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Chapter 7 **Dental microwear: 2D and 3D approaches**

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Introduction

Human dental microwear – microscopic pits and scratches – is caused by hard particles that are dragged between (sheared) or driven into (compressed) opposing tooth enamel surfaces as the jaw moves through the chewing cycle. Conventional scanning electron microscope (SEM) approaches to microwear analyses are based upon two-dimensional size and frequency measurements.

Studies using this approach have established consistent associations between microwear and the toughness and hardness of the food consumed (plus the presence of any contaminants such as grit from cereal grinding). For example, frequent microscopic scratches are associated with shearing tough and abrasive plant foods (*e.g.* Walker *et al.* 1978; Teaford and Walker 1984; Teaford 1988; Nystrom *et al.* 2004), or with the presence of contaminants derived from food preparation (*e.g.* Teaford and Lytle 1996). In contrast, harder diets require greater compressive forces, producing larger microwear features and more frequent dental pits (*e.g.* Teaford and Runestad 1992; Strait 1993).

Because of these correlations, dental microwear is often used to provide dietary insights into the weeks and months, not days (Teaford *et al.* 2010), preceding death, across a range of fossil species (*e.g.* Teaford *et al.* 1996; Ungar *et al.* 2008) as well as archaeological samples of modern humans (*e.g.* Nystrom and Cox 2003; Nystrom 2008; Schmidt 1998; 2001; 2010; Mahoney 2004; 2006a & b; 2007).

Recent methodological developments have led to the three-dimensional characterization of microwear surfaces: dental texture analysis (DTA). This automated quantification of microwear in three dimensions is achieved by combining confocal microscopy with scale-sensitive fractal analysis (*e.g.* Ungar *et al.* 2003; Scott *et al.* 2005; Schmidt *et al.* 2011). Unlike SEM-based microwear analysis, DTA is free from the need to identify and measure individual pits and scratches. Therefore, DTA eliminates observer measurement error, and thus holds great potential for the future of dietary reconstruction in an archaeological context. As for SEM-based microwear analysis, consistent associations have begun to emerge between diet consumed and microwear texture. For example, studies on non-human primates report that those consuming tough leaves have high mean values for anisotropy (Scott *et al.* 2006; see *Methods*, below, for definitions). Diets that are very abrasive, very hard, or both tend to remove more enamel (*e.g.* Schmidt 2011), leading to higher values for textural fill volume.

Study aims

This study recorded dental microwear on 64 human permanent molar teeth from 64 individuals from England, Scotland and Wales (Tables 7.1, 7.2), to gain insights into the quality of food consumed – whether hard, soft, tough, or abrasive. All the individuals were part of the *Beaker People Project* and all but six (namely SK 21,43,67,95,116 and 132) definitely or probably date to the core Chalcolithic-Early Bronze Age period, 2500–1500 BC. These microwear results from Britain were then compared with results from several human groups of different periods from the Levant and North America that represent a range of subsistence strategies. Evidence for regional differences within Britain was also sought. A further aim was to produce dental texture data for a sample of the British adults and sub-adults, to integrate these findings with the microwear data and, in so doing, to produce the first human dental texture analysis for archaeological samples from Britain.

Materials

Sixty four mandibular permanent second molars were used in the study, with dental microwear being recorded for 52 of these (Table 7.1) and dental texture data being obtained for the remaining 12 (Table 7.2).

Methods

Casting

Standard procedures were followed (*e.g.* Schmidt 1999; 2001). Contaminants were removed from the occlusal surface of each molar using ethanol and cotton wool. Two impressions of the occlusal surface were taken using a rubber-based, addition-curing silicone (Coltène; President Jet®, lightbody). Facet 9 was excised from each impression using a scalpel and surrounded with Coltène President Putty® to create a depression. A cast of the facet was produced using an epoxy resin (Araldite MY 753, hardener HY 956, Ciba-Geigy®).

Dental microwear

Each cast was mounted on an aluminium stub after its base had been coated with an electrode paint (Electrodag 1415 M). The stub was placed into a sputter-coating unit (EMSCOPE; SC500) for 3 minutes, and coated with 20-nm of gold-palladium. Digitized micrographs were taken at a magnification of 500x using an SEM (CAMSCAN) at the Sorby Centre for Electron Microscopy and Microanalysis, University of Sheffield. The CAMSCAN was operated in the secondary electron emission mode with a spot size (resolution) of 3.0 and an accelerating voltage of 15 kV. Dental casts were oriented perpendicularly to the primary beam (tilt angle 0^o). Each digitized micrograph (1004 x 744 pixels) represented approximately 0.044 mm^2 of the tooth surface. A single digitized micrograph was taken from the bottom of facet 9, towards the central fossa, to try to reduce microwear variation due to location on the facet (Mahoney 2004; 2006a).

