chronological group were excluded as by their very nature they are potentially of mixed form.

Given the normal distribution of the indices for each group, *t*-tests were conducted to test for significant differences between the means of each group, being parametric and therefore robust to violations of its assumptions (Bryman & Cramer 2009). Groups were compared as follows:

a) Neolithic males *vs* Beaker males
b) Neolithic males *vs* Beaker females
c) Neolithic males *vs* Early Bronze Age males
d) Beaker males *vs* Beaker females
e) Beaker males *vs* Early Bronze Age males
f) Beaker females *vs* Early Bronze Age males.

Taking the extremely small group sizes into account, the Kolmogorov–Smirnov *Z* non-parametric test was also applied. This tests whether two groups have been drawn from the same population; it is more powerful than the similar Mann–Whitney test for samples fewer in number than 25 (Field 2009, 548). An Exact statistic was also computed as this also provides greater accuracy for tests on small samples (*ibid*., 786). All significances were assumed at the $p < 0.05$ level for these and all subsequent tests throughout the statistical procedures. It was not necessary to correct the cranial index values for size as they are a ratio presented as a percentage and are therefore unaffected by differing sizes.

In addition to the cranial index, the cranial module values were also calculated for each sex, using all individuals from the sample. This calculation provides an average as opposed to a ratio and indicates the size of the cranium. The formula for the cranial module follows Bass (2005).

The results were subjected to the same tests as the cranial index values; the mean and standard deviation were found, the normality was tested using the Kolmogorov–Smirnov and the Shapiro–Wilk tests, and the means were tested using the parametric *t*-test, the non-parametric Kolmogorov–Smirnov *Z*, and the Exact test. In this way, the size difference between males and females could be tested as to whether it is significant or not.

A second series of univariate tests was performed to illustrate which measurements from this suite of 35 significantly differed between groups. The mean and standard deviation of all measurements for each viable category were calculated, and included in further tests of normality of distribution. Although linear measurements have a propensity for normality (Mays 2000), the samples were particularly small, and following tests would rely on normal distribution. The Kolmogorov–Smirnov and the Shapiro–Wilk tests were used to test the distribution for normality. The specimens not assigned to a chronological group were excluded. The normality of each measurement was compared between all categories as outlined a) to f) above.

For those measurements that had an adequate number of representative individuals, tests comparing the means for significant differences were conducted. In accordance with high levels of normality and homogeneity of variance throughout each group, *t*-tests were conducted to compare the means. However, with such small groups it was necessary to consult the non-parametric Kolmogorov–Smirnov *Z* and Exact statistic significances also.

Since the results of the comparison of means tests for the cranial module values for males and females produce a significant difference between the sexes, it was necessary to take the size difference between sexes into account. In the instances where the Beaker females were being compared to any other group – which are all male – the descriptive statistics and the univariate tests were re-conducted on the data for all 35 measurements which had been corrected for the influence of size. This was accomplished by taking two measurements indicative of cranial size, finding their average for each individual, dividing all measurements for that individual by the average, and repeating for each cranium.

The two measurements selected were maximum cranial length and maximum cranial breadth; these were chosen on the basis of their use in the cranial module formula. In addition, two measurements alone were selected as the numbers of individuals with these values were high. Ideally, cranial height would also have been used, but not enough individuals possessed a value for this measurement and the dataset would have been restricted. This dataset, standardised for size, was exposed to the same series of statistics and tests as the raw dataset. The results of each were then presented in sequence and compared.

Multivariate statistics

Two sets of multivariate statistics were conducted: discriminant function analysis and principal component analysis. Firstly, discriminant function analysis was performed for all measurements and on all groups. This included the two Early Bronze Age females and the ungrouped specimens, which were entered as an indeterminate group in order to predict a group to which the latter may belong.

The analysis also provided a predicted group based on the measurements for already grouped individuals; the predicted group provided by the statistical analysis could then be compared to the chronological categories to which these skulls had already been assigned on the basis of the associated material culture. As not all measurements were available for each individual, the SPSS analysis included only 21 of 41 individuals, who are listed in the results section below. The eigenvalues, the associated statistics Wilks' lambda and chi-square significances, the function coefficients and correlation matrix were also produced and discussed in turn.

As females and males were included together in one dataset, the discriminant function analysis was conducted for a second time on all individuals and measurements, using the data that had been standardised for size as described above. This prevents groups being formed according to size. The predicted variables and all associated statistics for the standardised dataset were produced and discussed independently before being compared to the analysis of the raw dataset.

Secondly, the standardised dataset was analysed using principal components analysis. On this occasion, 15 measurements only were incorporated for the procedure and these are listed in the results section below. These were selected on the basis of their particular significance as revealed in the univariate series of tests. In addition, a reduced number of variables eliminated many of the missing elements associated with other measurements. The eigenvalues and associated variance for each component, and the component matrices, were produced and discussed in turn.

Results

Descriptive and univariate statistics

Since the components of length and breadth contribute fundamentally to cranial shape as calculable by the cranial index, it was necessary to illustrate their relationship to each other using the data from this sample, to see whether they impact on the grouping of individuals when compared to chronological groups derived from associations with material culture. Their relationship is demonstrated in a bivariate plot (Fig. 6.9).

As a general overview, it is sufficient to say that the Neolithic individuals are grouped together, showing that they are closely similar due to their cranial length.[6] Male crania in the Beaker category do not vary greatly in terms of length, and are all broader than the Neolithic group. Beaker females again group together, occupying a middle ground in terms of cranial

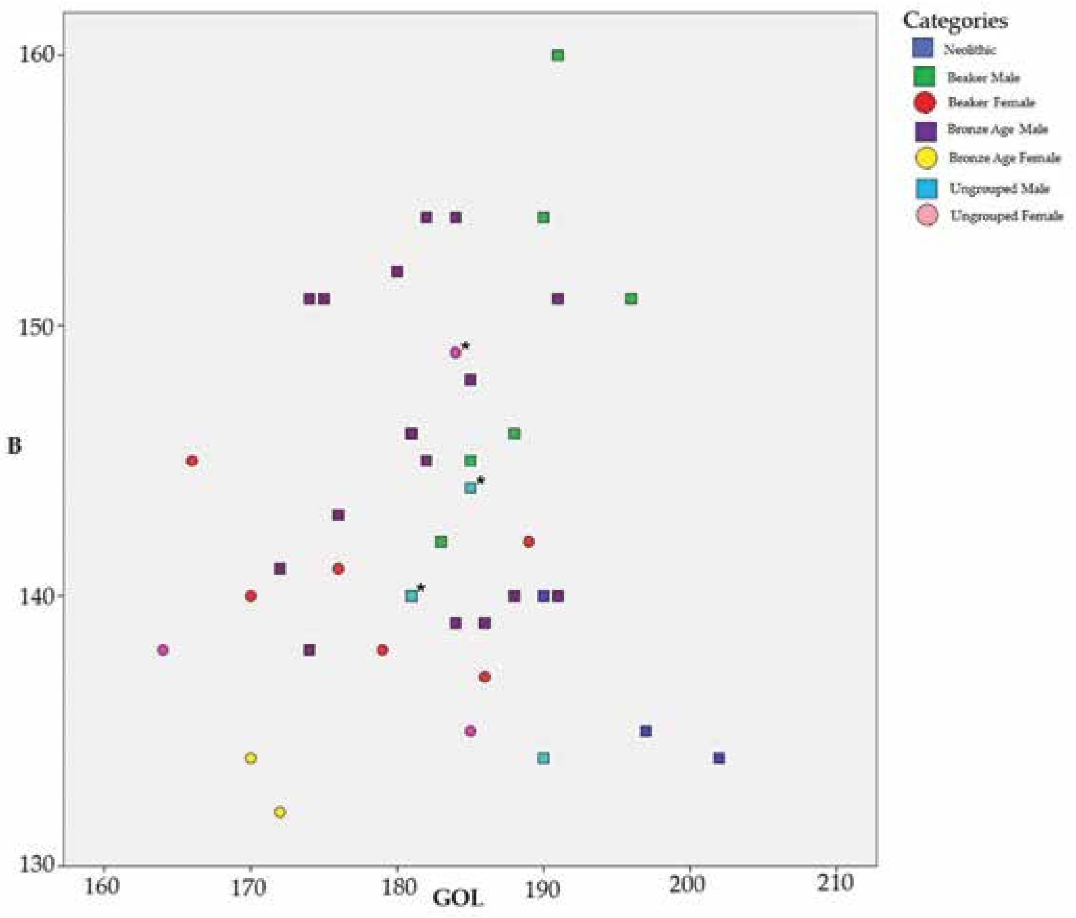

Figure 6.9: Bivariate plot comparing maximum cranial length (GOL) to maximum cranial breath (B) for all individuals in the Peak District sample (Illustration: Sandra Thomas)

length and breadth. Males in the Early Bronze Age category are largely grouped according to cranial breadth and are separate from the Neolithic examples, being primarily shorter. Two Early Bronze Age female individuals group together. These results give an overview of the dataset and emphasise the legitimacy of these two measurements as indicators of cranial shape and the groups that can be determined from these. Sexual dimorphism in terms of size can also be detected in this plot and this will be examined further below.

The cranial index was calculated and a corresponding shape category defined for all individuals (Table 6.10). In order to illustrate visually how the groups compare, they are presented in a box-plot (Fig. 6.10). The Neolithic examples all group separately from other groups, as they are exclusively dolichocranic. Males in the Beaker category are confined to the brachycranic and mesaticranic range of indices, whereas Beaker females and Early Bronze Age males demonstrate a broad range of cranial shapes, perhaps indicative of differing population groups being represented. Both females in the Early Bronze Age category are mesaticranic.

The mean, standard deviation and normality of the cranial indices were calculated in preparation for comparisons of means tests and are presented here for each group (Table 6.11). The descriptive statistics are followed by the results of the parametric (*t*-tests) and non-parametric tests (Kolmogorov–Smirnov *Z*, Exact) for significant differences between means. The *t*-test significances were selected on the basis of Levene's test for homogeneity of variance, and equal variances were assumed at the 0.05 level of significance. Early Bronze Age females were not included in these or any further tests, as the group contains fewer than five individuals; an exception was made for the small Neolithic group as outlined above.

