Cattle teeth: differences between first and second molars, and variability in the accessory pillar

In the report on the cattle remains from Ferry Fryston, Yorkshire, two aspects of particular relevance to methods for studying age at death from cattle teeth were published. Differences in the morphology and size of first and second molars are described, which may allow loose teeth to be identified in most cases and therefore be more easily used in age estimates. And the height of the accessory pillar (the small pillar which sits between the first and second elements in molar teeth) was measured for all three molars and its variability shown. The variability was greatest in M3, which is used in some summary methods for defining older cattle. The work was published in Appendix 11, which is included here, with some additional tables, omissions, errata and photographs.

The cattle studied came from the upper layers of the ditch surrounding the 3rd to 2nd century BC chariot burial at Ferry Fryston. In this layer, there was a deposition at least 162 cattle, of early 2nd to 4th century AD date. They consisted predominantly of heads and right forelimbs.

Jones, G. G. 2007b Variations of mandibular tooth accessory pillars, and Metrical and morphological differences between M1 and M2, in the Assemblage of cattle associated with the chariot burial, in Brown, F, *et al*, *The Archaeology of the A1(M) Darrington to Dishforth DBFO Road Scheme.* Lancaster Imprints, Appendix 11, 618-625.

This file and Jgg codes:
Jones_GG_2007b_A1M_App11_Cattle_acc_pillar_M1_M2.pdf
Jgg07b_A1M_Cattle; BatesJggDO07_A1M_FFChariot

The excavation report:
Brown, F, C Howard-Davis, M Brennand, A Boyle, T Evans, S O'Connor, A Spence, R Heawood, and A Lupton 2007 *The Archaeology of the A1 (M) Darrington to Dishforth DBFO Road Scheme.* Lancaster Imprints.

The other animal bone sections:
Bates, A, Jones, G G and Orton, D C 2007 Animal Bone from Site D (Ferry Fryston) in the Iron Age and Romano-British Periods, 148-150, Animal Bone from the Ferry Fryston Chariot Burial, 326-337.

Bates, A 2007 Animal bones from other sites, 337-351.

Orton, D 2007 Radiographic method for ageing cattle mandibles within the chariot burial ditch fill, Appendix 11, 625-635.

Errata and omissions from Appendix 11
The following two tables were not included in Appendix 11. They summarise the metrical and morphological differences which were observed and give suggested scoring.

Additional Table 1. M1/M2 differences: measurements

Width anterior (WA)	Figures 245, 246, 247, Table 133
Accessory pillar height (if unworn)	Figure 242, Table 132
Crown height (FE) by Tooth Wear Stage	Table 134
Cervical length (CervL)	Figure 247

Additional Table 2. M1/M2 differences: morphological characteristics and suggested scoring

	M1	M2
(a) Indentation, Figure 248	1	1
(b) Anterior edge, Figure 248	1	1
(c) Steepness of the anterior CEJ, Figure 249	1	1
(d) Steepness of the posterior CEJ, Figure 249	½	½
(e) Anterior root, Figures 248, 249	1	1
(f) Lingual side, Figure 250	2	2
Total	6½	6½

Some edits done after submission introduced the following errors. The errors in the published copy are listed below, but are correct in this copy.
The title 'Metrical and Morphological Differences Between M1 and M2' was changed from a main title to a sub-title.
Fig. 242, Graph D x-axis title. This title was wrongly named in an earlier draft, the corrected copy was not used in the published text, but it is used here. It should read:-
Height (mm) above pillar to the (unworn) mid-tooth valley.
It is correct in Table 132.
Fig. 246 Title should read:-
M1 and M2 difference in anterior width - **the area of overlap**.
Page 619, first main paragraph: '93% of examples falling **between 24 and 30mm**'.
It is correct in Table 132.

References for the cattle accessory pillar and M1 M2 differences section.

Beasley, M J, Brown, W A B, and Legge, A J, 1993 Metrical discrimination between mandibular first and second molars in domestic cattle, *Int J Osteoarchaeol*, **3,** 303-14

Grant, A, 1975 The animal bones, in B Cunliffe, *Excavations at Portchester Castle: I Roman*, Res Rep Soc Antiq London, **33**, London, 262–87

Grant, A, 1982 The use of tooth wear as a guide to the age of domestic ungulates, in R Wilson, C Grigson, and S Payne (eds), *Ageing and sexing animal bones from archaeological sites*, BAR Brit Ser, **109**, Oxford, 91–108

Jones, G.G. 2002 The Animal Bones. In Baker, N., ed., *Shrewsbury Abbey: Studies in the Archaeology and History of an Urban Abbey*. Shropshire Archaeological and Historical Society, Monograph Series, No. 2, 145-158. ISBN: 0 9501227 7 7

Jones, G. G. and Sadler, P. 2012. A review of published sources for age at death in cattle. *Environmental Archaeology*, 17, 1-10.

Jones, G. G. and Sadler, P. 2012. Age at death in cattle: methods, older cattle and known-age reference material. *Environmental Archaeology*, 17, 11-28.

Legge, A J, 1992 *Excavations at Grimes Graves, Norfolk, 1972-1976, Fascicule **4**: Animals, environment and the Bronze Age economy*, London

Sadler, P, and Jones, G G , 2007 The mammal bone, in (ed) I Soden, *Stafford Castle*: *Survey, Excavations and Research 1978-98,* **2**, Stafford Borough Council, 161-72

[below, p.3 – further photos of sets of M1, M2 and M3, included in the Handout and Summary for a talk at the Professional Zooarchaeology Group meeting, University of Bournemouth, 15th August 2009, see also the minutes of the meeting]

M1 M2 differences

Three sets of M1, M2 and M3, additional to the A1(M) chariot report Appendix 11.

