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EXPLORING LOW-MAGNIFICATION DENTAL MICROWEAR OF DOMESTIC UNGULATES: QUALITATIVE OBSERVATIONS TO INFER PALAEODIETS

-Sergio JIMÉNEZ-MANCHÓN (Corresponding author) (sergiojimenezmanchon@gmail.com)

Archéologie des Sociétés Méditerranéennes, UMR 5140, University Paul-Valéry, CNRS, MCC, F-34000, Montpellier, France

LabEx ARCHIMEDE program IA- ANR-11-LABX-0032-01, Montpellier, France

-Émilie BLAISE (emilie.blaise@gmail.com)

Archéologie des Sociétés Méditerranéennes, UMR 5140, University Paul-Valéry, CNRS, MCC, F-34000, Montpellier, France

-Armelle GARDEISEN (armelle.gardeisen@cnrs.fr)

Archéologie des Sociétés Méditerranéennes, UMR 5140, University Paul-Valéry, CNRS, MCC, F-34000, Montpellier, France

LabEx ARCHIMEDE program IA- ANR-11-LABX-0032-01, Montpellier, France

1 **Abstract**

2

3 Low-Magnification Dental Microwear Analysis (LMDA) has been widely applied to reconstruct
4 the palaeodiet of wild ungulates. Quantitative observations of the microscopic scratches and pits
5 on the surfaces of the dental enamel of these species allow to distinguish different diets. LMDA
6 has more recently also served to shed light on the palaeodiets of domestic ungulates such as
7 caprines. This technique, however, has not been widely applied to domestic ungulates. In fact,
8 the findings of a recent experimental study indicate that the quantification of pits and scratches
9 affecting the dental enamel of two groups of ewes do not allow to discriminate between feeding
10 in rangelands and grasslands. The current study therefore explores the potential of a number of
11 different qualitative observations (e.g. presence/absence of surface damage or furrows) to
12 identify the diet of the aforementioned group of ewes. Despite the fact that the results are prone
13 to intraobserver error, they nonetheless indicate that certain variables can serve to discern
14 palaeodiets. The model gleaned from the extant ewes was then applied to archaeological
15 material of caprines from La Ramasse and *Lattara*, two Iron Age sites in southeastern France.
16 The preliminary results indicate disparities of the type of dental microwear of caprines from one
17 site to another, differences that could derive from different feeding patterns stemming from
18 dissimilar environmental conditions or different strategies employed by herders.

19

20 Keywords: caprine palaeodiet, experimentation, Iron Age, southern France, La Ramasse,

21 *Lattara*

22 1. Introduction

23

24 Low-magnification dental analysis (LMDA) is a tool that has widely served since the 2000s to
25 reconstruct the last feeding of animals before their death (e.g. Teaford and Walker, 1984;
26 Solounias and Semprebon, 2002; Semprebon et al., 2004; Semprebon and Rivals, 2010). Unlike
27 other techniques known since the 1970s such as examining Scanning electron microscope
28 (SEM) images (e.g. Rensberger, 1978; Teaford and Walker, 1984; Mainland and Halstead, 2005;
29 Henton et al., 2017) or the more recent confocal microscopic techniques, as is the case of Dental
30 Microwear Texture Analysis (DMTA) through Scale Sensitive Fractal Analysis (SSFA) and ISO
31 parameters (e.g. Scott et al., 2005, 2006; Merceron et al., 2005; Ungar et al., 2007), LMDA
32 offers the advantage of speed, low cost, and simplicity of interpretation (Solounias and
33 Semprebon, 2002). LMDA involves direct observation through a low-resolution
34 stereomicroscopic (35x) of the micro-features (pits and scratches) caused by food, as well as
35 dust and grit particles, on the occlusal surface of dental enamel. Quantification of the
36 microscopic scratches and pits has served to shed light on the diet of wild ungulates (e.g. Rivals
37 et al., 2012). Grazing, in general, is characterised by a great number of scratches and a moderate
38 number of pits, whereas browsing is evidenced by numerous pits and few scratches (Semprebon
39 and Rivals, 2007).

40

41 The LMDA technique has more recently served in research on the palaeodiets of domestic
42 ungulates, in particular caprines (sheep and goats), and to a lesser extent on bovines (e.g. Rivals
43 et al., 2011; Rieau, 2014; Vaiglova et al., 2014; Gallego et al., 2017; Jiménez-Manchón et al.,
44 2019). This application sheds light on the livestock practices and strategies of herders/farmers
45 that cannot be garnered through traditional archaeozoological approaches. Although most of this
46 type of research has resorted to the same quantitative and reference variables used to observe
47 the dental microwear of wild ungulates (Solounias and Semprebon, 2002), the use of these
48 variables in domestic ungulates from experimental programs is largely untested. Consequently,
49 the capability of these observations to distinguish different diets in domestic ungulates is quite
50 unknown (Rieau, 2014). This question has been addressed in a present-day referential study
51 carried out by Ibáñez et al. (this volume). In it, the application of LMDA techniques to two
52 groups of domestic sheep (Blaise, 2006, 2010; Blaise and Balasse, 2011), respectively grazing
53 in grassland and rangeland during the last month of their life, points to an overlap of the two
54 groups. In other words, the use of these variables did not allow discriminate both groups. This is
55 the reason why we wonder if the use of other variables, like qualitative observations, can be
56 applied to better distinguish different diets in domestic ungulates.