The results presented in Table 6.12 indicate that the Neolithic sample is significantly different from all other groups but that all other groups cannot be said to be statistically different from each other. This suggests that

SK No.	*Findspot*	*Date*	*Sex*	*Cranial Index*	*Shape Category*
–	Longlow	Neolithic	Male	66.3	Dolichocranic
SK214	Liffs Low	Neolithic	Male	73.7	Dolichocranic
–	Five Wells Hill	Neolithic	Male	68.5	Dolichocranic
SK198	Green Low	Beaker[1]	Male	81.1	Brachycranic
SK215	Mouse Low	Beaker	Male	77	Mesaticranic
SK208	near Castern	Beaker	Male	83.8	Brachycranic
–	Haddon Field	Beaker	Male	78.4	Mesaticranic
SK204	Hay Top	Beaker	Male	77.6	Mesaticranic
SK211	Parcelly Hay	Beaker	Male	77.7	Mesaticranic
SK221	Bee Low	Beaker	Male	–	–
SK195	Hay Top	Beaker	Female	87.3	Hyperbrachycranic
SK190	Stakor Hill	Beaker	Female	82.4	Brachycranic
SK210	Bee Low	Beaker	Female	73.7	Dolichocranic
–	Blake Low	Beaker	Female	80.1	Brachycranic
SK216[2]	Bee Low	Beaker	Female	75.1	Mesaticranic
SK222	Bee Low	Beaker	Female	77.1	Mesaticranic
–	Near Monsal Dale	Early Bronze Age	Male	80	Brachycranic
SK196	Hay Top	Early Bronze Age	Male	79.1	Mesaticranic
SK197	Near Monsal Dale	Early Bronze Age	Male	86.8	Hyperbrachycranic
SK207	Gratton Hill	Early Bronze Age	Male	84.4	Brachycranic
–	near Cross Low	Early Bronze Age	Male	80.7	Brachycranic
–	Rolley Low	Early Bronze Age	Male	84.6	Brachycranic
SK206	Gotham	Early Bronze Age	Male	75.5	Mesaticranic
–	Gratton Hill	Early Bronze Age	Male	82	Brachycranic
SK205	Galley Low	Early Bronze Age	Male	79.7	Mesaticranic
SK199	Three Lows	Early Bronze Age	Male	79.3	Mesaticranic
–	Ballidon Moor	Early Bronze Age	Male	74.7	Dolichocranic
SK192	Waggon Low	Early Bronze Age	Male	74.5	Dolichocranic
SK191	Wetton Hill	Early Bronze Age	Male	83.7	Brachycranic
SK200	Bee Low	Early Bronze Age	Male	88	Hyperbrachycranic
–	Rolley Low	Early Bronze Age	Male	81.3	Brachycranic
SK213	Shuttlestone	Early Bronze Age	Male	80.7	Brachycranic
–	New Inns	Early Bronze Age	Male	73.3	Dolichocranic
–	Galley Low	Early Bronze Age	Female	78.8	Mesaticranic
SK212	Bailey Hill	Early Bronze Age	Female	76.7	Mesaticranic
–	Bole Hill	Ungrouped	Male	71	Dolichocranic
SK202[2]	Middleton Moor, near Arbor Low	Ungrouped	Male	77.3	Mesaticranic
SK219[2]	Hazlebadge Hills	Ungrouped	Male	77.8	Mesaticranic
SK203	Smerrill Moor	Ungrouped	Female	84.1	Brachycranic
SK209	Bole Hill	Ungrouped	Female	73	Dolichocranic
SK201[2]	Smerrill Moor	Ungrouped	Female	81	Brachycranic

1. See chapter endnote 3 regarding the author's use of the term 'Beaker [period]'
2. Although placed in the 'No group' category, SK201, SK202 and SK219 were later radiocarbon-dated to the Early Bronze Age and SK216 was radiocarbon-dated to the Middle Neolithic. Also note that sex of SK 202 needs to be checked through aDNA analysis

Table 6.10: The cranial index values and the associated shape category for each individual in the Peak District sample for whom the component measurements were available, listed according to period and sex

this aspect of cranial shape (ie, the length–breadth ratio) was particularly distinctive in the Neolithic, changing by the Beaker period and remaining relatively consistent throughout the Early Bronze Age. The lack of distinctiveness among the skulls in the 'Beaker' and 'Early Bronze Age' groups reflects a broad range of cranial shapes during these times, the means of which are comparable, with less variety of cranial shape occurring during the preceding Neolithic.

Further to the comparison of cranial indices, and of paramount importance to the subsequent comparisons of the full suite of 35 measurements, the cranial module values were examined and the means of each group compared statistically. A box plot illustrating the comparative ranges of modules for each

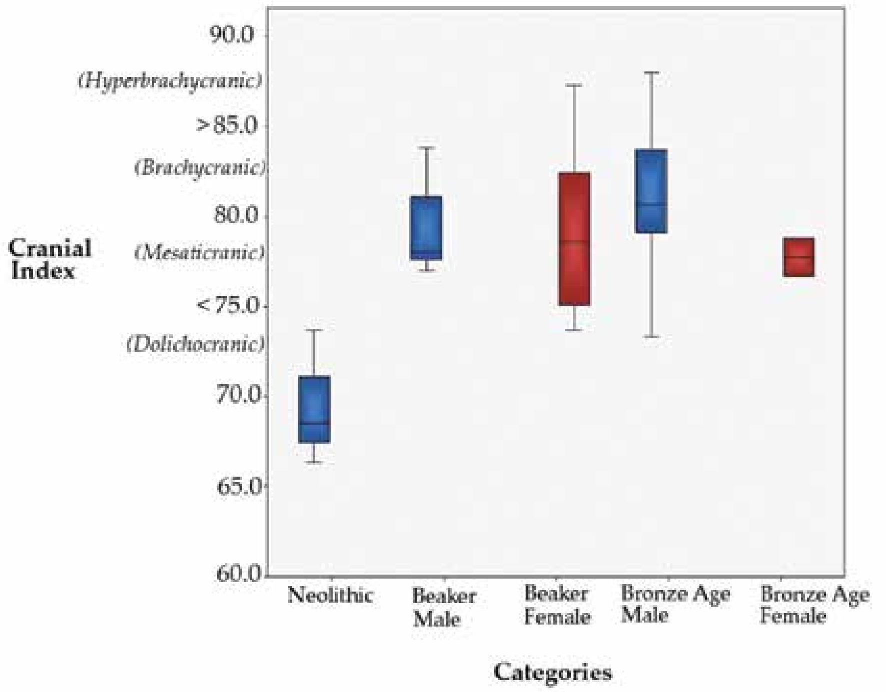

Figure 6.10: Box plot of cranial indices in the Peak District sample, grouped for each category (Illustration: Sandra Thomas)

Table 6.11: The descriptive statistics for the cranial indices of each group in the Peak District sample: the chronological category, the number of individuals for which the cranial index was available, the mean and standard deviations and normality of cranial indices for each group

Category	*No.*	*Mean ± 1SD*	*Normal*
Neolithic	3	69.5±3.8	Yes
Beaker Male	6	79.3±2.7	Yes
Beaker Female	6[1]	79.3±5.1	Yes
Bronze Age Male	17	80.4±4.3	Yes
Bronze Age Female	2	77.8±1.5	–

1. One of these was subsequently radiocarbon-dated to the Middle Neolithic

Table 6.12: Comparison of means tests for cranial indices in the Peak District sample: the categories for which mean were compared; the Levene's statistic for the homogeneity of variance; and the significance values for the three tests comparing means – the t-test, the Kolmogorov–Smirnov Z test and the Exact test. Significant values are indicated in bold and underlined

Categories	*Levene's*	*t-test*	*Kolmogorov–Smirnov Z*	*Exact*
Neolithic *vs* Beaker[1] Male	0.510	**0.003**	**0.037**	**0.024**
Neolithic *vs* Beaker Female	0.497	**0.022**	0.124	0.095
Neolithic *vs* Bronze Age	0.770	**0.001**	**0.022**	**0.007**
Beaker Male *vs* Beaker Female	0.142	0.994	0.893	0.931
Beaker Male *vs* Bronze Age Female	0.319	0.522	0.381	0.287
Beaker Female *vs* Bronze Age Male	0.572	0.576	0.915	0.819

1. See chapter endnote 3 regarding the author's use of the term 'Beaker [period]'

sex is presented in Figure 6.11. The male range appears to have higher cranial module values, with the exception of an outlier, and thus the males have larger skulls than the females.

The descriptive statistics of the cranial module values for males and females were followed by results of the *t*-test, Kolomogorov–Smirnov *Z* and Exact test, comparing the means of each range. All three tests have significant results, demonstrating that male skulls are significantly larger than female skulls, which may influence the differences between individual measurements when males and females are compared. The effect of this size difference on individual measurement comparisons is explored below.

Comparing measurements between the Neolithic and Beaker male groups, it is unmistakable that, of the two influencing factors of length and breadth, breadth is significantly different. As the Neolithic crania are dolichocranic with maximum cranial length strongly influencing shape, the Beaker male crania are evidently the broader of the two groups. PAC (the parietal sagittal chord measurement) is significantly different for the *t*-test and not too far removed from significance in the Exact test. This indicates that the length of the parietal bones is different between the two groups. Palatal breadth (G2) is also significant according to the *t*-test, and this may be related to overall cranial breadth since the Neolithic specimens have the smaller measurements; however, the two further tests were not significant.

Seven of the nine available comparisons between Neolithic male and Beaker female crania show significance in one or more tests. Even considering the fact that the Exact significance ought to be considered the most reliable, these results overall appear to be a strong indication of size differences between males and females. This is important to note in its own right, but unfortunately obscures the difference between measurements, which could contribute to understanding cranial shape differences. Having observed these indications of size differences, the tests were conducted again on the same groups and measurements, having been corrected for size influence. The number of individuals, therefore, remains the same and does not need to be re-presented. Having been standardised for size, all of these measurements for these groups tested normal, as concluded from the Kolmogorov–Smirnov and Shapiro–Wilk significance values.