The size and frequency of microscopic pits and scratches were measured and counted using a semi-automated image analysis computer program (Microware Version 3; Ungar 2002). A resolution of 0.254 µm per pixel (DPI 200) was selected. Three variables representing the size and frequency of microwear were created from each micrograph: per cent pits, mean pit and scratch width. A 4:1 length-to-width ratio was used to distinguish between pits and scratches. All micrographs were recorded and a mean value produced for each individual.

Dental microwear texture

Facet 9 of each specimen was scanned using a white-light confocal profiler with a 100x objective lens at the University of Indianapolis. This produced a cloud of data points from four adjacent areas on the facet, which were stitched together automatically using Sensoscan® software, producing a 0.056 mm^2 area of study. The resulting surface representations were levelled using SolarMap® software. Any occlusal debris such as dust particles was digitally removed prior to analysis.

Following this, data were analysed via scale-sensitive fractal analysis (Toothfrax® and Sfrax® software) to produce two measures of microwear texture: anisotropy (**epLsar**, the degree to which microwear features are similarly oriented) and textural fill volume (**Tfv**, the amount of enamel surface removed by microwear). Feature orientation may be linked to dietary homogeneity, with homogeneous diets leading to repetitive chewing motion and highly anisotropic feature orientations. Therefore, it is important with DTA to consider the texture variables together.

Analysis

1. Dental microwear variation was compared between the samples from England and Scotland (all periods combined, and then just the Chalcolithic–Early Bronze Age samples) using an independent samples *t*-test. (Wales was excluded because of small sample size.) The *t*-test assumes data normality and approximately equal variance, which was checked with a Kolmogorov–Smirnov goodness-of-fit test. Outlying data points were identified in pit width using a de-trended Q–Q plot and their influence was reduced through a log transformation (base-10 logarithm).

2. Microwear variation was compared between the Chalcolithic–Early Bronze Age samples from Scotland (north east and south east: Location Groups 1 and 2), East Yorkshire (Location Group 3), the Peak District (Location Group 4) and southern England (Location Group 9) using a non-parametric Mann–Whitney *U* test, which does not make any assumptions about the distribution of the data, and is suitable for data sets with small sample sizes. (Regions were excluded where n = fewer than 3. This applies to the samples from South Wales, Kent and central England, Location Groups 5,7 and 10 respectively.)

3. Microwear variation was compared between individuals grouped by accompanying vessel type (Beaker, Food Vessel, or none), age (older adults being excluded because of the small sample size), and sex (males and probable males combined, and the same for females) for the Chalcolithic–Early Bronze Age period.

4. Dental microwear from England and Scotland (all periods combined) was compared to a range of previously published microwear values from modern and ancient human groups using a discriminant function analysis (DFA). The comparative data are:

- Natufian hunter-gatherers whose diet did not include domesticated plants or animals, but instead relied upon wild foods (Mahoney 2006a);
- Early Neolithic (PPNA) people from the Levant who subsisted on both wild and cultivated foods (Mahoney 2004);
- Iron Age people from the Levant (Mahoney 2006a);
- Chalcolithic farmers from the Levant (Mahoney 2007);
- early and late Mission period people from Florida[1] (Organ *et al.* 2005);
- Aleutian islanders with a dietary emphasis on marine animal foods (fresh, dried and frozen);
- the Arikara of South Dakota who consumed some cultigens and wild foods including large amounts of dried bison meat (Ungar *et al.* 2006; taken from their appendix 2).

A DFA was chosen to assess visually how the width of dental pits and scratches contributed to variation between these modern human groups. (For a DFA methodology, see Mahoney 2006b.) All analyses were undertaken in SPSS version 17 with the significance value set at $p < 0.05$.

[1] The Florida Mission period is AD 1587 to 1706.

5. Descriptive statistics for dental texture data are presented (all periods combined). Differences in mean values are described for the age groups, sex, vessel type, and two regions (others being excluded because of small sample size).

Results

The results are presented in Tables 7.3 and 7.4. Since they are not from a single homogeneous population but rather derive from an amalgamation of individuals from a wide range of locations throughout Great Britain, there must be caution when seeking patterns within the data.

The heterogeneity within the sample is reflected in the wide range of values present for the microwear features examined here (namely percent pits, pit width and scratch width). Even though the average frequency of pits is 34%, it ranges between 6% and 79%. Likewise, the average pit width is 2.07µm, but it ranges from 0.91µm in one individual to 4.83µm in another. Only scratch width shows a more consistent pattern (range 0.8µm to 1.63µm).