57

58 Prior observations resorting to the SEM technique have concluded that the consumption of
59 different types of feed is not only reflected in the type and scratches and pits, but of other traces
60 gleaned by qualitative observations (e.g. Walker et al., 1978; Puech et al., 1983; Harmon and
61 Rose, 1988; Ryan and Johanson, 1989; Kelley, 1990; Mainland, 1997). The analysis by Walker
62 et al. (1978) of two hyrax specimens characterised respectively by browser and grazer regimes
63 suggests that browsing yields an extremely fine polish to the teeth bringing the underlying
64 structures into relief, whereas grazing yields an intense wear and multiple episodes of abrasion.
65 Mainland (1997), in turn, successfully identified, through SEM images, a distinction between
66 the feeding regimes of domestic sheep by means of the presence/absence of variables such as
67 parallel scratch marks, surface damage and features with sharp/rounded edges. In spite of that,
68 this type of observations has not been explored through LMDA techniques.

69

70 The aim of this study is therefore to explore if qualitative observations of the teeth, based on
71 LMDA, can be applied to distinguish different diets in domestic caprines. A second purpose is,
72 if the answer is affirmative, to determine which observations contribute most in the model. The
73 analysis is conducted on the same sheep from a present-day pilot experimental program used by
74 Ibáñez et al. (this volume). Moreover, the model gleaned from this experimental program is
75 applied to the reconstruction of palaeodiets of archaeological domestic caprines (sheep and

76 goats) such as those from La Ramasse and *Lattara*, two Iron Age sites from the Mediterranean
77 area of France.

78

79 2. Materials and methods

80

81 2.1 Extant comparative material

82 The analysis was carried out on the right hemimandibles of 35 different ewes (*Ovis aries*) of the
83 “Préalpes du Sud” breed from an experimental research program developed by É. Blaise
84 (Blaise, 2006, 2010; Blaise and Balasse, 2011). The sheep, products of an extensive breeding
85 system, are from the Carmejane farm (Digne-Le Chaffaut, Alpes-de-Haute Provence, France).
86 The sheep, ranging from 1 to 10 years in age, were slaughtered in May 2004. During the last
87 month of their life, 18 individuals (Group A) grazed in rangelands while the other 17 (Group B)
88 grazed in grasslands.

89

90 The rangeland areas of Group A comprised a mixture of monocot (50%) and dicot plants (50%)
91 made up of black pine, shrubs (ash, shadbush and dogwood), oak and grasses (brachypod,
92 bromegrass fescues, Montpellier aphylland, sedge and small legumes). The grasslands of Group
93 B especially, mostly meadows, consisted for the most part of monocot plans (<80%), a blend of
94 grasses (cocksfoot), legumes (trefoil, sainfoin, clover) and alfalfa.

95

96 2.2 Archaeological material

97 The archaeological analyses were carried out on 12 hemimandibles or low isolated molars from
98 the sites of La Ramasse and *Lattara*, two Iron Age settlements in the Hérault, a department in
99 the south of France (Fig. 1). The criteria advanced by Halstead et al. (2002) and Helmer (2000)
100 served to distinguish the teeth or hemimandibles of the sheep (*Ovis aries*) from the goats (*Capra*
101 *hircus*). When this distinction was not possible, the samples were classified simply as caprines
102 (Caprinae). Thus, the final archaeological sampling consisted of eight sheep (*Ovis aries*), three
103 goats (*Capra hircus*) and one caprine (Caprinae), all adults whose ages were determined
104 following the criteria of Payne (1973).

105

106 La Ramasse (Clermont-l’Hérault, Hérault) is an Iron Age *oppidum* perched on a small hill (257
107 m.a.s.l.) in the Hérault River Valley. The settlement, occupied from 530 BC to 400 AD, is
108 respectively 30 km north of the Greek colony of *Agathé* (Agde) and 30 km northwest of
109 *Lattara*, sites on the Mediterranean coastline. The seven samples (four sheep, two goats and one
110 caprine), from different stratigraphic units of Dwelling 6 (450-350 BC) are linked to domestic
111 consumption (Garcia, 1992, 1993).

112

113 The site of *Lattara* (Lattes, Hérault) was, by contrast, a port city set along a lagoon in the Lez
114 delta that saw a long continuous occupation ranging from the 6th century BC to the 3rd century
115 AD. Due to its strategic location, it served as a key centre of trade between the indigenous
116 populations and Etruscan and Greek merchants. The five samples (four sheep and one caprine)
117 come from several stratigraphic units of Zone 1 (Py, 1995; Gailledrat, 2014) dated between 450-
118 325 BC.