Comparing Neolithic male and Beaker female crania after removing the effect of size, fewer measurements are significantly different, showing that the highly significant results for cranial lengths and the parametrically significant results for orbital breadth, frontal chord and frontal arc appear to be the product of sexual dimorphism. With size having been eliminated, these data produced significant results only for the *t*-test. Although the Exact test results are more accurate, it is interesting to note that these measurements in particular reveal some significance, with maximum cranial breadth and parietal chord having already shown significance between Neolithic male and Beaker male groups.

It is possible, therefore, that parietal length changed between the Neolithic and Beaker periods, the effects of which can be seen on the ratio of cranial length to breadth. These results reflect the observation that Neolithic parietal lengths are much longer than Beaker parietal lengths; overall cranial length is also greater in the Neolithic, but breadth is increased in the Beaker period.

The results comparing the means of the Neolithic and Early Bronze Age groups show a very distinct significant difference between the two cranial length measurements for each. This would suggest that, by the Early Bronze Age, individuals were exhibiting much shorter skulls than in the Neolithic. Cranial breadth, palatal breadth and the nasal subtense also hint at significant difference, indicating a difference in cranial breadth and nasal prominence if the subsequent tests were significant.

Both the parietal chord and the parietal arc are significantly different when comparing the Neolithic group to the Early Bronze Age group. In fact, there is a *c.* 20 mm difference between the mean values of each group for these measurements, the Neolithic specimens being the longer of the two. This directly implicates the parietal bone as the osteological source of the difference.

In comparing males and females belonging to the Beaker group, the only cranial measurement that is significantly different in all three tests is maximum frontal breadth. This is not an indication of different cranial form and may be an expression of size difference between sexes. The only other significant value, which is also close to significant, according to the Kolmogorov–Smirnov *Z* and Exact tests, is the parietal chord. This is interesting as it is also a point of difference between Neolithic and Early Bronze Age skulls and, according to *t*-tests, when Beaker male and Beaker female crania are compared to the Neolithic group. This may indicate a difference in the parietal bone across time and between sexes.

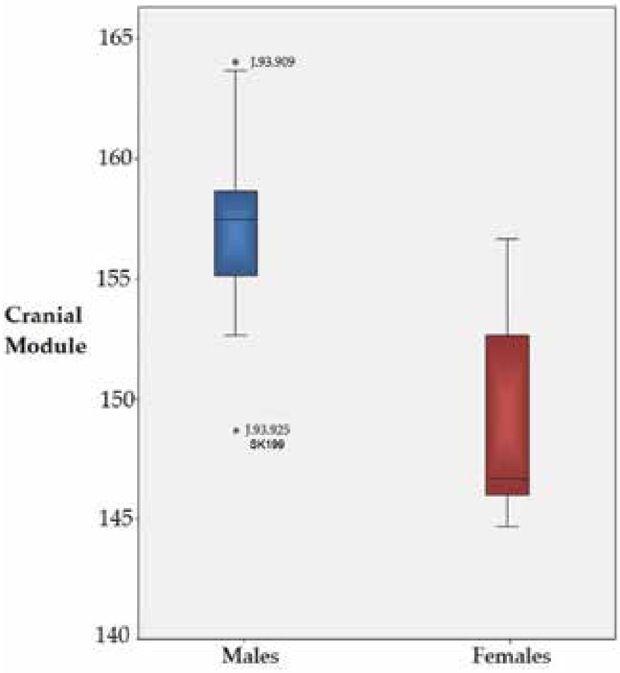

Figure 6.11: Box plot of the cranial module range for each sex from the Peak District sample (Illustration: Sandra Thomas)

However, as with the comparison of the Neolithic group with the Beaker female crania, these tests have been re-run with the same groups and measurements that have been standardised to remove the effect of size. The descriptive statistics shall not be repeated here for these two comparisons; all measurement ranges for both groups are normal when standardised for size except for maximum frontal breadth for Beaker male skulls. There is one individual fewer represented in the Beaker male group as this particular skull is missing the value for maximum cranial breadth and could not be used for standardization or in subsequent tests using standardised material.

The two non-parametric tests have yielded significant results for the comparison of the maximum frontal breadth. The male skulls have yielded greater values for this measurement and, although these measurements have removed the effect of size, shape might have been affected by post-mortem events:

- Two female skulls show distinct signs of taphonomic flattening: specimens J.93.935 (SK210; Bee Low burial 4; see Fig. 4.10) and 1981.412 (SK222; Bee Low burial 8; see Fig. 4.10) appear to have had the shape of the frontal altered by post-mortem pressure on the head, presumably from the weight of the soil.
- Another skull shows signs of faulty reconstruction that might have affected the shape (specimen J.93.941; Blake Low).

Alternatively, the breadth across the coronal suture may just be an area of difference between males and females, since sexually dimorphic features on the skull in general are well-known. This difference was not detected between the Neolithic male and Beaker female groups on account of the Neolithic measurements only being available for two specimens.

Comparing the males of the Beaker group and the males of the Early Bronze Age group, it is clear that two measures of cranial length (including maximum cranial length and two measures of the parietal, length and arc) are significantly different.[7] This is exactly comparable to the differences between the Neolithic and Early Bronze Age groups, indicating that, through time, crania were becoming shorter; this appears to relate directly to a changing length of the parietal bone, at least among males.

Two frontal measures and orbital breadth appear to reflect the differences between the Beaker female and the Early Bronze Age groups. Considering the above statistics, where female versus male comparisons have yielded results due to the effect of size, it is prudent to examine first the comparison of size-standardised results before inferences are drawn. The Beaker female distributions remain normal after standardization and only the frontal subtense of the Early Bronze Age measurements is not in the standardised data.

Between these two groups (Beaker female and Early Bronze Age), the maximum frontal breadth of the cranium is significantly different. This particular measurement was also found to be different between Beaker males and Beaker females, with the measurements for females being the smallest of all three groups. This does not seem to indicate sexual dimorphism in general, as the Neolithic group also has smaller values for this measurement, similar to the Beaker females. In fact, it appears that the Neolithic male and Beaker female groups are similar in this respect, due to the overall narrow tendencies of the Neolithic specimens, and that the Beaker male skulls and the Early Bronze Age crania are significantly broader at this point.

Multivariate statistics

Discriminant function analysis

Discriminant function analysis was conducted on all specimens and measurements, including the two Early Bronze Age females and all crania ungrouped by any associated material culture, to establish whether the assigned groups were supported statistically and/or to reveal any statistical association with other groups. Additionally, this analysis was utilised to predict a category membership for the ungrouped specimens. When the analysis was conducted, not all measurements were present. Given the requirement for more complete sets of measurements for multivariate studies, SPSS selected a small subset of 17 individuals on which to conduct the analysis, calculating eigenvalues, Wilks' lambda and chi-square significances, and canonical coefficients.

The analysis generated three discriminant functions. The first explains 88.4% of the variance, whereas the second explains an additional 11.3%; the third is thus below 1% and therefore ineffectual. In combination, these discriminant functions significantly differentiated the groups; if the first function is removed, however, the following functions do not differentiate the groups significantly.

The standardised discriminant function coefficients reveal the variables that influence group formation: the higher the canonical variate correlation, the greater the influence (Field 2009, 619). The case-wise statistics reveal which group can be assigned for each individual based on the discriminant analysis, and there are some variations from the chronological identifications by means of associated material culture. The anomalies are:

- Two Beaker males can be regrouped by this aspect of the statistical analysis of cranial measurements as belonging to the same category as the Early Bronze Age males
- The same can be said for two Early Bronze Age males that can be regrouped using this method as belonging to the Beaker male category.
- Similarly, an Early Bronze Age female can be regrouped as a Beaker female.[8]

For none of the crania is there any reassigning of sex; this method groups all skulls to the sex to which they are already assigned. This may indicate that these measurements accurately detect sex differences. This is important to note, because size may be an influencing factor in the predictions and, in the light of this, all discriminant function analysis was rerun on data corrected for size differences.

On the basis of the discriminating factors, four ungrouped individuals can be assigned to a group:

- One specimen (J.93.923; SK203; Smerrill Moor) can be classified as belonging to the Beaker male group, despite being anthropologically sexed as female and despite the lack of an identifiable Beaker associated with this individual. (Only sherds of an unidentified ceramic vessel were found with the burial). This sex assignment may well be a correct classification as this particular individual is described in the records as a 'possible' female who displays some morphological features common to both sexes; this 'possible female' skeleton was grouped with females in this study to augment the sample.

Two more of these newly-grouped individuals arouse interest:

- J.93.938 (Bole Hill) is dolichocranic and potentially from a Neolithic context, but this type of analysis groups him as belonging to the Early Bronze Age male group. The size-corrected data, however, reassigns this individual to the Neolithic (see below).
- J.93.942 (SK202; Middleton Moor near Arbor Low) is grouped by this method as belonging to the Beaker male group. This individual had been previously been assigned a Neolithic date in the archival records, despite the fact that the skeleton had been found associated with an Early Bronze Age spacer plate necklace (Howarth 1899, 61–2; Woodward & Hunter 2015, 307–313), but the new *BPP* radiocarbon date places this individual at 2010–1770 cal BC (at 95% probability; see Table 2.1), confirming the expected Early Bronze Age date, and within the overall time frame of Beaker use (despite the absence of a Beaker in the cist).[9]

The fourth newly-grouped individual is:

- J93.940 (SK201; Smerrill Moor, no grave goods) was classified by this analysis as belonging to the Beaker male group, even though anthropologically sexed as a female. The newly-obtained radiocarbon date places this individual at 2030–1770 cal BC (at 95% probability; see Table 2.1), an Early Bronze Age date that once again arguably falls within the overall time frame of Beaker use, even though the individual was not buried with a Beaker. Verification of the sex through DNA analysis is recommended.

Figure 6.12 displays a scatter plot of the actual groups; only 17 specimens were utilised by SPSS. Some groups are represented by a single individual. These can be taken as examples nevertheless.

- Early Bronze Age males form a clear grouping and Beaker males are found close by, even if slightly dispersed.
- The one Neolithic specimen is positioned far away from any other individual on the scatter plot. This replicates previous group results, such as the cranial index from the univariate series of tests, which would imply that the Neolithic crania are distinctively shaped overall, when shape-related measurements are used and when the full set is used.