Views are buccal, lingual, anterior and posterior

The photos are archive ones. The Chariot report reference -

Jones, G G 2007 Variations of mandibular tooth accessory pillars, and metrical and morphological differences between M1 and M2, in the cattle associated with the chariot burial, Appendix 11, 615-625. In Brown, F, C Howard-Davis, M Brennand, A Boyle, T Evans, S O'Connor, A Spence, R Heawood, and A Lupton, The Archaeology of the A1 (M) Darrington to Dishforth DBFO Road Scheme. Lancaster Imprints.

Dental pathology: DEH 3/11; caries 4/17; AMTL 1/18; calculus 7/13
Skeletal pathology: SDJD: slight lipping of tubercle articular surface of L and R ribs and corresponding changes to costal articular surfaces on mid-thoracic vertebrae; slight lipping of mid-thoracic and L4 and L5 bodies
Metrical indices: platymeric L 73.4, R 75.38; platycnemic R 74.66
Non-metric traits: enamel pearl on maxillary second molars; double facet on L calcaneous; L mastoid foramen patent

Skeleton: *1128*
Completeness: 30-40%
Preservation: poor
Age: 20-25 years
Sex: possible female
Stature: no complete long bones present
Dental inventory:

				k						k				k	
8	7	-	5	4	-	2	1	1	-	3	4	5	6	7	8
8	7	-	5	4	3	-	1	-	-	3	4	5	-	7	8
							k							k	

Dental pathology: DEH 6/24; calculus 5/24; caries 0/24; AMTL 0/24
Skeletal pathology: nil observed
Non-metric traits: nil noted

Skeleton: *1620*
Completeness: 60-70%
Preservation: poor to fair
Age: 18-19 years
Sex: male
Stature: 1.650±0.033 m
Dental inventory:

	k	k	k	k	k	k	k	k		k	k	k	k	k	k
8	7	6	5	4	3	2	1	1	/	3	4	5	6	7	8
8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8
k	k	k	k	k	k	k	k	k	k	k	k	k	k	k	k

Dental pathology: DEH 15/31; caries 0/31; calculus 30/31; AMTL 0/32; abscess 0/32
Skeletal pathology: nil observed
Metrical indices: platymeric R 86.42; platycnemic R 71.78; robusticity (humeral) R 18.29; nasal index 54.3; orbital index 66
Non-metric traits: nil noted

Skeleton: *1698*
Completeness: 10-15%
Preservation: destroyed (very weathered, leached and fragmented)
Age: probably adult
Sex: unknown
Stature: no complete long bones
Dentition: dentition absent
Skeletal pathology: nil noted
Non-metric traits: nil noted

Site C4SA

Skeleton: *3722*
Completeness: 20-30%
Preservation: poor
Age: young to prime adult
Sex: unknown
Stature: no complete long bones present

Variations of Mandibular Tooth Accessory Pillars in the Assemblage of Cattle Associated with the Chariot Burial

Gillian Jones

Variation in Accessory Pillar Height

The initial research question concerned study of the variability of the accessory pillar, on which the later Grant Tooth Wear Stages (TWS) are based (Grant 1975; 1982), as part of a study of older cattle, mandible stages, and the position of the cement-enamel junction (Jones and Sadler forthcoming; Jones 2002; Sadler and Jones 2007). For the molar teeth, the TWS 'h' and beyond depend on wear of the accessory pillar, which sits between the first and second elements of the tooth, on the buccal (cheek) side. It is known that the pillar is variable (*eg* Grant 1982, 95; Legge 1992, 23) and sometimes absent, and the opportunity to study this variable in a large sample is useful in assessing the reliance that can be put on the later Grant TWSs.

The results of the analysis of the teeth from the cattle associated with the chariot burial are shown in Table 132. The pillar was measured from the (unworn) pillar tip (Point D) to the root arch (Point E) in projection, following the vertical represented by the pillar and the second element; accuracy to more than 1 mm was not attempted (Fig 241). Ideally, the pillar height should be related to overall, unworn tooth height, but in cattle the molar teeth come into wear before the root arch has formed. By taking a measurement at the mid-tooth valley (Point F), which remains unworn during early wear stages, some unworn tooth height measurements were possible, mainly on M3, with a few on M2, and none on M1. As with measurement DE, FE was taken in projection, aligned with the pillar and second element, on the buccal side; once in wear, the highest point of the mid-tooth valley is on the lingual (tongue) side of

	N	Range (mm)	Mode	3 mm from mode	Central 11-12 mm	Median	Mean	SD	CV
M1 DE	55	23-33	27	93% (24-30 mm)	100% (23-33 mm)	28	27.62	2.164	7.84
M2 DE	89	0, 9-43	33	71% (30-36 mm)	80% (27-37 mm)	32	30.80	5.173	16.80
M3 DE	56	0, 14-39	30	52% (27-33 mm)	79% (25-36 mm)	30	28.85	5.324	18.45
M3 FD	91	10-31	17	65% (14-20 mm)	84% (12-22 mm)	17	17.69	4.635	26.20
M3 FE	36	41-53	47.5	72%(44.5-0.5 mm)	94% (42.5-52.5 mm)	47	46.89	2.906	6.20

DE = pillar height to root arch; FD = height above pillar to (unworn) mid-tooth valley; FE = crown height from mid-tooth valley to root arch. Mean, SD, and CV excluded the zero values. For M2 FE, see Table 134

Table 132: Cattle teeth from the chariot burial: accessory pillar height, the third molar height above the pillar, and crown height

Figure 241: Measurement points on molars

the tooth; measurements were taken to the nearest 1 mm. For each record, Point F was recorded as in wear or unworn.