119

120 2.3 Moulding and casting process

121

122 The moulds and casts serving to make replicas of the teeth for the study of both the present-day
123 and archaeological samples followed the protocol described by Solounias and Semprebon
124 (2002) and Semprebon et al. (2004). The process began with a thorough cleaning of their
125 occlusal surfaces with acetone and ethanol (96%) to eliminate preservation adhesives and dust
126 particles. The mould was fashioned by first applying a layer of high precision polyvinyl
127 siloxane dental impression material Provil Novo Light C.D.2 (Heraeus Kulzer) to the teeth. This
128 first level was then reinforced by a putty (Blue Eco, Detax). The mould, after setting, was then
129 filled with a transparent epoxy resin cast (C.P Chemistry CPOX P 1069/A - CPEN 1585/B)
130 produce the replica (Fig. 2). The process was carried out in the CNRS laboratory UMR5140

131 *Archéologie des Sociétés Méditerranéennes* (ASM-University Paul-Valéry Montpellier 3) in
132 Montpellier (France).

133

134 2.4 Dental microwear analysis

135

136 The analyses were conducted on the anterior or posterior facet of the second lower molar
137 protoconid (M2) of each right hemimandible. In the case of the younger sheep the analyses were
138 carried out on the lower first molar (M1). All teeth were scrutinised by a single experienced
139 observer (SJM). A total of 11 variables, related to the type of enamel surface and scratches, were
140 taken into account while viewing the teeth with a Leica MZ16 stereomicroscope at a
141 magnification of either 35x or 60x (depending on the variable). Any form of pit was not used in
142 the analysis. The origin of these different variables derives either from prior studies (Mainland,
143 1997; Solounias and Semperbon, 2002) or is original to the current study. The variables
144 observed at 35x made use of an ocular grid measuring 0.16 mm² (Table 1). All samples (extant
145 and archaeological material) with badly preserved enamel (features with unusual morphology
146 and size or fresh features made during collecting process) were removed from the analysis
147 (King et al. 1999). Also, modifications stemming from the casting process such as air bubbles
148 were discarded.

149

150 The variables correspond to the presence/absence of a total of 11 features on the enamel
151 surfaces. The variables analysed at 35x are scratches with an Anterior-Posterior Orientation
152 (APO, Fig. 3.A), scratches with a Buccal-Lingual Orientation (BLO, Fig. 3.B), more than four
153 Crossed Scratches (XS, Fig. 3C), Empty Areas (E, Fig. 3D) describes as surfaces devoid of
154 microwear corresponding to a ninth surface of the grid (0.017 mm²), Parallel Scratches (PS, Fig.
155 3.E) and Non-Parallel Scratches (NPS, Fig. 3.F), (E), and Gouges (G). The variables analysed at
156 60x correspond to the presence/absence of an Enamel Edge (EE, Fig 4.A and 4.B) (e.g.
157 notches), Furrows (F, Fig. 4.C), Surface Damage (SD, Fig. 4.D), Gouges (G, Fig. 4E) while
158 Rough Surface Texture (RST, Fig. 4.F and 4.G) relates to the presence/absence of a rough
159 and/or porous surface visible at either 35x or 60x. Figures 3 and 4 correspond to
160 microphotographs that illustrated each of the variables. Table 1 summarises and offers a brief
161 description of each.

162

163 The set was randomly re-analysed twice in order to determine the general level of intraobserver
164 error as well as to know which variables have a higher error rate. This was carried out by
165 calculating the percentage of cases for each variable where the results concur. The average of
166 the two total percentages is hence the index serving to calculate the intraobserver error.
167 Moreover, the variables most prone to error are discarded for the statistical analysis.

168

169 The descriptions were then followed by the design of a probabilistic and predictive analysis
170 applying a Logistic Regression (LR), an analysis that allows attaining a probabilistic
171 classification of the dichotomous categories (Group A: rangeland and Group B: grassland)
172 based on independent and qualitative variables (predictors). To determine the significance of the
173 model, this study carried out tests to determine the pseudo R-squared Cox & Snell and
174 Nagelkerke values as well as the p-value of the Chi square test attaining significance value of
175 ≤ 0.05 . Hence, individuals in Group A fall into the well-classified category when their value is
176 ≤ 0.4 . Between 0.41 and 0.59 they are considered unclassified, and poorly classified when ≥ 0.6 .
177 Individuals of Group B are well-classified when their value is ≥ 0.4 . Values between 0.41 and
178 0.59 are unclassified while those of ≤ 0.39 are poorly classified. The model obtained was then
179 applied to the archaeological samples to predict the probability, based on the extant comparative
180 database, which each individual could have grazed in either rangelands or grasslands. This
181 analysis was carried out using Statistica v.10 (Addinsoft). The model obtained was then applied
182 to the archaeological samples to predict the probability, according to the extant comparative
183 database, that each individual could have grazed in either rangelands or grasslands.