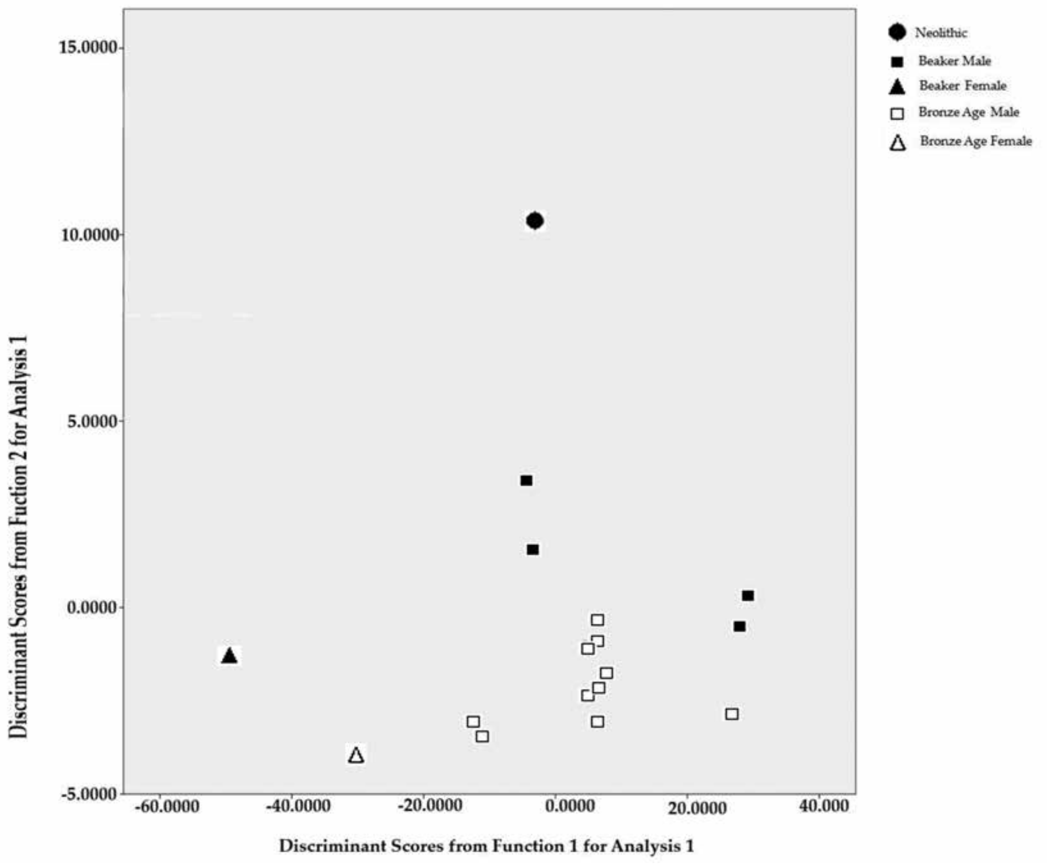

Figure 6.12: Scatter plot of groups in the Peak District sample based on discriminant scores from functions 1 and 2 from analysis of the raw data set (Illustration: Sandra Thomas)

- One of two Early Bronze Age females and a Beaker female have been included in the analysis of this subset, and they both appear to be closest to Early Bronze Age males, although at the opposite ends of that group.

Even with a small sample, discriminant function analysis can detect distinctions between groups; however, looking at the spread of individuals, males and females are grouped separately, showing the dichotomy of size at work.

Discriminant function analysis using size-corrected data

Discriminant function analysis was conducted once more on the data that had been corrected for size difference. The analysis reveals three discriminant functions. The first explains 93.5% of the variance, whereas the second explains only 4.9% and the third just 1.5%, therefore not contributing significantly to the explanation of variance. Together, these discriminant functions do not significantly differentiate the groups.

The case-wise statistics reveal which group is predicted for individuals, based on the discriminant analysis on the data corrected for size.

- Now a Beaker male can be regrouped as an Early Bronze Age male, which is a result in common with analysis of the raw data for this specimen, and is therefore likely to be genuine, especially as there is dating overlap across these two periods.
- The size-corrected data analysis appears to affect specimen J.93.941 (Blake Low, assigned in the literature to the Early Bronze Age on the basis of the form of the barrow), now allocating it to the Neolithic; this is problematic because this specimen is decidedly brachycranic and female, as opposed to dolichocranic and male.[10] The blurring of sex boundaries may be a product of size standardisation; with size removed, the Neolithic identification may be the closest result based on cranial data but only radiocarbon-dating will resolve this.
- The blurring of sex boundaries as a possible product of size standardisation

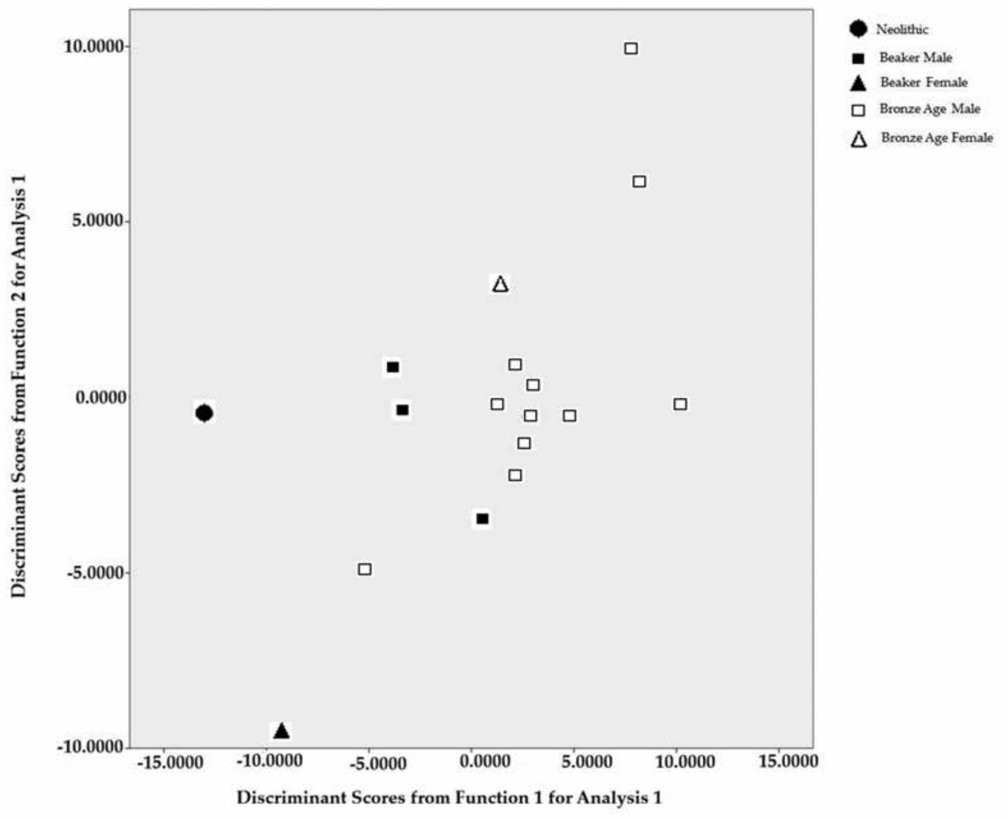

Figure 6.13: Scatter plot of groups in the Peak District sample based on discriminant scores from functions 1 and 2 from analysis of the standardised data set (Illustration: Sandra Thomas)

also affects two Early Bronze Age males being reclassified by the size-corrected analysis as Early Bronze Age females. Both of these individuals have particularly masculine morphological features.

- One specimen (J.93.932; SK192; Waggon Low) that appears in this analysis did not appear in the analysis of raw data. This individual has been re-categorised from Early Bronze Age male to Beaker male (although the burial has no Beaker), which is acceptable because of the chronological overlap between these two groups.

As noted above, four ungrouped crania can be classified on the basis of the raw data; with the effect of size removed, for two of them the predicted category indicated by the size-adjusted data is the same as that predicted by the raw data:

- One of these (J.93.942; SK202; Middleton Moor) is grouped with Beaker males (but see Note ix) and its Early Bronze Age date falls within the overall time frame for Beaker use.
- With the effect of size removed, J.93.923 (SK203; Smerrill Moor) is classified as female which corresponds with its anthropologically identified sex, although it has morphological features of both sexes.
- In this size-corrected analysis, J.93.938 (Bole Hill, assigned in the literature to the Early Bronze Age on the basis of the barrow form, but published as 'Neolithic?' (Howarth 1899, 166)) is grouped as Neolithic, which accords with its dolichocranic shape.

Overall, when the data are standardised for size differences, groups based on cranial shape become clearer but groups based on sex become obscured. This emphasises the need to use both series of analyses and reiterates the earlier findings of size differences between the sexes.

Finally, a scatter plot has been included (Fig. 6.13) to demonstrate visually the relationship between groups when the data are size-standardised. The Neolithic example still appears to be rather separate, but not to the