Similar variation can be seen in the texture data (Table 7.8), suggesting a diet that was heterogeneous, perhaps by constituent, season, locality, or some combination of these. Despite this caveat, it is possible to seek general commonalities or differences within the sample (Figure 7.1).

Dental microwear

When individuals from all time periods in England were compared to those from Scotland, no significant differences were detected (Table 7.3). However, when average microwear values for just Chalcolithic–Early Bronze Age England and Scotland were compared, dental pits from the English sample were significantly wider, compared to Scotland ($t = -2.158$; $n = 34$; $p = 0.039$) (Table 7.4; Figure 7.2).

Further differences emerge between the regions (Table 7.5), and some of these are significant when just the Chalcolithic–Early Bronze Age samples are compared (Table 7.6):

- The wider scratches ($U = 17.000$; $Z = -2.503$; $p = 0.011$) and more frequent pits ($U = 21.000$; $Z = -2.220$; $p = 0.026$) on the molars from southern England differ significantly when compared with those from East Yorkshire.
- The wider ($U = 21.000$; $Z = -2.220$; $p = 0.026$) and more frequent pits ($U = 18.000$; $Z = -2.433$; $p = 0.014$) on the molars from the Peak District differ significantly when compared with those from East Yorkshire.
- The wider pits on the molars from the Peak District also differ when compared with those from south-east Scotland ($U = 7.000$; $Z = -2.236$; $p = 0.026$).

Age, sex and accompanying vessel type do not appear to correlate closely with the microwear results. Pit frequency is generally lower, and pit and scratch size generally smaller, among the younger as compared to the older adults, but not significantly so (Figure 7.3). Sex differences are not consistent: even though males have more and larger pit features, it is only pit width that is significantly larger in comparison with females ($U = 43.500$; $Z = -2.308$; $p = 0.021$; Table 7.7). However, this finding is not confirmed by scratch width, which is larger in females. Individuals buried with Food Vessels during the Early Bronze Age have smaller scratches, and more frequent but smaller pits, than those buried with Beakers or with no pot, although the differences are not significant.

Two discriminant functions were calculated with a χ^2 (20) of 366.206, p <0.001, and χ^2 (9) of 175.407, p <0.001 (Figure 7.6). The first function (x axis) is created mainly from pit width and accounts for 53% of the variance. The second function (y axis) is created mainly from scratch width and accounts for 47% of the variance. There is good visual separation between the small (width) dental pits from Scotland and England, compared with the much larger pits of the Aleutian islanders. The small (width) scratches of the early Mission period and Levantine Chalcolithic samples are also clearly separated from the larger scratches of both the English and Scottish samples. The Natufian hunter-gatherers have the largest dental scratches.

Dental microwear texture

The mean Tfv value for the sample as a whole is 29,174, with a range between 5,097 and 51,687 (Figure 7.5; Table 7.8). The mean value for epLsar is 0.0044, with a range of 0.0009 to 0.0077.

As with the microwear results, the texture data show no consistent correlation with age or sex. Sub-adults have a low mean Tfv of 19,190, and this increases to 35,360 in the middle-aged adults. However, epLsar values do not follow this trend although, as expected, the sub-adults have the highest epLsar value.

Females have a slightly higher mean Tfv value of 30,187 and a higher epLsar value of 0.0043, compared with the male values of 28,948 and 0.0036 . However, the range of texture values for females overlaps with the values from the males.

As with the 2D microwear results, no clear trend emerges between the samples when mean values are grouped and compared by vessel type. Those buried with a Food Vessel have higher Tfv and epLsar values relative to those buried with Beakers, but again, there is a great range of values within each of the groups of samples. Those from the Peak District have higher mean Tfv values in comparison with those from southern England.

Discussion

Comparison between human groups

Dental pits (1.82–2.19µm) on the molars from Scotland and England are much smaller compared to the Aleutian islanders' dental pits (6.34µm), suggesting a much softer diet, or at least one that did not require the high compressive forces needed to consume frozen and dried animal meat habitually (Figure 7.4). In contrast, when compared to the Levantine Chalcolithic people (pits = 1.51µm; scratches = 0.86µm), the width of both dental pits (1.82–2.19 µm) and scratches (1.18–1.20µm) is greater in the British sample, suggesting a relatively harder diet that might not have been as highly processed as the softer foods consumed by the farmers from the Levant.

Based on texture analysis, the mean Tfv value for the English sample is not the same as the value created by a diet based solely on wild foods, or one that included large amounts of contaminants (Mahoney 2006b). Mean Tfv for the Natufian hunter-gatherers was 37,521 (Schmidt *et al.* 2011). This value is greater than the mean value of 29,174 for the English sample. Diets that are very abrasive, very hard, or both tend to remove more enamel (*e.g.* Schmidt 2001), leading to higher textural fill volume values. Thus, enamel is being lost from the molar surfaces of the English sample, but the removal is not as rapid as that seen in the hunter-gatherers of the Levant.