For the first molar, the pillar was found to vary in height by 11 mm overall, with 93% of examples falling between 242 and 230 mm (Fig 242). For M2, the pillar was longer, which is a characteristic helpful in identifying loose first and second molars, and the spread of results was wider. Almost a fifth were small or very small pillars, one was absent, and a few were unusually long. For M3, the pillar heights were somewhat shorter than for M2, and were more varied, with a much flatter central grouping and, as with M2, about a fifth outside of the main distribution. Small and very small pillars were quite frequent; in one case the pillar was absent, and one was very long. The sample size was smaller for M3 pillar height, because many of the teeth were immature, with the root arch not yet formed. The measurement above the pillar tip to the mid-tooth valley (when unworn), FD, provided a much larger sample size, and is in a sense more useful, as it represents the amount of tooth worn down before TWS 'h' is reached. The FD average was found to be 17.7 mm. Compared to M3 DE, results showed a clearer central grouping, and suggest a slightly lower proportion of short pillars (values of FD above 22 mm). They also confirm the flatter central grouping, so that, although 84% are within a range of 11 mm, only 65% are within 3 mm of the mode. It can be seen that the coefficients of variation for M2 and M3 DE and FD are very high (and much higher than for crown height, FE).

There were some very useful examples of M3s with both the root arch (Point E) formed and the mid-point valley (Point F) still unworn, so the pillar could be related to the tooth height as a whole (Fig 243). The accessory pillar formed 56–75% of the tooth height for most of the sample, with, as expected, a tail of smaller values (Fig 244); in five of thirty-six specimens the accessory pillar formed less than 56% of the tooth. There is some correlation between tooth height and pillar height with, for example, the three longest pillars all belonging to unusually high-crowned specimens.

The height of the accessory pillar was found to be variable, and increasingly so for M2 and M3. It is with M3, in particular, where mandible age stages have been based on the pillar coming into wear, that concern over variability is shown to be justified, and where, therefore, other characteristics related to age should be recorded. Legge observed that 'the very variable form of the bovine pillar in the permanent molars of cattle renders [it] at best an uncertain guide to the … stages of wear' (1992, 23). This work has quantified the uncertainty somewhat, indicating that in about 80% of cases the variation is of about 10 mm. When recording teeth, the presence of unusually small pillars should be noted. It may be appropriate to add an estimated stage in these cases, *eg* 'gk', where the strict TWS is 'g', plus 'k' as the estimated TWS, had the pillar been of normal height.

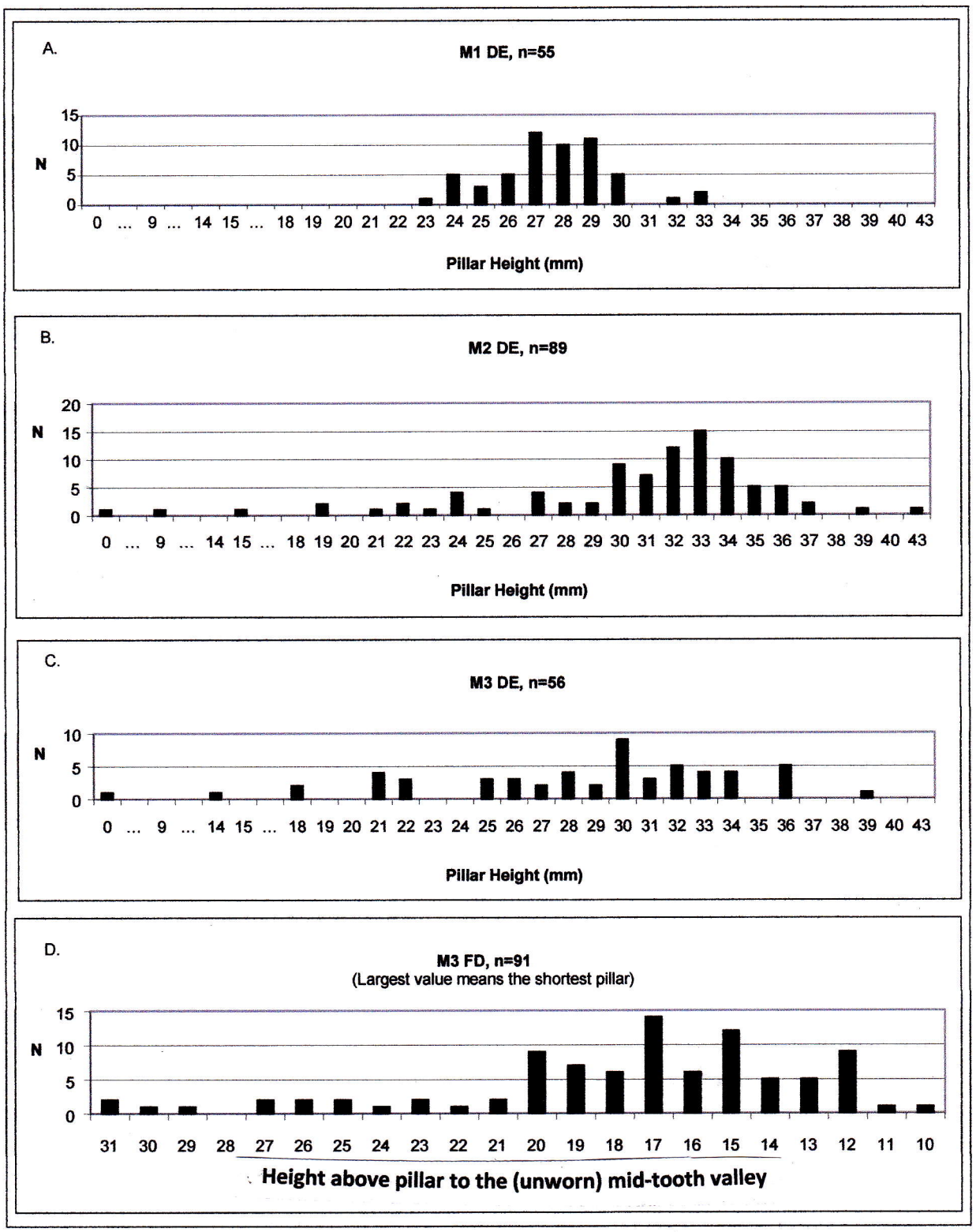


Figure 242: Height of accessory pillars in cattle molars from the ditch surrounding the chariot burial