184

185 This was followed by a Multiple Correspondence Analysis (MCA) so as to visualise the
186 relationship between the data. The MCA was designed based on all data, except variables
187 presenting a high intraobserver error rate and variables that contribute less to the model. The
188 validity of these variables was made through the Cosine2 values. Finally, archaeological
189 samples were introduced as supplementary material in order to visualise their distribution in a
190 second MCA. The analyses were carried out using “FactoMineR” (Husson, 2008) and
191 “Factoextra” (Kassambara and Mundt, 2017) packages in R statistical software.

192

193 3. Results

194

195 3.1 Extant material

196

197 This section describes the results of Group A (rangeland grazing) and Group B (grassland
198 grazing) (Supplementary material 1). The dental surfaces of the individuals of Group A (n=18)
199 are characterised by, in descending order, scratches with an Anterior-Posterior Orientation
200 (77.8%), Parallel Scratches (61.1%), scratches with a Buccal-Lingual Orientation (55.6%), Non-
201 Parallel scratches (55.6%) as well as a presence of Furrows (55.6%). The remaining variables,
202 Crossed Scratches (44.4%), Enamel Edges (38.9%), Surface Damage (33.3%), Empty Areas
203 (27.8%) and Gouges (27.8%) are only observed in less than half of the examples. Moreover,
204 about 50% present a Rough Surfaces Texture.

205

206 The dental surfaces of Group B (n=17), in turn, are characterised, in descending order, by
207 scratches with an Anterior-Posterior Orientation (76.5%), Parallel and Non-Parallel scratches
208 (70.6% in both cases), scratches with a Buccal-Lingual Orientation (52.9%) and Empty Areas
209 (52.9%). The remaining variables, Crossed Scratches (41.2%), Gouges (29.4%), Surface
210 Damage (23.5%), Enamel Edges (17.6%) and Furrows (11.8%), are less relevant. Otherwise the
211 surfaces of 47.1% are rough (Table 2).

212

213 When comparing the two, individuals of Group A (rangeland grazing) reveal a greater number
214 of Furrows (F), Surface Damage (SD) and rough enamel edges (EE). Group B (grassland
215 grazing), in turn, is dominated by non-parallel scratches (NPS), Empty Areas (E), and to a lesser
216 extent Parallel Scratches (PS). The percentages of the remaining variables are analogous.

217

218 The modern material of sheep was analysed twice more in order to measure the intraobserver
219 error of both the set and the variables. Of the total of 385 (11 variables multiplied by 35
220 individuals), this second round yielded the respectively 326 and 361 concurrences, values that
221 are tantamount to levels of error of 15.3% and 6.2%. The average of the two percentages
222 equates with an intraobserver error of 10.8%. Observations of the results by variable type (Table
223 3) indicate that the variables with the lowest probability of error are Parallel Scratches (PS) and
224 Surface Damage (SD). By contrast, those with a highest probability of error are Rough Surface
225 Texture (RST) and scratches with Buccal-Lingual Orientation (OBC). These two variables are
226 reclassified correctly in 65% of the cases. As a result of this low percentage, RST and OBC
227 variables are excluded from further statistical analyses.

228

229 3.2 Statistical results

230

231 To obtain the statistical results the study firstly designed a Logistic Regression (LR) for Groups
232 A (rangeland) and B (grassland) based on qualitative variables. The resulting model is
233 statistically significant as indicated by chi-squared p-value (≤ 0.05) and the R2 values (Table 4).
234 The model presents good classifications of 12 individuals from Group A (66.7%) and 12
235 individuals from Group B (70.6%) (Table 5 and supplementary material 2). This suggests a
236 correct classification of more than two thirds of the set (68.6%). The model did nonetheless
237 incorrectly classify six cases (16.7%), three from Group A and three from Group B, and
238 ambiguously classified five cases (13.8%), three from Group A and two from Group B. The data
239 thus indicate a slightly better classification of individuals of Group B than of Group A
(Supplementary material 2).