The mean anisotropic value for the sample from England is 0.0044. Molars that have more anisotropic surfaces (and are dominated by frequent scratches orientated mainly in the same direction) should reflect the consumption of tough foods. High epLsar values can also indicate a more consistent rather than varied jaw movement during chewing.
Like the hunter-gatherers (Mahoney 2006b), the English sample is characterized by a greater percentage of scratches compared to dental pits. However, the mean epLsar value of 0.0044 is slightly higher compared to the mean value of 0.0038 for the hunter-gatherers (Schmidt *et al.* 2011). This comparison indicates that the wear features from the English sample are relatively more similar in orientation. Therefore, it is likely that the foods consumed by this English sample were as tough as those consumed by the hunter-gatherers, but not as hard or abrasive.

Overall, the British sample appears to indicate the consumption of foods lying in between the extremes of a diet based upon heavily processed soft foods, and a diet that was based solely on wild foods or that introduced large amounts of contaminants into the diet.

Regional comparison
Even though only one microwear variable differs significantly between the samples from Chalcolithic–Early Bronze Age Scotland and England, there is a consistent trend in the data. Dental pits are more frequent, and pits and scratches are wider, on the molars from England compared to Scotland (Figure 7.1).

When sub-divided into the regions, it is apparent that the variation in this feature is largely due to geographical differences between certain areas. Teeth of individuals buried in the south and central regions of England (Location Groups 9 and 10), as well as the Peak District (Location Group 4), have consistently larger microwear features and more frequent dental pits compared to the more northern regions (Yorkshire and Scotland: Location Groups 1–3). This trend is visible not only when all of the archaeological periods are combined (Table 7.5), but also when only the Chalcolithic–Early Bronze Age samples are included (Table 7.6). The single sample from Kent (Location Group 7) also follows the southern trend and shows more frequent pits and wider scratches compared to the more northern regions. Frequent pits and large microwear features are associated with harder diets. In contrast, the more frequent scratches and smaller microwear features in the north are associated with a softer but still abrasive diet.

These differing microwear patterns may reflect differences in plant food consumption. The more abrasive diet indicated by the samples from the north may be due to a relatively greater dietary emphasis on plant foods, either through increased consumption or through contaminants introduced during preparation. In contrast, the harder diet consumed in southern England may be due in part to an environmental contaminant. Samples from southern England were retrieved from a chalk matrix but then so were those from East Yorkshire. Chalk contains silica particles that are harder than tooth enamel. However, if this were to have been a microwear causal agent, the results should be similar for southern England and East Yorkshire – which they are not. Moreover, the effect was not great compared to the samples from central England and the Peak District.

The samples from central England and the Peak District were not from a chalk matrix, yet they also have a microwear pattern that correlates with a relatively hard diet. Furthermore, for the Chalcolithic–Early Bronze Age period, the Peak District samples had the highest proportion of dental pits, greater even than the samples from southernmost England, suggesting a hard diet. This latter pattern is also evident in the dental texture data. The mean Tfv value of 29,367 for the sample from the Peak District is greater than the mean value of 19,778 from southern England. The higher value indicates that, on average, microwear had removed more enamel from the molars of those buried in the Peak District.

At first glance it is unclear how to interpret the microwear differences between the Peak District (Derbyshire and Staffordshire) samples and those from nearby Yorkshire, given the proximity of these regions. Pit size and frequency were significantly greater in the Peak District compared to Yorkshire. This difference is not explained by variation in the age profile of each group (see below), given that the majority of the adults from the Peak District were young adults. The sex of the individuals (see below) may account for some of the microwear size differences, as the majority of the sampled individuals from the Peak District were males, unlike the sample from Yorkshire where there were equal numbers of males and females. Alternatively, the different patterns may reflect the broad division in diet argued above, whereby the samples from north of Derbyshire, including Yorkshire, were characterized by more frequent scratches and narrower pits, and south of this area including the Peak District is characterized by more frequent and wider pits (Figure 7.1).

Overall, while the microwear suggests a great degree of overlap between the regions, the north had a relatively softer and more abrasive diet that is consistent with a greater dietary emphasis on plant foods (and their contaminants). The south had a relatively harder diet, which reflects the consumption of foods that required greater compressive forces, such as seeds or seasonally available nuts.