Metrical and Morphological Differences Between M1 and M2

Measurement results

Measurements were taken of the cervical length and anterior width of first and second molars. These proved to be of interest in addition to the work of Beasley *et al* (1993) on identifying loose first and second molar teeth. At sites where loose teeth are common, ageing summaries need to include loose teeth data, and this is very much

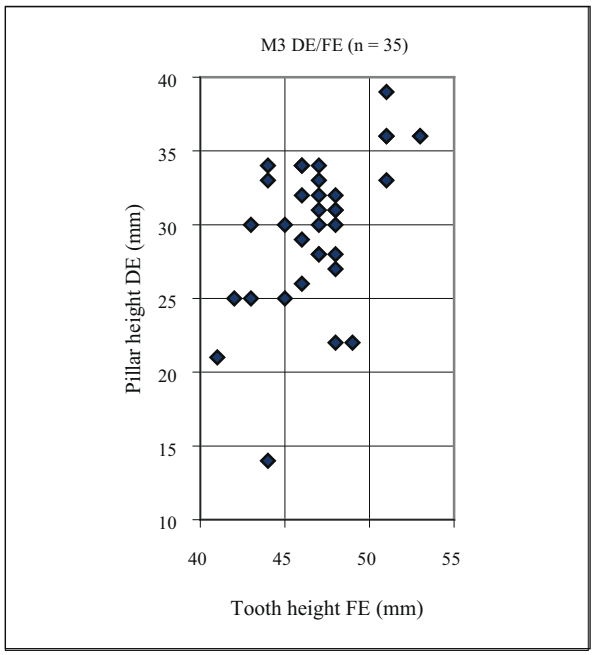


Figure 243: Tooth height and accessory pillar height of the third molar

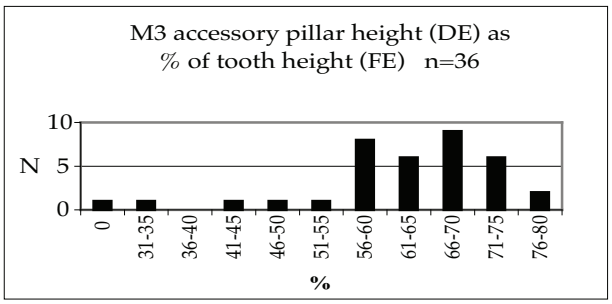


Figure 244: Accessory pillar height of the third molar (DE) as a percentage of tooth height (FE)

restricted if the first and second molars cannot be differentiated.

Molar Teeth

It was found that the anterior width of the first molar (M1; Fig 245) was smaller than that of the second molar, and that the anterior width of the second and third molars (M2 and M3) was very close. The width of the third molar, which can almost always be identified, may therefore be used as a reference point at sites where the size of teeth is different from that of the cattle associated with the present study. The anterior width was taken as the maximum bucco-lingual width of the first element of the loose tooth (WA, as taken for pigs in Payne and Bull (1988)). The widest part is usually about 10 mm above the lowest point of the cement–enamel junction (CEJ). It can be seen in Table 133 that the median and mean values are smaller for M1 than for M2, and that the interquartile ranges do not overlap; that is, the central half of M1 values are all smaller than the central half of M2 values. Taking the values which overlap (13.5–15.4 mm), the proportion found at each size is shown in Figure 246. The likelihood of a tooth being an M1 at less than 14.3 mm, or of being an M2 at 14.3 mm or more, is thereby demonstrated, and thus, used in combination with other characteristics, an identification of the specific tooth may be possible. The WA can be taken in older mandibles with teeth in place, where the widest part of the tooth is above the alveolar border, again as a reference point.

The same data on the late nineteenth-century Halle sample from various European breeds is broadly similar (Jones and Sadler in prep), confirming the usefulness of the M3 WA as a method of dealing with different sized cattle types. There are some interesting differences, however. All the sample statistics from the Halle sample were larger, with a smaller overlap in M1 and M2 size, and with the M3 a little larger than M2.

Molar length

Some difficulty was found in taking the cervical length measurement (Beasley *et al* 1993, fig 1), because the exact base of the CEJ (bCEJ) is rather variable, and not necessarily at the same level of the tooth anteriorly and posteriorly. After some experimentation, a measurement was taken at the widest point above the CEJ, on the buccal side, 6-7 mm up from the lowest

	M1 WA	M2 WA	M3 WA	M1 CervL	M2 CervL
N	100	102	75	95	98
Range	12.0 - 15.4	13.5 - 17.1	13.4 - 17.2	19.2 - 24.3	20.5 - 26.3
Median	13.6	15.0	15.0	21.4	23.3
Interquartiles	13.0, 14.0	14.4, 15.5	14.4, 15.6	20.5, 22.0	22.4, 23.9
Mean	13.62	15.01	15.05	21.34	23.21
SD	0.692	0.761	0.773	0.991	1.184
CV	5.08	5.07	5.13	4.64	5.10
68% range*	12.9 - 14.6	14.3 - 15.8	14.3 - 15.8	20.4 - 22.3	22.0 - 24.4