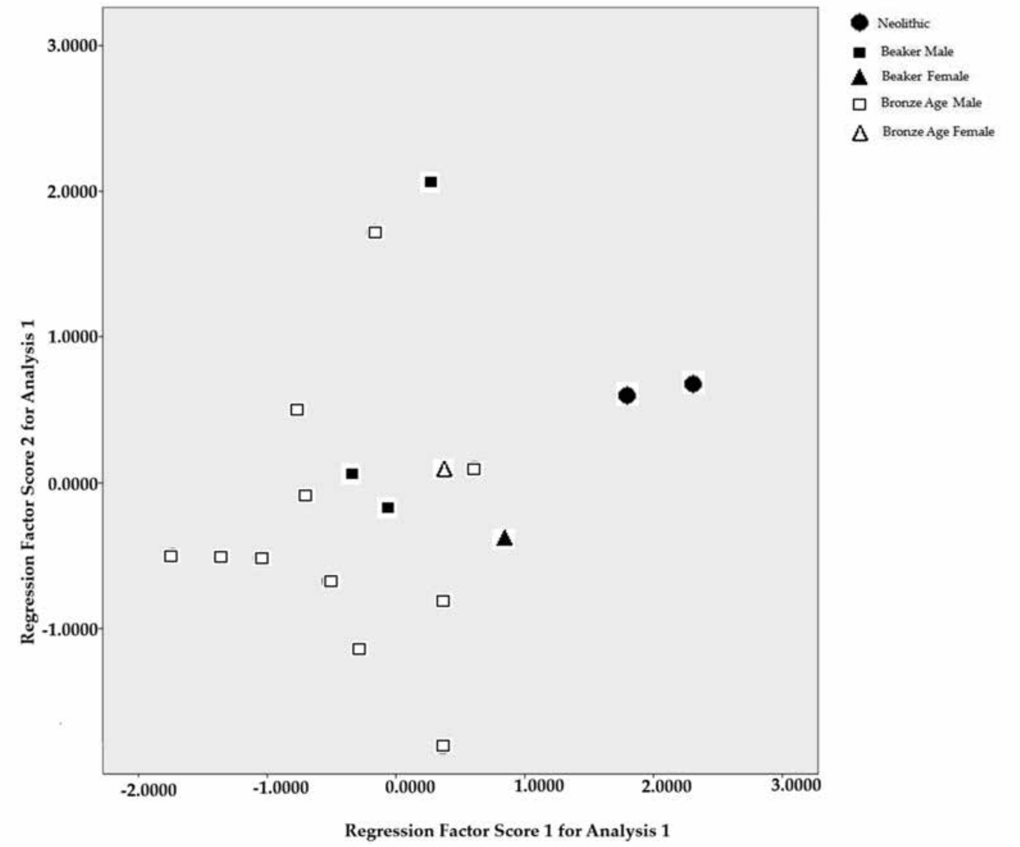

Figure 6.14: Scatter plot of factor groups in the Peak District sample formed from the first and second principal component scores (Illustration: Sandra Thomas)

extreme witnessed in the raw data analysis. The Beaker female example is also far removed from similar-shaped specimens, as in the previous analysis; thus her degree of difference is not due to size. Early Bronze Age male, Early Bronze Age female and Beaker male crania are all grouped similarly together, except for two Early Bronze Age male outliers. By and large, this scatter plot resembles that of the raw data and reveals no surprises, merely confirming previous grouping results.

Principal component analysis

After consideration of all previous tests, principal component analysis was conducted on a sub-sample of 18 individuals with a reduced suite of 15 measurements, selected on the basis of previously significant differences between groups. These were standardised to remove the effects of size.

With 15 variables, there are 15 components, four of which have eigenvalues greater than one. Of these, the first explains 35.9% of variance, the second 20.4%, and the third 14%.

The first three components account for more than 70% of the variance, and this is reflected in the component matrix in which the first three components have component scores (ie, correlations with individual variables) greater than 0.7, which can be considered high.

- In component one, the highest component scores, either as negative or as positive, are measures of cranial length and breadth. It is evident also that cranial breadth is negatively correlated with length and thus it can be said that breadth decreases when length increases.
- The orbital breadth and parietal lengths have the highest scores in the second component. These are also reversely correlated; the greater the parietal length, the narrower the orbits.
- Finally, in the third component, the occipital length has the highest component score. This suggests that occipital length represents a major part of the cranial variation that is distinct from overall cranial length.

The scatter plot in Figure 6.14 illustrates the groups when the first two components are compared, demonstrating the effect of cranial

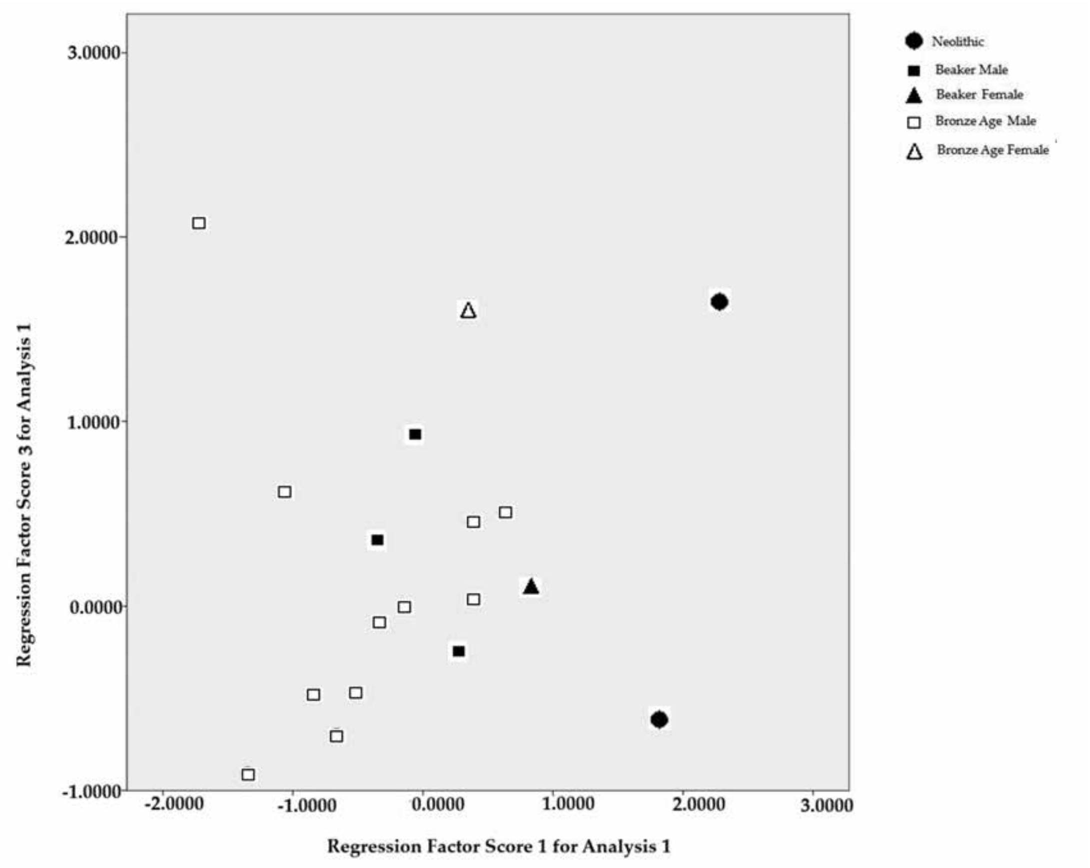

Figure 6.15: Scatter plot of factor groups in the Peak District sample formed from the first and third principal component scores (Illustration: Sandra Thomas)

length and breadth, frontal breadth, orbital breadth and parietal length on separating out groups. Beaker male and female groups and Early Bronze Age male and female groups are generally distributed together, except for two outliers. Two Neolithic specimens again group together but somewhat separately from the other specimens.

The scatter plot in Figure 6.15 illustrates the groups when the first and third components are compared and demonstrates the effect of cranial length and breadth, frontal breadth and occipital length on distinguishing groups. Beaker male and female groups and Early Bronze Age male and female groups are generally clustered together, except for one outlier. Two Neolithic specimens are separated, but along the same axis.

Summary

Size, shape and other factors creating distinctions between groups were all explored with univariate and multivariate analyses. The effects of length and breadth on crania were initially explored using a simple two-dimensional scatter plot, which also revealed the effect of size in relation to sex. These two effects were demonstrated by comparing cranial index and cranial module values, which clearly distinguished the Neolithic cranial shape from all other groups, and separated out male and female cranial sizes from each other.

Specific measurements were found to differentiate groups; maximum cranial breadth measurements are significantly smaller for the Neolithic skulls than for all other periods yet are indistinct between these later groups. Cranial length decreases through time, since maximum cranial length and nasio-occipital length are significantly greater for the Neolithic crania than for specimens in the Early Bronze Age group, and significantly greater for Beaker male crania than for the Early Bronze Age group. These measurements are indistinct among the other groups.

Female crania in the Beaker group have significantly smaller maximum frontal breadths than Beaker male or Early Bronze Age male crania, even with the effect of size removed, but this measurement was not available for assessment of the Neolithic group. When comparing the Beaker females to other groups as raw data and when comparing these results to standardised data, cranial length and orbital breadth are the measurements most likely to be affected by size.

The only unexpected result in the univariate series was the significant degree of differentiation found among the parietal chord and parietal arc measurements. These measurements were increasingly shorter throughout the male groups from Neolithic to Beaker to Early Bronze Age, with no difference between Beaker females and either Beaker males or Early Bronze Age males.

The multivariate analysis confirmed many of the established groups and allocated categories for otherwise ungrouped specimens. These tests in particular showed that the removal of the effect of size is important for grouping by cranial shape, but that size-standardisation obscures the differences between crania of different sexes. This illustrates the need for tests to be run with both raw and standardised data for comparison and affirmation of results.

The principal component analysis revealed a clear relationship between cranial length and breadth, the connection between parietal length and orbital breadth, and the correlation between cranial differences and occipital length, which was not detected from the univariate statistics.

Despite the small sample size, these results seem to be reliable. In terms of robusticity, the overall number of 41 individuals is above the recommended minimum sample size of 30 (Madrigal 1998, 9). The Kolmogorov–Smirnov and the Shapiro–Wilk tests were carried out, which established the normality of the data distributions in this sample. *T*-tests were then undertaken to test for significant differences between the means of each group. The non-parametric Kolmogorov–Smirnov *Z* test, especially designed for small samples, was also executed, and was preferentially selected for two groups drawn from the same population. An Exact statistic was also computed, as this also provides greater accuracy for tests on small samples (Field 2009, 786). The results are robust because it is highly unlikely that the measurements previously known to contribute to differences in cranial shape would be the very measurements to prove statistically significant by chance. This is particularly pertinent in light of the fact that these results correlate so neatly with previous work carried out by Brodie on a nationwide scale (1994).

Discussion

Craniometry

As a general overview, these statistics reveal that cranial length and breadth are negatively correlated with each other and are also primary sources of difference between skull types. The Neolithic crania were found to be longer and those of subsequent periods shorter. These findings concur with traditional observations of crania from these periods and with Brodie's comprehensive statistical assessment of the same, based on material from all over Britain (1994).

In more specific terms, the traditional view has been that skull shape is pre-determined by the genotype, which can be altered through the long-term process of natural selection or through the action of gene flow (Relethford 2004, 379). Environmental conditions also appear to play a part in the morphology of the cranium. The strongest evidence for this would appear to come in the form of Howells' work (1973; 1989), which successfully discriminated between samples from 18 populations with divisions occurring between climatically different areas.