Age, sex and vessel type association of Chalcolithic-Early Bronze Age individuals

Microwear frequency and size increased with age, though not significantly so. This is reflected by changes in textural fill volume, though not in the single oldest adult. Microwear reflects diet several weeks before death so older adults may not necessarily be expected to have higher values; in other words, progressive removal of enamel with age should not greatly influence the values.

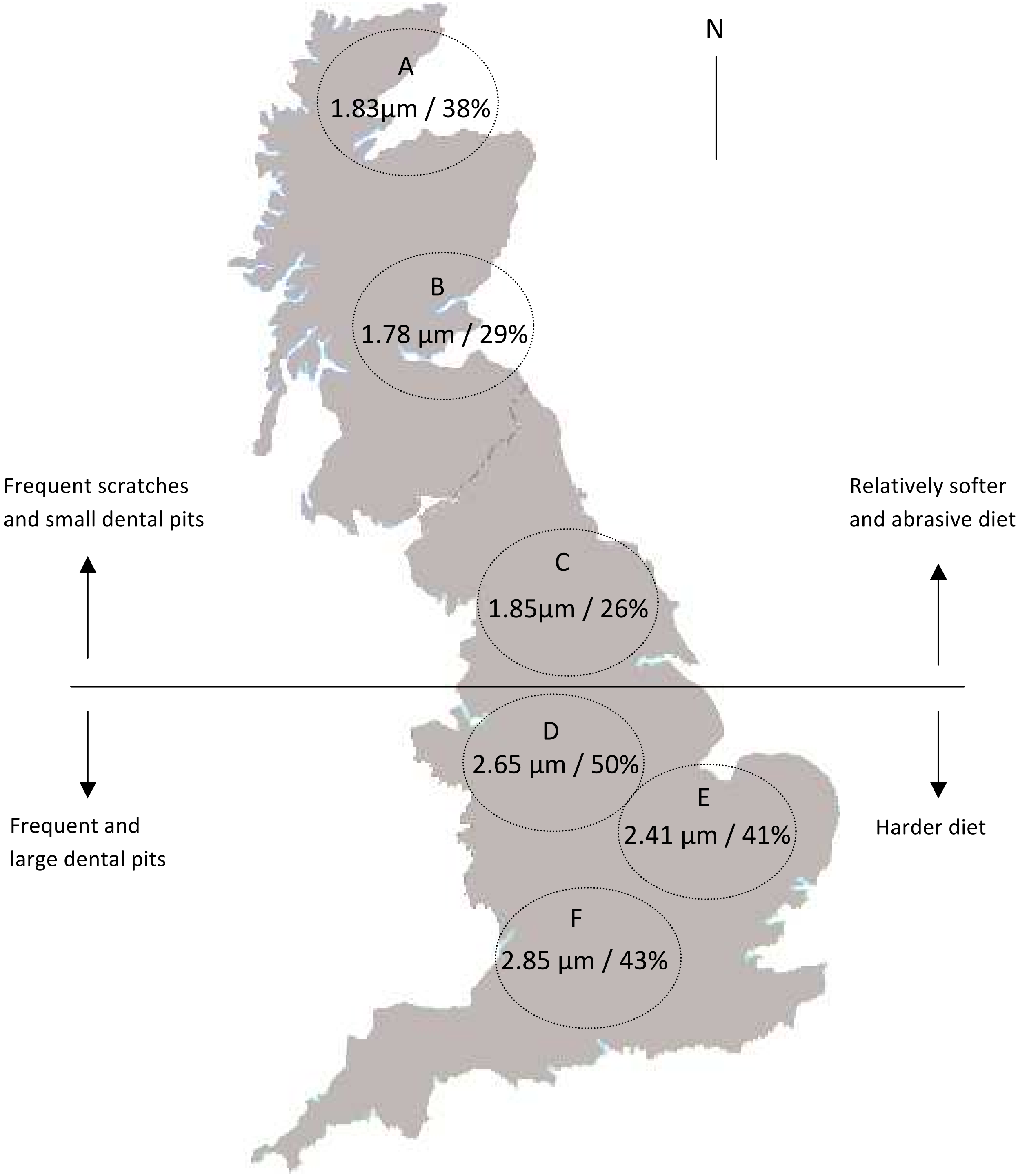
Individuals buried with Food Vessels during the Early Bronze Age have smaller scratches, and smaller and more frequent pits compared to either the Beaker-associated individuals or those buried without a vessel, though the difference is not significant. This may indicate that those buried with a Food Vessel consumed a slightly softer diet, or smaller abrasives. It is difficult to be more certain, because the texture data do not follow this pattern, though sample sizes are very small when sub-divided by vessel type.