240
241 The study then carried out a Multiple Correspondence Analysis (MCA) applying all the
242 qualitative variables, except variables previously excluded due to high intraobserver error. The
243 two main dimensions (1 and 2) of the MCA account for 39.7% of the total inertia. In three of the
244 nine variables (F, XS and G), the Cos2 value is very low (inferior to 0.2) (supplementary
245 material 3). These data indicate that the contribution of these three variables is less important in
246 explaining the variations in the dataset. Subsequently, a second MCA was carried out using the
247 rest of variables (PS, NPS, E, APO, SD and EE) that contribute more significantly (Cos2 value
248 is superior to 0.3). This second case revealed that dimensions 1 and 2 account for 57.8% of the
249 total inertia. The variables that contribute most to the model are, in decreasing order, NPS, PS,
250 EE, SD, APO and E. Thus, group A reveals positive values in Dimension 1 and 2. Group B, in
251 turn, reveals negative values in Dimension 1 and 2. However, the vertical axis (Dimension 2)
252 explains the main differences between both groups. The variables that contribute most in the
253 Dimension 2 are PS, NPS, EE and SD. Plotting the classification variables in the MCA reveals
254 the presence of Non-Parallel Scratches and scratches with an Anterior-Posterior Orientation,
255 together with the absence of Empty, Enamel Edges, Surface Edges and Parallel Scratches in the
256 negative part of the axis, like Group B. In contrast, the presence of Surface Damage and Parallel
257 Scratches, together with the absence of Empty, Non-Parallel Scratches, and scratches with an
258 Anterior-Posterior Orientation plot in the positive part of the axis, like Group A.

259
260 The analyses of archaeological samples were carried out on the occlusal surfaces of seven
261 caprines (four sheep, two goats and one caprine) from La Ramasse and five caprines (four sheep
262 and one caprine) from *Lattara* (Supplementary material 3). No sample had to be discarded for
263 taphonomic reasons. The tooth enamel of the assemblage of the first site is characterised by
264 more rough/porous Surface Texture (RST), more Parallel Scratches (PS), a higher percentage of
265 scratches with a Buccal-Lingual Orientation (BLO) and the absence of Empty Areas (E). The
266 rest of observations were identified in less than half of the samples. At *Lattara* the dental
267 enamels are characterised by less rough/porous Surface Texture (RST), less Parallel Scratches
268 (PS) and more Non-Parallel Scratches (NPS). Noteworthy is also a greater presence of Empty
269 Areas (E), scratches with an Anterior-Posterior Orientation (APO), Furrows (F) and Crossed
270 Scratches (XS) (Table 5 and Fig. 6).

271
272 The classification of individuals based on the predictive model garnered from the Logistic
273 Regression (see section 3.2) placed four individuals from La Ramasse in Group A (rangeland),
274 one in Group B (grassland) and one as unclassified (Table 6). Three individuals from *Lattara*
275 are placed in Group B (grassland) and two in Group A (rangeland). This implies that 71.4% of
276 La Ramasse caprines reveal a palaeodiet compatible with rangelands (Group A) while 28.6% are
277 compatible with grasslands (Group B). An opposite trend is observed for the individuals from
278 *Lattara* as 60% of the caprines are linked to grasslands (Group B) while 40% are linked to
279 rangelands (Group A). Subsequently, the results of the analyses of dental microwear of the
280 caprines from La Ramasse and *Lattara* were introduced as supplementary material in the
281 Multiple Correspondence Analysis (MCA) (Fig. 7). The results were correlated with those of the
282 Logistic Regression (LR). Hence, five individuals from La Ramasse plot in the positive part of
283 the vertical axis (closer to group A) and two in the part negative (closer to group B). Three
284 caprines from *Lattara*, in turn, are located in the positive part (closer to group A) and two in the
285 negative part (closer to group B). These data could indicate a predominance of caprines grazing
286 on rangeland areas in La Ramasse and a more variable diet in *Lattara*.

287 288 4. Discussion

289 This study focuses on the dental microwear of 35 ewes (*Ovis aries*) from a present-day pilot
290 experimental program (Blaise, 2006, 2010; Blaise and Balasse, 2011). During the last month of
291 their life, 18 fed in rangelands (mixture of dicot and monocot plants) and 17 in grasslands
292 (mostly monocot plants). The supposition is that the different means of feeding of these two
293 groups during their last month of life should be reflected by different patterns of dental
294 microwear (e.g. Teaford and Walker, 1984; Grine, 1986; Teaford and Oyen, 1989). The findings

295 indicate that identification and quantification of the pits and scratches by means of LMDA, a
296 technique serving to distinguish browser and grazer palaeodiets among wild ungulates, does not
297 serve to distinguish between rangeland and grassland feeding among domestic sheep of the
298 referential experimental program (Ibáñez et al., this volume). It is for this reason that the current
299 study chose to delve into the question of whether qualitative variables obtained through LMDA
300 techniques can serve - or not - to distinguish these two types of diets. To carry this out the
301 current analysis resorted to 11 variables that are either original to the current study or gleaned
302 from previous research (Mainland, 1997; Solounias and Semprebon, 2002). This is the first time
303 that this type of work is applied through LMDA techniques.