The cranial index has been found to correlate with climate on a global scale, with humidity and temperature both indicators of cranial shape (Howells 1973). Specifically, cranial length has been found to correlate positively with humidity, particularly on a European scale, whilst brachycrany has been related to colder conditions and stockier builds (Brodie 1994, 51–3). An early study found that immigrant children moving from the Mediterranean to regions with a more temperate climate were more brachycephalic than their parents, which would suggest that the thermo-regulatory response time for bone is exceedingly fast, particularly at an early age (Boas 1940). This is compatible with the concept of developmental plasticity (Lasker 1969).

Taking both of these influencing factors into account, the time-span between the Neolithic and Chalcolithic/Early Bronze Age burials – some 700 years or more – seems too short for natural selection, but an adequate amount of time for gene-flow-related change or environmental response to have occurred. The self-evident hypothesis is that brachycranic

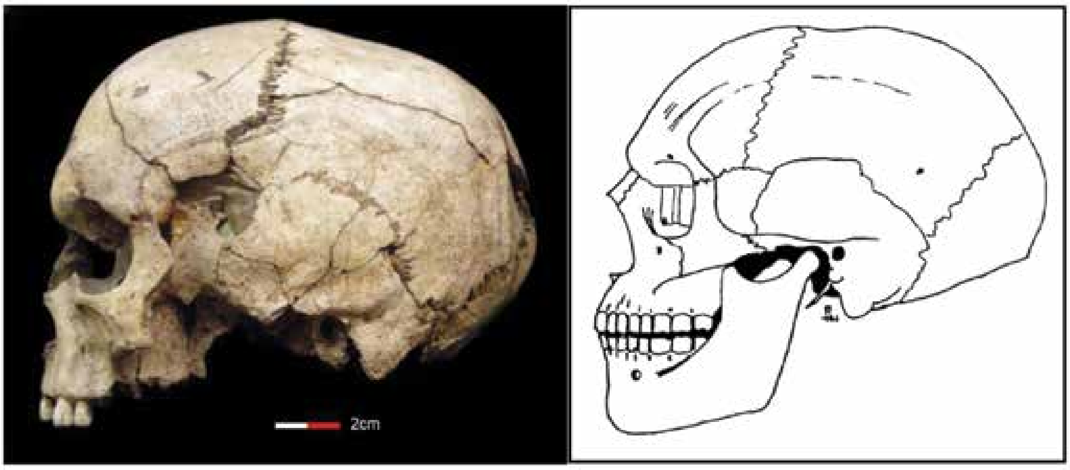

Figure 6.16: Comparing a skull with long parietals to a skull with post-bregmatic depression: A: Five Wells Hill, Derbyshire (J.93.937) (Illustration: Sandra Thomas)

migrants from a different population arrived in Britain. Other explanations for the changes in cranial shape during this period have proposed climatic change as a cause: perhaps migrants came to Britain and then reacted morphologically to a different climate, or perhaps existing inhabitants reacted to a changing climate. That said, the climatic downturn is normally considered to be a feature of the later Early Bronze Age rather than earlier (Barnatt & Smith 1997, 43), and was, in any case, smaller than the climate changes typically experienced by individuals engaged in long-distance migration.

With strong arguments for both environmental and genetic control of cranial shape, it would be fruitless to attempt to isolate the exact or primary influencing factor at play in the case of this sample. The ancient DNA studies which have recently been undertaken (Olalde *et al.* 2018) help to elucidate the matter and provide fascinating results but, from the perspective of craniometry, the answer is beyond the scope of this study. Suffice it to say that there are indeed significant changes in cranial shape that occurred both across Britain and within the Peak District region during the fourth and third millennia BC.

Deformation

A major finding of the craniometric analysis is the trend of diminishing parietal length through time. These statistical tests have thus isolated a specific osteological element implicated in the variation of cranial length. Multiple facets of osteology were explored in order to explain the involvement of the parietal bones in cranial lengthening. No cranial thickening, bone porosity, lesions or trauma were identified on the parietals that could specifically indicate bone modification caused by pathology or fracture.

Taphonomic changes and post-excavation methods can affect the shape of the cranium; of the seven crania in the dataset with the highest parietal chord and parietal length values, one specimen (J.93.920; SK205, Galley Low) is affected by post-mortem cranial shape change, with its reconstruction resulting in modification of the shape of the vault. However, taphonomic effects cannot account for changes in the lengths of individual cranial vault bones.

The parietals are not commonly perceived as an osteological feature directly associated with ancestry. A post-bregmatic depression – a slight dip on the superior-anterior portion of the parietals near the landmark bregma at the intersection of the coronal and sagittal sutures – is, however, recorded as a non-metric trait of the cranium found among 'blacks' (to use the term employed by White & Folkens 2005, 404). It seems extremely unlikely that in this sample this would be an indication of the presence of individuals of indigenous African descent, as other common traits of ancestry associated with a black African classification are absent, such as a wide nasal aperture, marked facial prognathism, and a low cranial vault. Figure 6.16 illustrates the difference between a skull with a true post-bregmatic depression and one of the skulls from the current study (J.93.937; Five Wells Hill Neolithic chamber tomb) which has a slight depression of the post-bregmatic region along the coronal suture.

The depression or, more accurately, impres-

Figure 6.17: The skull from Five Wells Hill (J.93.937) with a circumferential depression on the parietals (Illustration: Sandra Thomas)

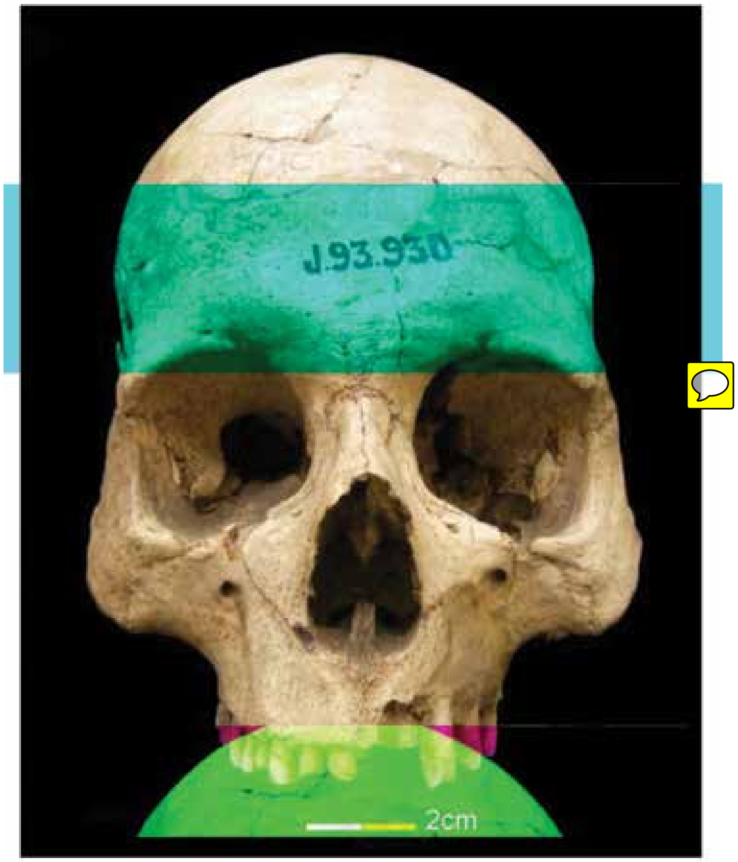

Figure 6.18: The skull from Long Low barrow, Staffordshire (J.93.930), with its circumferential depression on the frontal bone (Illustration: Sandra Thomas)

sion on the Peak District skull is not restricted to the immediate post-bregmatic region and tends to continue beyond it, following the line of the coronal suture on the parietal section. Nevertheless, this feature has been referred to simply as 'post-bregmatic' or circumferential in the literature on cranial modification (*ibid.*; Lorentz 2009). This impression on the skull is consistent with circumferential pressure on the cranium during the development of the skull. Figure 6.17 provides further illustration of the contour of this specimen.

This specimen (J.93.937; Five Wells Hill) has a distinct, banded depression associated with artificial cranial deformation, the result of infant head-binding, a socio-cultural practice recorded at low frequency around the world. It is interesting to note that another skull among the top seven crania graded by greatest parietal length also has an impression. J.93.930 (Long Low Neolithic long barrow) displays evidence of a depression across the frontal, between the superciliary ridge and the frontal bosses, also producing an indentation visible on the temporal lines (Fig. 6.18).

A high, narrow vault is also evident on this cranium, which sustains the idea of binding across the frontal bone of this individual, forcing the vault bones upwards. As shown in Figure 6.18, this appears to be caused by circumstances other than the skull merely exhibiting prominent morphological features. Binding in these areas may be statistically recognised by a negative correlation, detected in principal components analysis, between maximum cranial length and maximum frontal breadth, the latter of which is measured across the coronal suture. This is because both forms of binding – around the skull or over the top of the skull – would affect the width of the frontal bone. In their review of various ancient skulls from Britain and Ireland, Davis and Thurnam remarked upon the incidence of apparent head binding, and its apparently

Figure 6.19: Crania from Liff's Low (SK214; J.93.931), Monsal Dale (J.93.911), Haddon Field (J.93.921) and Bee Low (SK216; 1981.401), all in Derbyshire (Illustration: Sandra Thomas)

marked correlation with dolichocephalic skulls (eg, at Winterbourne Monkton cist 2: Davis & Thurnam 1865, Volume 2).

Of the seven crania with greatest parietal lengths, four (J.93.931 [SK214, Liffs Low], J.93.911 [SK196, Hay Top, Monsal Dale], J.93.921 [Haddon Field] and 1981.401 [SK216, Bee Low; see Fig. 4.10]) have especially long parietals without showing any signs of binding impressions. These are displayed in Figure 6.19. Of the two that have been radiocarbon-dated (SK214, Liffs Low and SK216, Bee Low[11]), both date to the Middle Neolithic in the late fourth millennium BC.