*(Mean – 1SD) to (Mean + 1SD); one standard deviation either side of the mean estimates 68% of the values

Table 133: Cattle teeth from the chariot burial: anterior width and cervical length

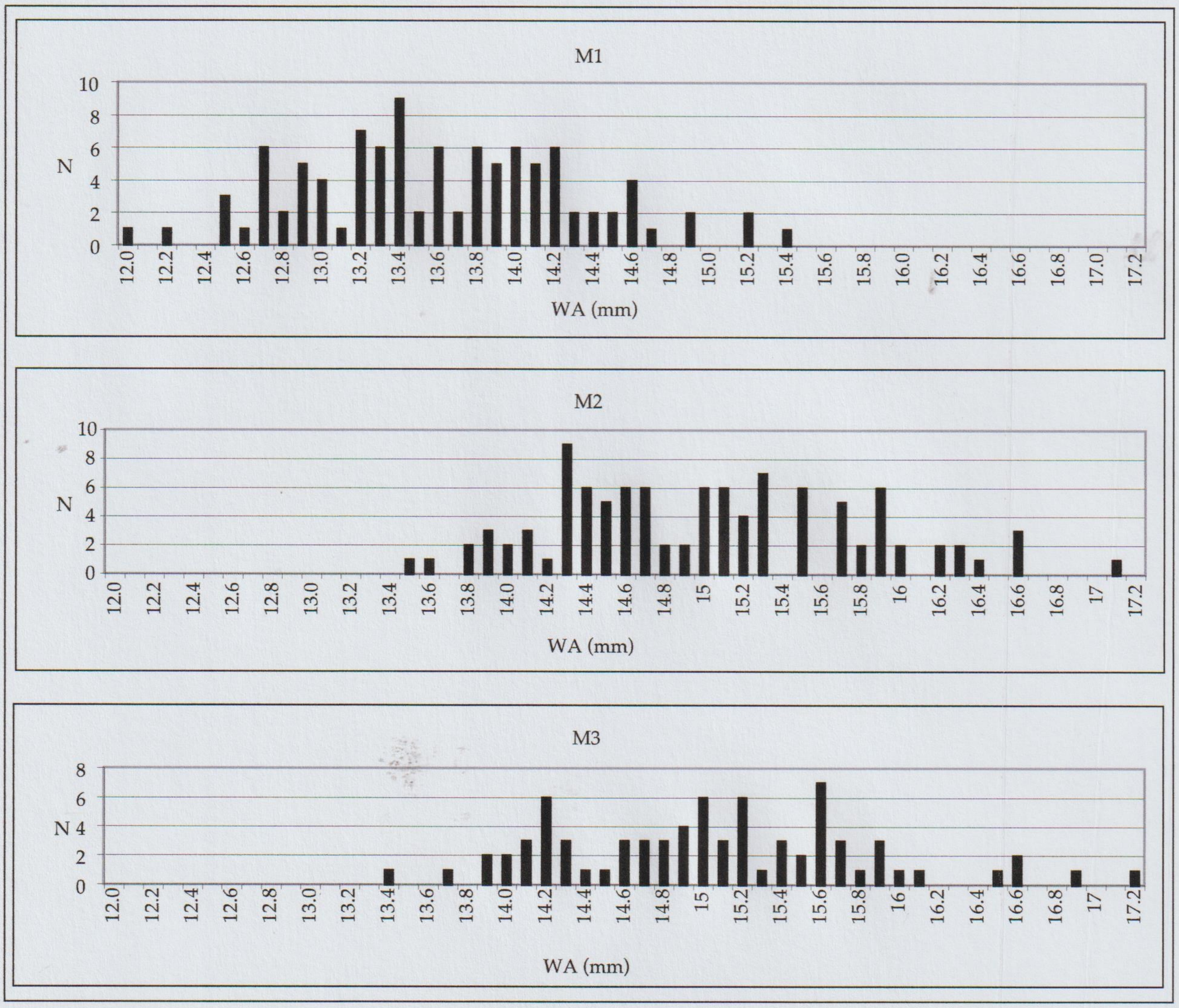
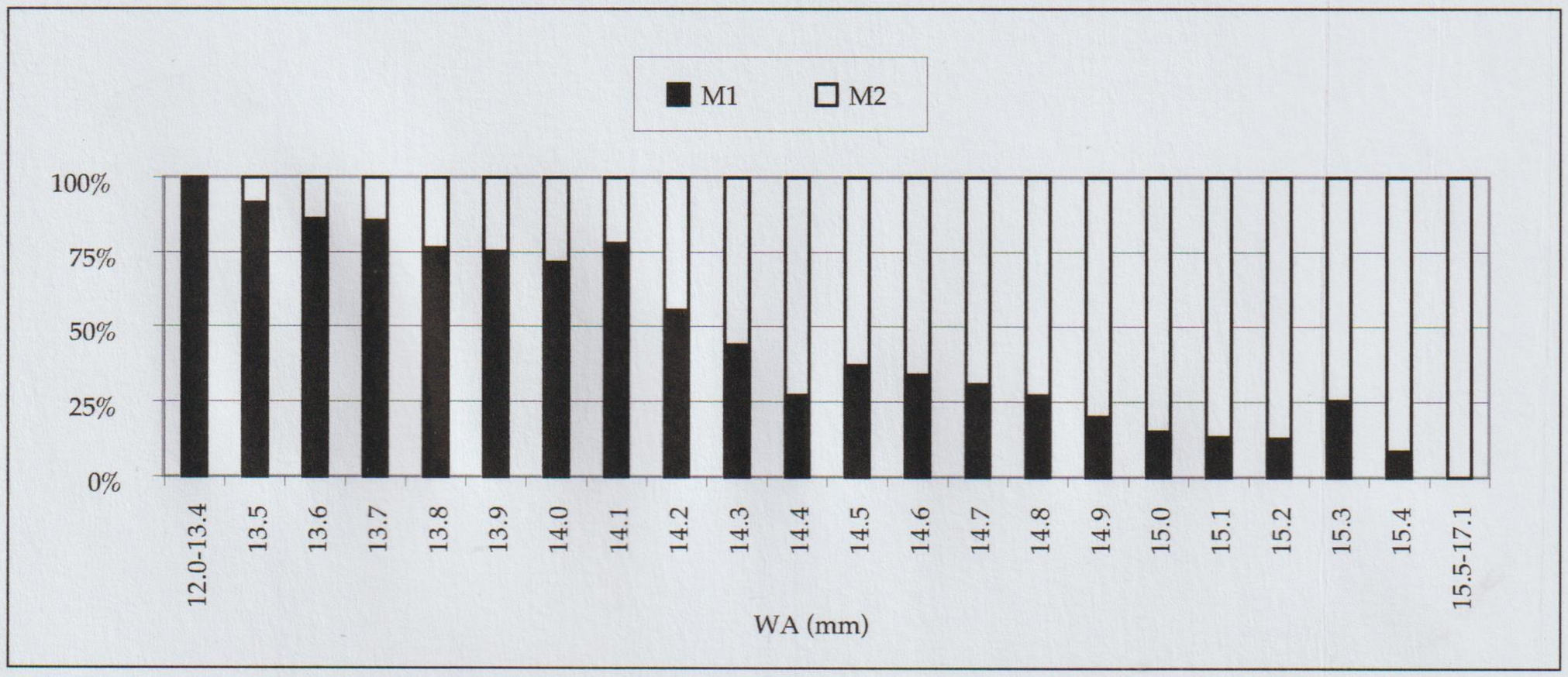