Pit size also differs between males and females, indicating at first glance that males might have had a harder diet. However, this finding is not confirmed by scratch width, which is larger in females. A similar situation is present in the texture data, with higher Tfv but lower epLsar values in females compared to males.

Conclusion

When compared to a range of modern human populations with different subsistence strategies, the British Chalcolithic–Early Bronze Age microwear results lie in between the dietary extremes of heavily processed soft foods, and those that are completely wild or that introduce large amounts of contaminants into the diet. When the microwear is compared between regions across Britain, there is great degree of overlap between the regions. Nevertheless, there are some consistent differences in the physical properties of the foods consumed by those in the more northerly regions, compared to those buried in the south. Samples from the Peak District, central and southern England are characterized by frequent and large dental pits, suggesting a relatively hard diet. Microwear from the more northern regions – Yorkshire and Scotland – is characterized by relatively frequent scratches and smaller dental pits, suggesting a softer but still abrasive diet. The age of an individual, their sex, and the vessel with which they were buried, exert a slight but not significant influence on both the microwear and texture patterns.

Fig 1. Map of Scotland and England showing Bronze Age microwear values for regions[1]



[1]Microwear values are for pit width (first figure in µm) and frequency (second figure in %). A = Scotland north east (Aberdeenshire, Angus, Inverness-shire, Caithness); B= Scotland south east (Lanarkshire, East and West Lothian, Fife). C = England (Yorkshire); D = England Peak District (Derbyshire and Staffordshire); E= Central England (Buckinghamshire and Cambridgeshire); F = Southern England (Wiltshire).

Fig 2. Representative 2D micrograph of large dental pits, a ‘hard diet’’

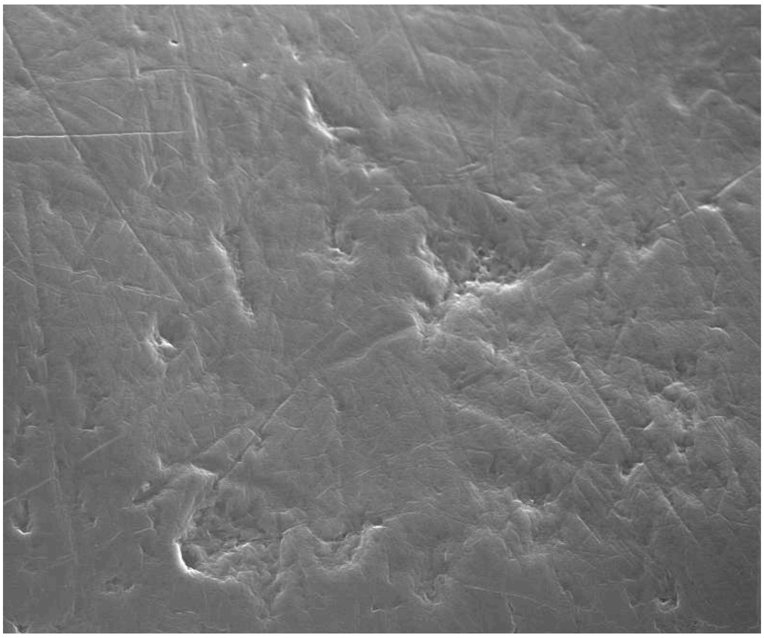


Fig 3. Representative 2D micrograph of no pits but frequent scratches, an ‘abrasive diet’