Four skulls in the sample possess particularly flat occipitals (Figs 6.20–6.23). This characteristic, known as occipital flattening, is frequently caused by laying an infant flat on its back or by securing it to a cradle-board. The four skulls in the dataset displaying such flattening are, incidentally, all found within the smaller measurement range for parietal bones; three are below the PAC average of 113 mm and the S2 average of 127 mm. In addition, the principal component analysis produced a high value for occipital length in the third principal component matrix, illustrating that occipital length has contributed substantially to the differentiation of cranial shape groups, independently of other measurements. The specimens in question are:

- J.93.944 (SK200, Bee Low), shown in Figure 6.20;
- J.93.923 (SK203, Smerrill Moor), shown in Figure 6.21;
- J.93.911a (SK195, Hay Top, Monsal Dale), shown in Figures 4.12 and 6.22;
- J.93.947 (Rolley Low), shown in Figure 6.23.

This is not the first identification of skull deformation practices within this skeletal

Figure 6.20: The skull from Bee Low, Derbyshire (SK200; J.93.944), demonstrating occipital flattening in two views (Illustration: Sandra Thomas)

Figure 6.21: The skull from Smerrill Moor, Derbyshire (SK203; J.93.923), demonstrating occipital flattening in two views (Illustration: Sandra Thomas)

collection: Bateman himself mentioned the phenomenon in his publications. Furthermore, contemporary with Bateman's own reference, Daniel Wilson's remarks on prehistoric British crania in volume 1 of *The Prehistoric Annals of Scotland* (1863) include mention of occipital flattening, which he associates with broad-headed crania, suggesting cradle-boarding practices as a possible cause; he uses a comparative example drawn from Native American practices (Wilson 1863, 273–4). More recently, Neil Brodie identified a male from Green Low (SK198) and another from Garton Slack 163 (burial 2: SK111) as having been noticeably affected by cradle-boarding (1994, 70). Both these individuals were buried with Beakers, and have similar radiocarbon dates (Table 2.1).

Bateman's observations were based on the concept of non-natural shape change, and he makes reference to Wilson's cranial shape definitions.[12] Bateman remarks on two of the aforementioned crania (J.93.923 and J.93.921) regarding the occipital region. For J.93.923, he describes 'the occipital bone being much flattened, possibly by artificial compression in youth' (Bateman 1861, 102). Of the examples of occipital flattening identified in this analysis,

Figure 6.22: The skull from Hay Top, Monsal Dale, Derbyshire (SK195; J.93.911a, also known as J.93.1289), demonstrating occipital flattening in two views (Illustration: Sandra Thomas)

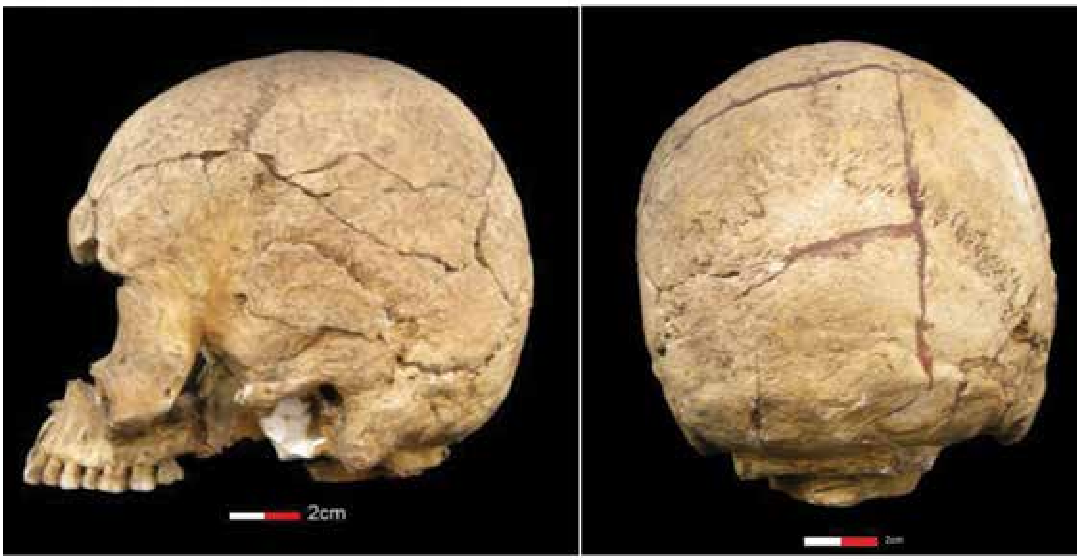

Figure 6.23: The skull from Rolley Low, Derbyshire (J.93.947), demonstrating occipital flattening (left) and extrasutural bone of the lambdoid suture (right) (Illustration: Sandra Thomas)

Bateman recognised only J.93.923; this is in fact the least pronounced example and therefore the most tentative identification of occipital flattening.

As his second example of occipital flattening in his collection, Bateman describes J.93.921 (Haddon Field) as possessing 'a peculiar flattening of the hinder part, extending from the upper edge of the occipital bone to those of the parietals adjoining the lambdoidal suture, a feature by no means uncommon in crania from barrows of the same remote antiquity, and by which may be attributed to some prevailing method of nursing during infancy' (*ibid*., 107). As discussed above, J.93.921 has one of the longest parietals but without any explicit signs of binding or flattening.

This apparent conundrum can be explained by the fact that Bateman refers to this skull as number 237 on his own list, which is attributed to a completely different specimen. He has mistakenly described the wrong skull when discussing this barrow and has thus mis-attributed the flattening to J.93.921. This observation is not without use, as it illustrates that crania with occipital flattening were recognised by both Bateman and Wilson during their mid-nineteenth-century work on skeletal remains.

Bateman also comments on two of the dolichocranic specimens (J.93.930 [Long Low; Fig. 6.18] and J.93.938 [Bole Hill, also probably Neolithic]), the former having been discussed above. He describes skull J.93.930 as having a 'laterally compressed appearance' (*ibid.*, 146), drawing attention to the shape but offering no further explanation. He also comments on J.93.938 as 'conveying the idea of lateral pressure' (*ibid.*, 91), which cannot be disputed, but this description conceals the fact that the shape is rather different from J.93.930, as it seems to have been caused in this case from compression within the ground. This skull has been reconstructed and plastered but, by all appearances, any evident shape change is due to taphonomic processes.

Lorentz (2009, 78–80) has assembled a list of criteria for distinguishing environmental alteration of cranial shape from other causes of bone modification. According to these criteria, artificial head-shaping does not alter cranial volume because it is not a pathological source of change such as a deficiency or growth disturbance (*ibid.*). As the volumes of the crania in our sample do not appear to be greatly reduced, nor do they exhibit lesions (as discussed above), they can be deemed to be environmentally rather than pathologically altered.

Premature suture closure and positional plagiocephaly result in asymmetrical cranial shape (Aufderheide & Rodríguez-Martín 1998, 53) which is the opposite of what is to be expected from artificial deformation: symmetry and binding impressions are usually both evident in examples of artificial deformation. Both of these characteristics are recognised in the current study.

In addition, the presence of Wormian bones – the presence of extrasutural ossicles on the skull – is strongly associated with artificially-deformed crania (O'Laughlin 2004). Of the six deformed skulls, four have Wormian bones, and 12 of the remaining 39 crania also exhibit this trait. Although not quite reaching statistical significance, this implies that the ratio is quite high, increasing the likelihood that these specimens represent artificially-deformed crania.

Finally, intentional head-shaping is usually expressed in varying degrees of severity, as a signal of social differentiation (Lorentz 2009, 80), which is not evident in these cases; this seems indicative, therefore, of unintentional secondary head-shaping for the occipitally flattened examples recorded in this study.

Indeed, this hypothesis could be extended to the two examples where binding is evident from the comparatively subtle nature of the shaping. It would not be inappropriate to suggest that head adornment might have caused the impressions, either as a deliberate action or as an unintended consequence. Similarly, given the locations of the impressions, hair-dressing might have either emphasised the shape of the head or concealed it.

The head-shaping noticed in these examples is subtle in comparison to many documented examples found in the Americas, which were clearly intentional (Brothwell 1981, 48–9; Buikstra & Ubelaker 1994, 160). In general, cranial deformation can qualitatively be described as the cause of vault deformity. This can be a result of antero-posterior compression, vertical compression, lateral compression, circumferential binding or use of a cradling device. There is evidence for cranial deformation on all continents (White & Folkens 2005, 314) but the archaeological evidence from Britain is rather scarce.

The most intriguing aspect of the artificially-deformed crania noted here is the dichotomy recognised yet again between cranial shapes and the respective periods to which they are dated. Both of the bound skulls are dolichocranic and date to the Neolithic. Those that exhibit occipital flattening are brachycranic or hyperbrachycranic, and three of the four are dated to the Beaker period or Early Bronze Age, whilst the fourth is undated. This difference between head-binding and occipital flattening could possibly be an indication of changing socio-cultural practices. Head-shaping may have been intended to exaggerate those characteristics that were already distinctive (and hence perhaps associated with some aspect of identity) in the different populations.

Lorentz (2009, 92–3) makes several excellent points about dynamic socio-cultural contexts and head-shaping. Material culture used for display encompasses objects of social and cultural mobility that can move more easily between populations than head-shaping practices, which require time to be adopted by a society – and, of course, time to become visible – and are unlikely to result from sporadic interaction. She states that, on account of its very nature as a permanent modification and one imposed on children, it is unlikely ever to have been adopted lightly. Furthermore, the obvious and permanent nature of head-shaping renders it a social marker of distinction in

SK No.	*Findspot*	*Local/mover*	*Museum ref.*	*Date cal BC (95% probability)*	*Pot*
211	Parcelly Hay	M	J.93.945 *(m)*	2480–2290	Beaker
222	Bee Low	M	1981.412 *(f)*	2470–2210	Beaker
208	near Castern	L	J.93.915 *(m)*	2340–2130	Beaker
221	Bee Low	M	1981.410 *(m)*	2270–2030	Beaker sherd
200	Bee Low	M	J.93.944 *(m)*	2210–2030	None
190	Stakor Hill	L	J.93.922 *(f)*	2200–1960	Beaker
198	Green Low	L	J.93.909 *(m)*	2200–1960	None
213	Shuttlestone	L	J.93.948 *(m)*	2140–1950	Beaker
215	Mouse Low	L	J.93.914 *(m)*	2120–1880	Beaker
210	Bee Low	M	J.93.935 *(f)*	2040–1880	Beaker
207	Gratton Hill	L	J.93.913 *(m)*		Beaker
195	Hay Top, Monsal Dale	M	J.93.911A *(f)*		Beaker
204	Hay Top, Monsal Dale	L	J.93.943 *(m)*		Beaker
205	Galley Low	M	J.93.920 *(m)*	2030–1880	Food Vessel
201	Smerrill Moor	M	J.93.940 *(f)*	2030–1770	None
202	Middleton Moor	M	J.93.942 (m)	2010–1770	None
197	Near Monsal Dale	M	J.93.912 *(m)*	1900–1700	Beaker?
219	Hazlebadge Hills	M	1957.32 *(?m)*	1880–1630	None
191	Wetton Hill	M	J.93.939 *(m)*		Food Vessel
199	Three Lows	L	J.93.925 *(m)*		Food Vessel
212	Bailey Hill	M	J.93.946 *(f)*		Food Vessel
196	Hay Top, Monsal Dale	L	J.93.911 *(m)*		None
206	Gotham	M	J.93.918 *(m)*		None
192	Waggon Low	M	J.93.932 *(m)*		None
209	Bole Hill	L	J.93.934 *(f)*		None
203	Smerrill Moor	M	J.93.923 *(?f)*		Sherds, unspecified type

Table 6.13: Local vs probably non-local Chalcolithic and Early Bronze Age individuals in the Peak District craniometric study, on the basis of isotope data

one regard or another, imposed from birth and thus neither adoptable not escapable in adulthood (*ibid.*).