304
305 The results from the Logistic Regression (LR) model show significant differences between ewes
306 grazing on rangeland and grassland areas. Most specifically, the model indicates a good
307 discrimination of more than two thirds of the individuals, nearly 70%. Hence, a relationship can
308 be established between diet and qualitative observations. One of the interests of this study is to
309 determine which observations contribute most in the model and which variables are more prone
310 to intraobserver error. Firstly, Rough Surface Texture and scratch marks with a Buccal-Lingual
311 Orientation present a high degree of intraobserver error. It means that there is a high probability
312 that these two variables introduce errors in the dataset. Consequently, these variables are not
313 suitable for further analyses. Secondly, the MCA analysis reveals the low contribution of three
314 variables: Crossed Scratches, Furrows and Gouges. Conversely, the variables that participate
315 stronger are, in decreasing order, Non-Parallel Scratches, Parallel Scratches, Enamel Edges,
316 Surface Damage, scratches with Anterior-Posterior Orientation and Empty. Enamel surface of
317 two groups of ewes present different trends. On the one hand, tooth enamel of ewes grazing on
318 rangeland areas is characterised by a higher contribution of the presence of Parallel Scratches, a
319 Surface Damage and Enamel Edge. On the other hand, enamel tooth of ewes grazing on
320 grassland areas is characterised by a higher contribution of the presence of Non-Parallel
321 Scratches, scratches with an Anterior-Posterior Orientation and Empty. Thus, it can be assumed
322 that differences between diets composed by a mixture of monocot and dicot plants (rangeland
323 areas) and diets composed mostly by monocot plants (grassland areas) can be identified through
324 qualitative observations, as presented in previous studies (e.g. Mainland, 1997).

325
326 It is compelling that, as in the case of the results obtained by DMTA (ISO parameters), Group B
327 (grassland) has a classification that is slightly better than Group A (rangeland) (Ibáñez et al., this
328 volume). This could be explained by the different turnover rates of the formation of microwear
329 features. More precisely, grazer diets generate microwear features quicker than browser diets
330 (Schulz et al. 2013; Teaford et al. 2017; Winkler et al. 2019). Both groups of ewes from
331 experimental program had a similar feeding during their life. It was in the last month where
332 ewes from group A fed on rangeland areas and ewes from group B on grassland areas.
333 Consequently, the diet of ewes from group B would generate a more rapid accumulation of
334 traces on tooth enamel due to the presence in grassland of a greater proportion of phytoliths and
335 abrasive elements than the diet of ewes from group A (rangeland areas). Another explanation
336 could be found by the higher diversity of plants present in rangeland areas. It would allow ewes
337 to choose different type of plants in the same rangeland areas (e.g. Schulz et al. 2013;
338 Ramdarshan et al. 2016; Merceron et al. 2017).

339 Both low-magnification techniques and qualitative variables gleaned from SEM images have
340 been criticised for lack of objectivity and intraobserver error (e.g. Grine et al., 2002; Galbany et
341 al., 2005; Purnell et al., 2006; Scott et al., 2006; Mihlbachler et al., 2012; DeSantis et al., 2013).
342 Given this situation, this study carried out two intraobserver analyses whose findings point to a
343 correlation average of 89.2%. This denotes that despite being carried out by an experienced
344 observer, one in ten observations did not match. This equates with a high degree of error when
345 characterising the features visible on the enamel of teeth, especially in the case of scratch marks
346 with a buccal-lingual orientation. The observations advanced in this study that offer new criteria
347 to differentiate the diets of domestic caprines are nonetheless complements to those already in
348 existence, including confocal techniques. Hence new analyses and methodological approaches
349 linked to experimental programmes could also serve to define and pinpoint the criteria.

350

351 The predictive model obtained through a Logistic Regression (LR) analysis, as well as the
352 results gleaned from MCA, then served to determine the diet of the archaeological domestic
353 sheep and goats from the Iron Age sites of La Ramasse and *Lattara*. Due to their low number, it
354 has not been possible to analyse and compare the diet between sheep and goats. Thus, despite
355 this low number, the results appear to indicate the predominance at La Ramasse of a diet in
356 rangelands (mixture of monocot and dicot plants) while the caprines from *Lattara* suggest a
357 mixed diet dominated by grazing in grasslands (predominance of monocot plants). Several
358 hypotheses could explain that. Firstly, these data could indicate different, or more varied,
359 strategies of feeding employed by herders and farmers in both sites. Secondly, these findings
360 can be correlated by each site's different environmental conditions. *Lattara* is along the coastal
361 delta dominated by wetland and lagoons (e.g. Began et al., 2010). La Ramasse is, in turn, an
362 inland settlement implanted along the southern edge of the Massif Central. Consequently, the
363 presence of more woodland areas in La Ramasse can be related to rangeland diets. In contrast, a
364 wet environment in *Lattara* can be compatible with a more grassland diet. A greater tendency of
365 diets rich in grass when caprines graze in wet areas has already been observed at the Iron Age
366 site of Ullastret (550-450 BC and 450-325 BC) (Jiménez-Manchón et al. 2019b). One important
367 consideration that must be taken into account is that dental microwear reflects the last feedings
368 traits in the animal life. This can imply, therefore, seasonal and food variations. This is why
369 techniques and methods to estimate the season of death of caprines will be required in future
370 research.