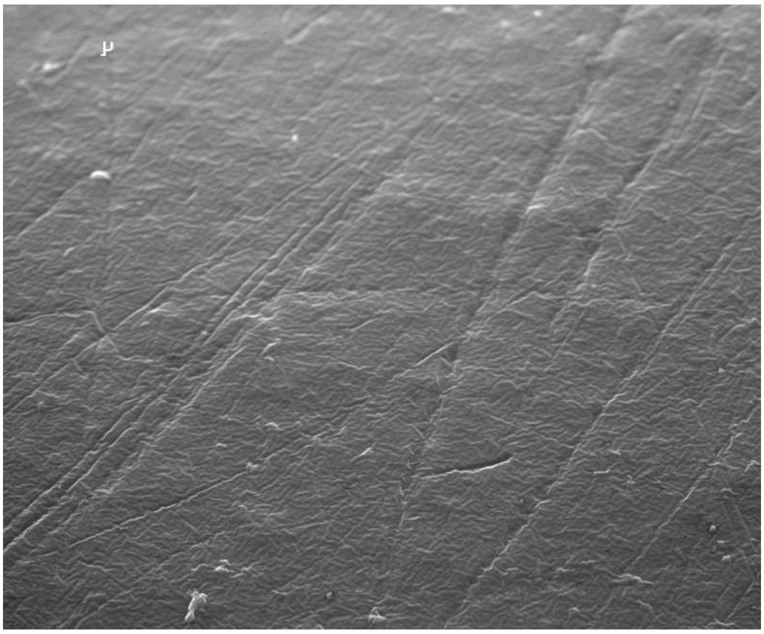


Fig 4. Plot of the discriminant function analysis

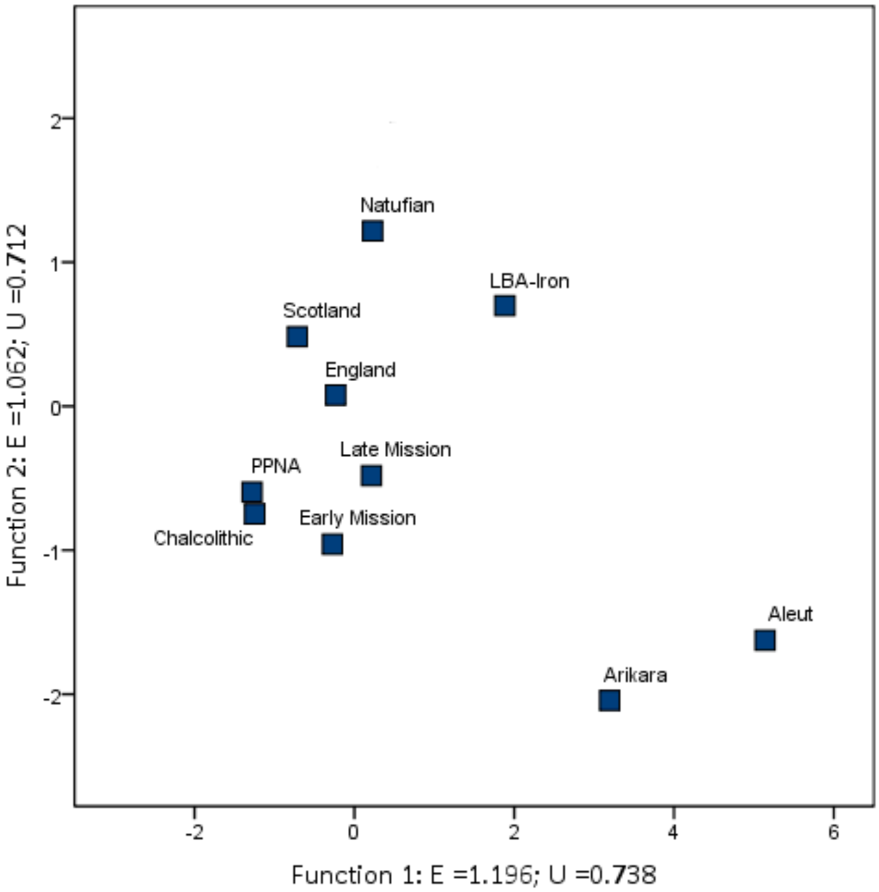


Fig.5. Dental texture image showing a 3D molar surface representation

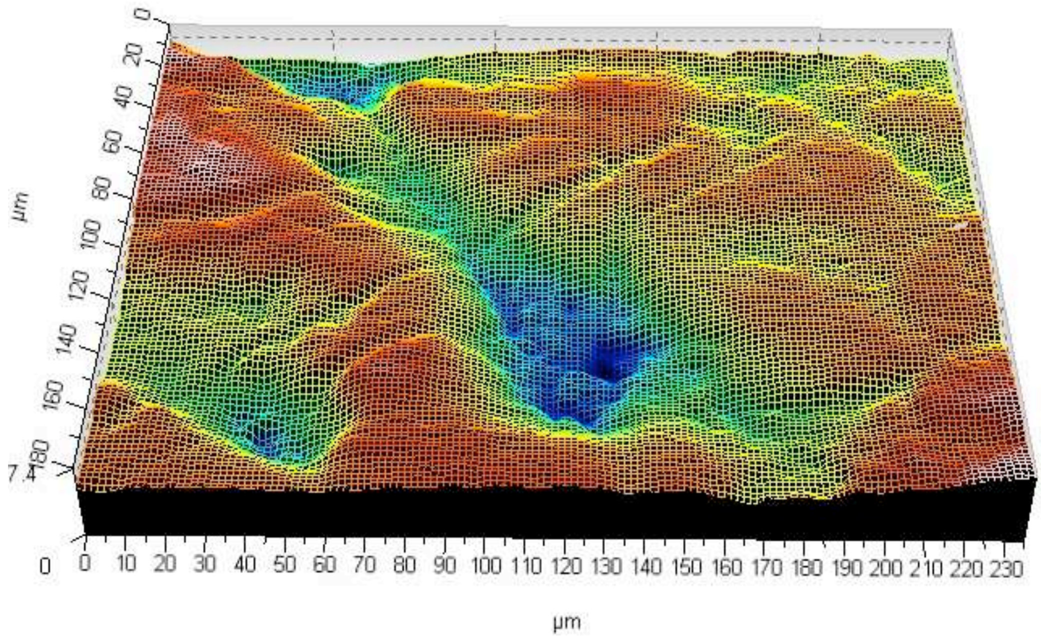


Table 1. Mean microwear measurements for England, Scotland, and Wales (all periods combined)