Finally, Lorentz emphasises that status and head-shaping are inextricably linked, as attested historically and archaeologically, and implies that this complex and time-consuming form of bodily modification is particularly associated with those of higher social status (*ibid.*). These are all factors to be considered when investigating differing cranial shapes and their relationships with possible social and cultural groups through time.

To conclude, the recognisably different cranial shapes identified in this study are primarily a product of the cranial index as calculated from measurements on crania of natural shape. There are six cases where the natural shape has been distorted in life, the subtlety of which suggests that this may be a secondary consequence of cradle-boarding and head-binding, or an intentional, primary consequence perhaps further emphasised by head adornment or hairstyle. Examples are infrequent within European archaeology but, to name one comparative example, antero-posterior head-shaping, involving occipital flattening, is known in an Early Neolithic example from Tharrounia in Greece (*ibid.*).

A comprehensive assessment of crania from the British Neolithic, Chalcolithic and Early Bronze Age will be necessary to understand this complex social process, to assess the extent of the practice and place the findings in a broader European context. It is unfortunate that, on this occasion, it was not viable to conduct statistical tests on the sample by excluding the deformed crania to understand the effect of their inclusion on overall results. Leaving out the deformed crania from the analysis would have rendered the Neolithic group inadequate for analysis (leaving only one individual).

Stable isotope results for individuals in the Bateman Collection

Sandra Thomas and Mike Parker Pearson

Of the 26 Beaker-associated and non-Beaker Early Bronze Age individuals in the Bateman Collection sampled for stable isotope analysis by the *BPP*, ten proved to have strontium isotopic ratios in tooth enamel inconsistent with their having grown up in the Peak District or in its environs (Table 6.13; see Chapters 10 and 11). Additionally, one of these (SK201) and three other individuals had unusual oxygen isotopic ratios that could indicate migration to the Peak District. That is to say, as children, ten of these individuals, and possibly three others, lived somewhere other than where they were eventually buried.

Of particular interest is the correlation of cranial form with evidence suggesting migration to the region. All three individuals with hyperbrachycranic crania (see Table 6.10) have unusually extreme values for strontium (SK196, Hay Top, Monsal Dale [see Fig. 4.12]; SK197, near Monsal Dale) or oxygen (SK200, Bee Low; see Fig. 4.10) that could be consistent with them growing up outside Britain. Similarly, all three non-Neolithic dolichocranic individuals sampled (see Table 6.10) have isotope ratios inconsistent with the Peak District or environs.

In contrast, the majority of brachycranic and mesaticranic individuals sampled have isotopic values that can be found in and around the Peak District.

- Two out of eight of the brachycranic individuals in this study are likely to be non-local: SK201 and SK203, both from Smerrill Moor.
- Of the 12 mesaticranic individuals in this dataset, five have non-local isotope values: SK205 (Galley Low), SK212 (Bailey Hill), SK219 (Hazlebadge Hills), SK221 (Bee Low; see Fig. 4.10) and SK211 (Parcelly Hay; see Fig. 4.9).

It should also be noted that three of the four individuals with evidence for cranial deformation causing occipital flattening (namely SK195, Hay Top, Monsal Dale; SK200, Bee Low and SK203, Smerrill Moor) were included in the isotopic analysis – the fourth, from Rolley Low, was not. All three the isotopically-analysed individuals are likely to be immigrants to the Peak District (as discussed in Chapters 10 and 11). The male from Green Low (SK198), identified by Brodie as an example of cradle-boarding (1994, 70), has isotopic values consistent with a local origin.

The burial locations of the likely immigrants to the Peak District are also of interest. Including isotope-sampled individuals from the Peak District not covered in the craniometric study, eight probable or definite migrants come from burial sites on Smerrill Moor, Hazlebadge Hills and Bee Low (see Chapter 10). This may indicate clan or origin-based burial practices.

The Peak District study: conclusions

Sandra Thomas and Mike Parker Pearson

Many facets of this study can be interpreted as indicating migration into the Peak District during the late third and early second millennia BC. Cranial index values change considerably between the Early–Middle Neolithic period (*c.* 4000–3000 BC) and the Chalcolithic–Early Bronze Age period (*c.* 2500–1500 BC). While one might try to explain this away as being a consequence of genetic drift, or a response to climate change, the changes in cranial shape are most likely to be due to the arrival of a non-indigenous population (see Chapter 12 for further discussion of this topic).

The individuals with artificially-deformed crania indicate potential differentiation between social or cultural groups. Although the craniometric procedures are inconclusive in terms of settling the questions surrounding migration hypotheses concerning the 'Beaker People', they do provide answers on some matters. We can now isolate the parietal as the source of differentiation in cranial length and thus produce a statistical anchor for the deformation processes that occurred.

It is now possible to revisit methods abandoned because of their formerly racist associations, because today we can look to craniometric procedures as a robust and independent source of categorisation that can be accessed inexpensively and without damage to skeletal material. It is also important to note that old collections still yield archaeological and anthropological gold – even 160 years after Thomas Bateman went barrow-digging – and that such work would not be possible without the commitment of museums to the long-term curation of skeletal remains from archaeological sites and the provision of access for research.

Notes (added by the Editors)

1 Twenty-five crania from the Peak District that are included in Deter and Mahoney's 'Northern England' sample are also part of the dataset for Thomas's craniometric study of Peak District skulls. There are minor discrepancies in the sex identifications between Thomas' and Deter and Mahoney's studies, and these

are indicated on Table 6.10; note that there is a more serious discrepancy between both Thomas' and Deter and Mahoney's sexing of SK202, a skeleton associated with a spacer plate necklace, as 'male', and Bateman's (1861, 24–6) and Davis and Thurnam's (1865) osteological identification of that individual as female. Of the sample of 39 individuals from Scotland in this analysis of age and sex, 31 are from eastern Scotland (location groups 1 and 2) and these 31 are also included in the larger dataset used for Hutchison's osteological analyses reported in Chapter 5.

2 This section is an abridged version of an MSc dissertation presented with distinction at the University of Sheffield (Thomas 2009). Full details of statistical analyses and results reported here can be found in that dissertation. The analysed skulls include 28 that feature in the *BPP*, namely SK190–2, 195–216, 219 and 221–2.

3 Note that the use of Beaker pottery extended into the Early Bronze Age, and six of the Beaker-associated individuals in this study (SK190, 197, 198, 210, 215 and 221) have been radiocarbon-dated to the Early Bronze Age rather than the Chalcolithic.

4 Radiocarbon dates for individuals in Thomas's sample that are also included in the *BPP* dataset were for the most part obtained only *after* Thomas had completed her dissertation. One individual (SK216, from Bee Low) that Thomas had allocated to her 'Beaker' group (on the grounds that the skull came from a cist containing multiple individuals and an All-Over-Cord Beaker) is in fact of Middle Neolithic date, while three (SK201, 202 and 219) that are in Thomas' 'Ungrouped' category were found to be of Early Bronze Age date. Moreover, as noted above, her 'Beaker' group includes six individuals that date to the Early Bronze Age, rather than the Chalcolithic. See Table 6.8 and remarks in *Multivariate statistics*.

5 See Note iv regarding SK216, a mesaticranic Neolithic female previously supposed to be of Chalcolithic/Early Bronze Age date.

6 See Note iv regarding SK216.

7 This is despite the fact that there is a chronological overlap between some of the Beaker-associated individuals and the dated, Food Vessel-associated individual SK205. Nevertheless, the point made here may indeed be valid.

8 Given that Beaker use extended into the Early Bronze Age, these regroupings are not surprising.

9 Thomas' craniometric assignment of this skull to the male sex (and Deter and Mahoney's identification of the individual as 'male?') is markedly at odds with Bateman's (1861, 24–6), and Davis and Thurnam's (1865) adamant claims – on osteological grounds, at least in the case of the latter publication – that the individual is female. It is also at odds with the association of the skeleton with a spacer plate necklace, a type of grave good that is overwhelmingly associated with Early Bronze Age females, as noted in Chapter 4 and discussed at length in Woodward and Hunter 2015. Verification of the sex of this individual through DNA analysis is strongly recommended to resolve this conundrum.

10 The unequivocal association of this individual with a Beaker (Howarth 1899, 145) and the fact that the grave is rock-cut in the manner of several Chalcolithic and Early Bronze Age graves in the area, argue strongly against this individual being of Neolithic date.

11 SK216 (Bee Low) was radiocarbon-dated to 3340–3010 BC (at 95% probability) after the completion of Thomas's statistical analysis. For the purposes of that analysis, SK216 had to be included in her 'Beaker' group, since the skeleton was one of six to seven individuals found together in a cist with a single Beaker, and it had been assumed that the Beaker was contemporary with the individuals. See The early Peak District burials in Appendix 1 for discussion of the Bee Low barrow.

12 Note that when Bateman himself refers to Wilson's work, it is *The Archaeology and Prehistoric Annals of Scotland*, published in 1851, that Bateman is citing. This is the earlier of Wilson's two books (with very similar titles).