Figure 245: Anterior widths of cattle molars from the ditch surrounding the chariot burial



Note: data were smoothed using a running mean three point, standardised to correct for the higher M2 sample size

Figure 246: Difference in anterior width between the first and second molars - the area of overlap

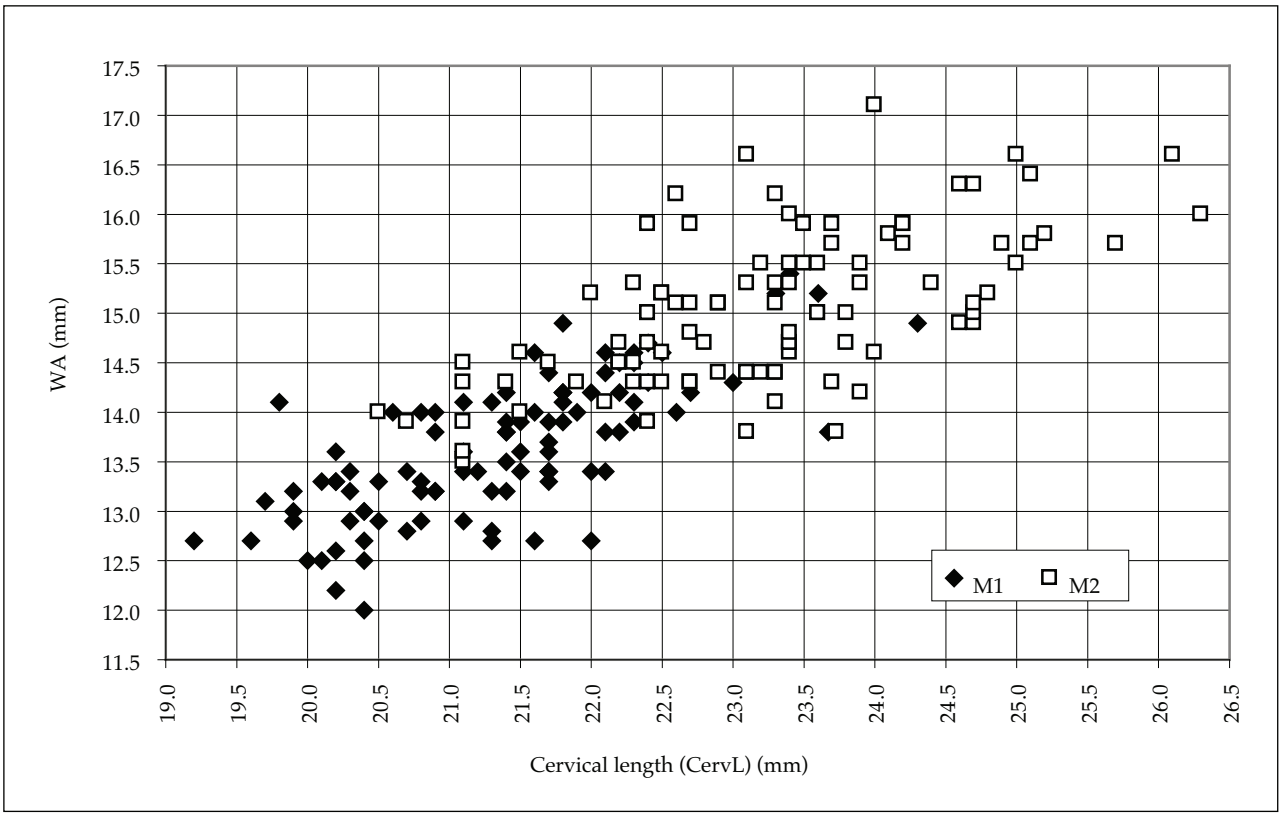


Figure 247: Comparison of tooth length and width between the first and second molars

point of the CEJ. This includes the slightly bulbous shape at the base of each element (the measurement was named CervL). It is, therefore, a larger measurement than Beasley *et al*'s (1993) cervical length. A similar difference in size between M1 and M2 was observed in this measurement as for anterior width, with no overlap in the central half of the results (interquartile range) (Fig 247; Table 133). A similar proportion of the values for CervL overlapped, but the extent of the range where values overlapped was much greater than for WA. Of the two measurements, therefore, anterior width gave more useful results because of this lower overlap, and because the M3 WA can be used as a reference point. The considerable spread of results is discussed in the metrical analysis of the chariot burial material (*Ch 8*).