		Pit				Scratch	
		%		width		width	
	n	X	sd	X	sd	X	sd
England	33	34.45	19.38	2.19	0.87	1.18	0.18
Scotland	17	31.81	21.13	1.82	0.49	1.20	0.23
Wales	2	25.00	5.66	1.98	0.48	1.22	0.06

Table 2. Mean microwear measurements for Bronze Age England and Scotland

		Pit				Scratch	
		%		width		width	
	n	X	sd	X	sd	X	sd
England	20	38.15	19.72	2.33	0.87	1.22	0.17
Scotland	14	34.89	21.92	1.81	0.53	1.18	0.19

Table 3. Mean microwear measurements subdivided by region (all periods combined) and grouped according to relative frequency and size. Yellow = relatively low; blue =relatively high. Also see Fig 1.

		Pit				Scratch	
		%		width		width	
	n	X	sd	X	sd	X	sd
Scotland NE	10	35.62	18.60	1.84	0.60	1.20	0.22
Scotland SE	7	26.36	24.74	1.78	0.33	1.18	0.26
Yorkshire	15	22.92	16.02	1.74	0.69	1.08	0.14
Wales	2	25.00	5.66	1.98	0.48	1.22	0.57
Peak District	7	39.86	15.44	2.35	0.39	1.18	0.15
Central England	3	45.33	21.36	2.71	0.71	1.26	0.02
South England	7	45.00	18.00	2.77	1.24	1.27	0.16
Kent	1	63.00	-	1.94	-	1.63	-

Table 4. Mean microwear measurements subdivided by region (Bronze Age only), and grouped according to relative frequency and size. Yellow = relatively low; blue =relatively high.

		Pit				Scratch	
		%		width		width	
	n	X	sd	X	sd	X	sd
Scotland NE	9	38.00	18.04	1.83	0.63	1.16	0.19
Scotland SE	5	29.29	29.14	1.78	0.35	1.20	0.21
Yorkshire	8	25.88	18.03	1.85	0.37	1.10	0.08
Wales	1	21.00	-	1.64	-	1.26	-
Peak District	3	50.33	24.08	2.65	0.45	1.23	0.17
Central England	2	41.00	28.28	2.41	0.70	1.25	0.01
South England	6	43.33	19.11	2.85	1.34	1.28	0.17
Kent	1	63.00	-	1.94	-	1.63	-

Table 5. Mean microwear and texture values subdivided by vessel type, age and sex (Bronze Age only)

		Pit				Scratch	
		%		Width		Width	
	n	X	sd	X	sd	X	sd
Beaker	18	36.30	18.48	2.17	0.84	1.18	0.17
Food Vessel	5	42.88	28.93	1.80	0.33	1.10	0.14
None	12	33.72	22.58	2.14	0.79	1.29	0.17
Young adult (18-24)	11	29.86	17.83	1.97	0.62	1.15	0.14
Mid adult (25-44)	21	37.12	19.88	2.10	0.65	1.22	0.19
Older adult (45+)	2	57.63	30.08	1.53	0.56	1.22	0.27
Male[1]	20	38.67	18.19	2.36	0.90	1.19	0.16
Female	9	35.61	26.17	1.67	0.40	1.28	0.20

Table 6. Mean texture values subdivided by vessel type, age, sex, and region (all periods combined)

		Tfv		epLsar	
	n	X	sd	X	sd
All	12	29,174	14,269	0.004442	0.00260
Sub adult	3	24,800	10,969	0.005366	0.003098
Young adult (18-24)	3	26,109	23,628	0.002666	0.003147
Mid adult (25-44)	5	35,360	11,528	0.004760	0.002347
Older adult (45+)	1	20,569	-	0.005400	-
Female	3	35,796	11,024	0.003167	0.002631
Male	6	26,143	15,445	0.004250	0.002848
Beaker	6	23,416	15,442	0.004450	0.002968
Food Vessel	3	35,232	12,569	0.005969	0.001861
None	3	34,633	12,906	0.002900	0.002170
Peak District	5	27,762	16,821	0.005100	0.002623
South England	4	23,986	9,103	0.004225	0.003408