371

372 **5. Conclusions**

373

374 This study reveals the potential of qualitative variables in identifying palaeodiets of domestic
375 ungulates through low-magnification dental analysis. Observations of the presence/absence of
376 different features on the surface of the enamel of teeth allowed to distinguish two different types
377 of diets (grazing in rangeland and grassland) among more than two-thirds of the present-day
378 referential group of domestic sheep. Contrary to the quantification of scratches and pits, this
379 approach more clearly distinguishes these diets among domestic caprines. The model obtained
380 from the referential assemblage of present-day sheep was then applied to the teeth of sheep and
381 goats from the Iron Age sites of *Lattara* and La Ramasse. The results point to a predominance of
382 the rangeland diet (mixture of dicot and monocot plants) for the samples from La Ramasse and
383 grasslands grazing (predominance of monocot plants) for those from *Lattara*. This scenario
384 could be compatible with palaeoenvironmental data which suggest wetter environment for
385 *Lattara* and a more forested setting for La Ramasse. However, we have to take into account
386 other variables affecting dental microwear such as the season of death, the intra-specific
387 variability (males and females for example) or the inter-specific variability (sheep vs goats).
388 This is the reason why more samples from these two sites, and from other Iron Age sites from
389 western Mediterranean area, will be required to validate these hypotheses in future research.

390

391 Overall, this paper demonstrates how the application of other techniques, in this case qualitative
392 observations, can help to determine the palaeodiet of domestic ungulates. Nevertheless, the
393 current study does not suggest that this approach replace quantitative variables (identification
394 and quantification of pits and scratches), but that it serves as complement to other methods,
395 including confocal techniques.

396

397

398

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400

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626 **Figures**

627

628 Figure 1. Map of the Iron Age sites of La Ramasse and *Lattara* in the south of France.

629

630 Figure 2. The moulding and casting process of the teeth of a caprine from the site of La
631 Ramasse (scale= 1cm).

632

633 Figure 3. Microphotographs (at 35x) of the variables Scratch Orientation (A and B), Crossed
634 Scratches (C), Empty (D), Parallel Scratches (E) and Non-Parallel Scratches (F). The orientation
635 of the scratch marks A and B is indicated with arrows (scale = 1 mm).

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637 Figure 4. Microphotographs (at 60x) of the variables Empty Edge (A and B), Furrows (C),
638 Surface Damage (D), Gouges (E), and Rough Surface Texture (F and G) (scale = 1 mm).

639

640 Figure 5. Graphic representations of the multiple correspondence analyses (MCA), indicating
641 the total inertia (57.8%). Variable colour scale is based on the squared cosine (Cos2). Higher
642 values indicate that they are better explained by two dimensions (Dim1 and Dim2). RST=
643 Rough Surface Texture, PS= Parallel Scratches, NPS= Non-Parallel Scratches, E= Empty Areas,
644 BLO= Buccal-Lingual Orientation, APO= Anterior-Posterior Orientation, F= Furrow, SD=
645 Surface Damage; EE= Enamel Edge; and G= Gouge.

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648 Figure 6. Microphotographs of the archaeological samples of La Ramasse (left, A-D) and
649 *Lattara* (right, E-H) taken at a magnification of 35x (scale= 1 mm).

650

651 Figure 7. Multiple correspondence analysis (MCA) of the individuals and centroid of Groups A
652 (circle) and B (triangle), together with the archaeological material of La Ramasse (blue) and
653 *Lattara* (yellow), added as supplementary materials to visualise their distribution.

654 **Tables**

655

656 Table 1. Summary of the variables and their abbreviations serving for the analysis. The table is
 657 completed with the amount of magnification, the number of the figure with a photograph and
 658 their description. The values 0 or 1 serve for the statistical analyses.

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Variable	Magnification	Photograph	Description	Bibliography
Enamel Edge (EE)	60x	2.A and 2.B	0= Absence of cracks along the edge. Rounded and smooth edge; 1= Edge with pronounced cracks.	By authors
Anterior-Posterior Orientation (APO)	35x	2.C	1= Presence of scratches with an anterior-posterior orientation. 0= absence.	Adapted from Mainland, 1997
Buccal-Lingual Orientation (BLO)	35x	2.D	1= Presence of scratches with a buccal-lingual orientation. 0= absence.	Adapted from Mainland, 1997
Crossed Scratches (XS)	35x	2.E	1= Presence of more than 4 crossed scratches in an area less than 0.16 mm ² . 0= absence.	Solounias and Semprebon, 2002
Furrows (F)	60x	2.F	1= Presence of deep and long scratches (furrows). 0= absence.	By authors. It can be analogous to hypercoarse scratches (from Solounias and Semprebon, 2002)
Parallel Scratches (PS)	35x	2.G	1= Presence of 2 or more parallel scratches. 0= absence.	Adapted from Mainland, 1997
Non-Parallel Scratches (NPS)	35x	2.H	1= Presence of parallel scratches. 0= absence	Adapted from Mainland, 1997
Empty Areas (E)	35x	3.A	1= Presence of a space devoid of microwear (scratches either pits) corresponding to a surface of 0.017 mm ² calculated by the grid. 0= absence	Adapted from Mainland, 1997
Surface Damage (SD)	60x	3.B	1= Presence or cracks on the surface. 0= absence	Adapted from Mainland, 1997
Rough Surface Texture (RST)	35x and 60x	3.3 and 3.4	0= surface and/or flat. 1= surface steep and porous. Often rough.	Adapted from Mainland, 1997