Molar height

The most obvious difference between M1 and M2 is in their unworn crown height, M2 being more hypsodont, or high crowned. Using the measurement from the valley between the first and second elements to the root arch, a crown height value can be obtained which does not change over the initial wear stages (Fig 241, measurement F-E). Unfortunately, the assemblage associated with the chariot burial had no loose first molars at early wear stages. For M2, at wear stages up to and including Grant stage 'e', the crown height (F-E) was 40–49 mm (n=47; Table 134). Comparable data for M1 and M2 did not occur before stage 'f'; the mean value for M2 was 5.5 mm greater than for M1, and there was no overlap in the 68% range. At stage 'g', the difference in the means is just as clear, but with a small overlap in the 68% range. The difference in the means of 3–4 mm indicates the amount of crown height that has been worn away. At Grimes Graves (Legge 1992), it was found that the M1 is approximately 43–45 mm high when erupted and the M2 is between 50 mm and 55 mm high when it, in turn, is erupted.

Morphological characteristics

In the process of taking the cervical length measurement, it was noticed that more problems were encountered with the second molar than the first, which suggested some morphological differences. These characteristics were listed and recorded while working through the assemblage, and much of the earlier material was re-examined.

The following differences were observed. These could be scored and totalled, in order to assess confidence or otherwise in making an identification. Most of the points are a question of degree, so that they are clearer in some cases than in others. It is likely that others studying the material, or similar large groups of loose cattle teeth of known identification, will observe other points.

(a) 'Indentation', buccal face, first element (Fig 248, annotation 'a'). The column is marked with

Tooth Wear Stage		N	Mean M1	Mean M2	68% range M1	68% range M2	Range M1	Range M2	SD
~~d~~	M1	0							
Unworn-d	M2	36		44.06		42 - 47		40 - 49	2.484
e	M1	0							
	M2	11		44.09		42 - 46		40 - 47	2.343
f	M1	9	36.56		35 - 38		35 - 39		1.424
	M2	31		42.10		39 - 46		33 - 51	3.448
g	M1	29	33.52		31 - 36		28 - 38		2.429
	M2	10		38.20		35 - 41		33 - 44	3.190
h	M1	16	30.50		28 - 33		26 - 34		2.53
	M2	0							
j	M1	26	30.04		27 - 33		22 - 35		2.891
	M2	2		30.5		30, 31		30, 31	
k	M1	14	27.50		25 - 30		21 - 33		2.981
	M2	2		28				22, 34	

FE - measured on buccal side, from valley between first and second elements to the root arch; 68% range - (Mean + 1SD) to (Mean + 1SD)

Table 134: Crown height of first and second molars, by tooth wear stage

an 'indentation' near the anterior edge, which continues from the tip of the crown down towards the base, or lowest point, of the cement–enamel junction (bCEJ). This line is easiest to see on M3, where the line is very strongly marked. It is also strong on M2, and can often be traced right to the bCEJ or within 3 mm of it. On M1 it is less strong and gradually merges with the curve at the anterior/buccal edge of the tooth, and is scarcely visible on the lowest 6–7 mm above the bCEJ.

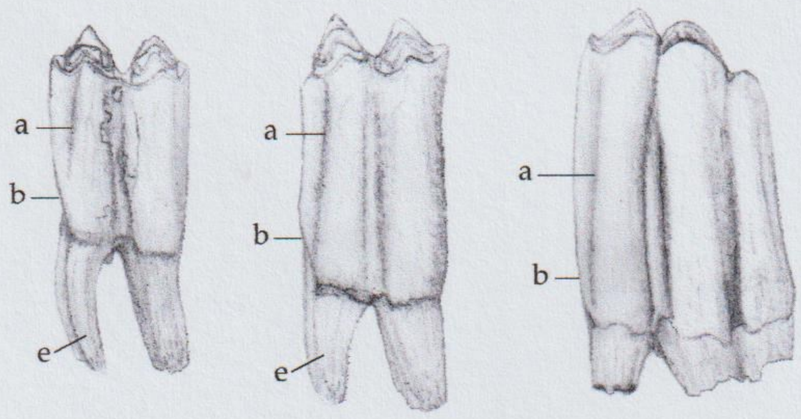


Figure 248: Buccal view of the left first, second, and third molars

(b) 'Anterior edge', on the buccal face, first element, the same column and 'indentation' (Fig 248, annotation 'b'). Again, this is easiest to see on M3. On M3, if the length of the tooth is measured (anterior–posterior direction) near the bulbous base of the tooth, it is obvious that the indentation is not the most anterior point of the tooth, and that one would need to move the callipers to the anterior edge. The most anterior part of M3 is near the centre of the anterior edge; the same is so for M2. For M1, the most anterior part of the tooth is much nearer the anterior/buccal corner. As a result, the length (CervL) is much easier to take on M1 than M2. Therefore, if taking the measurement in mandibles with teeth in position, care needs to be taken in the measurement of M2 that the most anterior point is reached.

(c) 'Steepness of the anterior CEJ', the cement-enamel junction. At each edge of the tooth, the CEJ rises steeply up to the lingual corner (Fig 249, annotation 'c'). This is very extreme on the anterior edge of M1, and much steeper than on M2. The posterior edge of M1 is less steep and often of similar steepness to the anterior edge of M2. For reference, the anterior steepness of M2 is similar to that of M3.

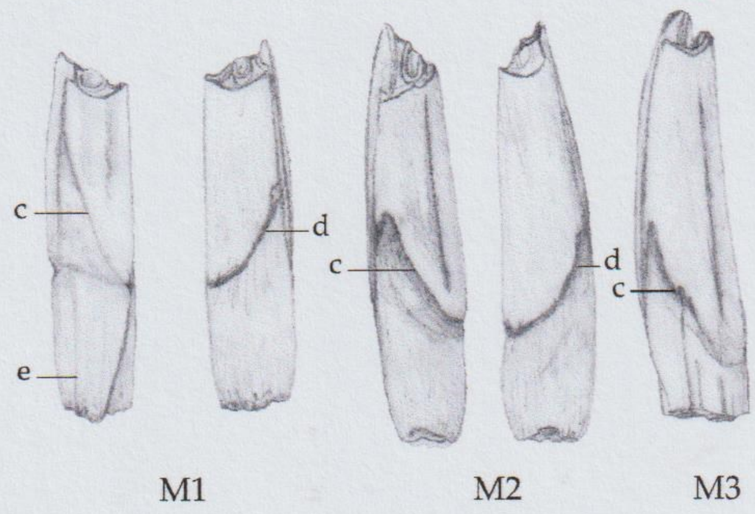


Figure 249: Anterior (A) and posterior (P) views of the first and second molars, and anterior view of the third molar

(d) 'Steepness of the posterior CEJ', the cement–enamel junction. Again, the CEJ on the posterior edge is steeper for M1 than for M2 (Fig 249, annotation 'd'), although the difference is much less marked. Often, on the posterior edge of M2, the CEJ does not begin to rise steeply until the central part of the edge.

(e) 'The anterior root' (Fig 249, annotation 'e'). In M1, the anterior root is more hooked than on M2. It also reduces to more of a point at the base. As a result, looked at in anterior-edge view (one eye closed), more of the distal root can be seen in M1 than M2.

(f) 'The lingual side'. The lingual side of the tooth, and the two folds which form the anterior/lingual and posterior/lingual corners of the crown of the tooth, should be examined, particularly about 5 mm up from the base of the CEJ (Fig 250, annotation 'f'). In M1 the anterior fold has almost disappeared, and the posterior one is slight, whilst in M2, the indentation of both the anterior and (especially) the posterior fold is well-shaped and the crease continues nearly to the bCEJ. The folds are covered in cementum (not enamel) at this point. As a result, looking at the lingual anterior/posterior length, in M1 the enamel extends to quite near the anterior and posterior border; in M2 the enamel extends less far, with the cementum clearly still bearing the shape of the corner folds. For both teeth, the posterior crease continues lower down the tooth than the anterior one.

The combination of measurement and morphological characters may thus provide a sound enough base to allow identification of loose molars in many cases, especially where note is taken while working through a sample of the loose teeth which can be refitted and are therefore of known identification.

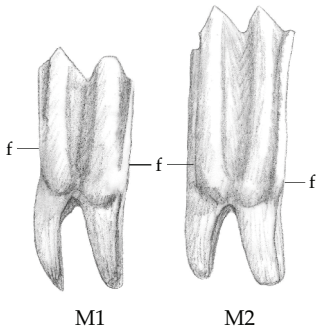


Figure 250: Lingual view of the right first and second molars

Radiographic Method For Ageing Cattle Mandibles Within the Chariot Burial Ditch Fill

David Orton

Introduction

The purpose of this study initially was to identify the spread of ages within the archaeological material recovered from upper deposit ***32*** in the ditch surrounding the Ferry Fryston chariot burial (*Ch 4*), and to test whether this supported or refuted a single kill hypothesis for these cattle. The radiocarbon dates (*Ch 4*) and work on the mandible wear scores suggest that the deposition of the animal bone can no longer be considered as a single event, which was the initial interpretation of the bone assemblage. The results of this study, however, are still valid in the interpretation of the material, especially if the question is broadened to encompass a concentration of slaughter at around an annual date on a repetitive basis.

Methodology

The Martin Luther University of Halle-Wittenberg collection

Forty-eight mandibles were selected from the Martin Luther University of Halle-Wittenberg collection, known as the Halle collection. These were concentrated in the 18–30 month age range within which most of the archaeological material falls, while retaining a good spread of ages throughout the first seven years of life.

Radiographic method

One mandible from each of the German reference specimens was radiographed from the lingual side. This work was carried out at the veterinary clinic of the Landwirtschaftliche faculty of the Martin Luther University, with the assistance of Jens Thielebein and Gabriele Hellriegel. Exposures were made on Konica SR-HG film using a GDR-era TUR D800 at 56 kV and 5.0 mA for 10 milliseconds, with a focal distance of 1 m. For the youngest specimens, the settings were reduced to 40 kV and 4.0 mA.

Radiographs of the archaeological sample were made using the Faxitron 43855A at the Department of Archaeology, University of York. Exposures were taken from whichever side allowed the tooth row to lie flattest against the plate, since the direction in which radiation passes through an object makes no difference to the resulting image. Radiographs of the archaeological mandibles were made at 40 kV and 3.0 mA with an exposure time of six minutes, using Kodak Industrex AA400 film at a focal distance of 622 mm. A graded bone wedge was used to ensure comparability in exposure between plates.