Gouges (G)	35x	3.5	1= Presence of gouges (large and irregular scars). 0= absence	Solounias and Semprebou, 2002

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Table 2. Percentage of individuals in Group A (rangeland) and B (grassland) revealing Rough Surface Texture (RST), Parallel Scratches (PS), Non-Parallel Scratches (NPS), Empty Areas (E), Buccal-Lingual Orientation (BLO), scratches with an Anterior-Posterior Orientation (APO), Furrows (F), Surface Damage (SD), Enamel Edge (EE) and Gouges (G).

Group	RST	PS	NPS	E	BLO	AP O	F	XS	SD	EE	G
A	50	61.1	55.6	27.8	55.6	77.8	55.6	44.4	33.3	38.9	27.8
B	47.1	70.6	70.6	52.9	52.9	76.5	11.8	41.2	23.5	17.6	29.4

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Table 3. Percentage of cases per variable where the classification is correct: Rough Surface Texture (RST), Parallel Scratches (PS), Non-Parallel Scratches (NPS), Empty Areas (E), Buccal-Lingual scratch Orientation (BLO), scratches with an Anterior-Posterior Orientation (APO), furrows (F), Surface Damage (SD), Enamel Edges with cracks (EE) and Gouges (G).

Variable	RST	PS	NPS	E	BLO	AP O	F	XS	SD	EE	G
% of correct classifications	65.7	97.1	80	82.9	65.7	82.9	82.9	85.7	97.1	91.4	91.4

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Table 4. Indexes and values of the Logistic Regression carried out on the modern caprines.

Index	Value
Maximum Likelihood	14.1384
Likelihood for this model	28.276
Likelihood for this intercept	48.491
Chi squared	20.21479
p Chi squared	0.0166
Degree of freedom	9
R2 Cox & Snell	0.86
R2 Nagelkerke	0.84

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Table 5. Percentage of the extant ewes classified by group according to the Logistic Regression (LR) model (A= rangeland; B= grassland).

Group	Group A	Group B	Unclassified
Group A	12 (66.7%)	3 (16.7%)	3 (16.7%)
Group B	3 (17.6%)	12 (70.6%)	2 (11.8%)

682

683 Table 6. Percentage of individuals from the sites of La Ramasse and *Lattara* whose dental
684 enamel bear Rough Surface Texture (RST), Parallel Scratches (PS), Non-Parallel Scratches
685 (NPS), Empty Areas (E), scratches with a Buccal-Lingual Orientation (OBC), scratches with an
686 Anterior-Posterior Orientation (OAP), Furrows (F), Surface Damage (SD), Enamel Edges with
687 cracks (EE) and Gouges (G).
688

Site	RST	PS	NPS	E	OBC	OAP	F	XS	SD	EE	G
La Ramasse	57.1	71.4	71.4	0	85.6	42.9	42.9	42.9	28.6	42.9	42.9
<i>Lattara</i>	40	60	80	40	80	60	60	40	0	20	20

689 Table 7. Classification of each of the individuals of La Ramasse and *Lattara* according to the
690 probabilistic model (from 0 to 1) of the Logistic Regression (LR) statistical model (A=
691 rangeland; B= grassland).
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Site	Individual	Species	Probability	Classification
La Ramasse	6032-2	<i>Capra hircus</i>	0.640	B
La Ramasse	6007-1	<i>Ovis aries</i>	0.072	A
La Ramasse	6004-1	<i>Ovis aries</i>	0.515	Unclassified
La Ramasse	6034-8	<i>Ovis aries</i>	0.883	B
La Ramasse	6024-1	<i>Ovis aries</i>	0.300	A
La Ramasse	6032-1	Caprinae	0.180	A
La Ramasse	6032-3	<i>Capra hircus</i>	0.256	A
<i>Lattara</i>	53473-8	<i>Ovis aries</i>	0.009	A
<i>Lattara</i>	53473-6	<i>Ovis aries</i>	0.959	B
<i>Lattara</i>	53473-8	<i>Ovis aries</i>	0.826	B
<i>Lattara</i>	53473-15	Caprinae	0.085	A
<i>Lattara</i>	53513-2	<i>Ovis aries</i>	0.842	B



La Ramasse

Montpellier

Lattara

Narbonne

Perpignan

50 km

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Archaeological sample



First layer of (high precision) silicone



Second layer of putty silicone
serving to support the mould



Moulds of teeth filled with epoxy
resin

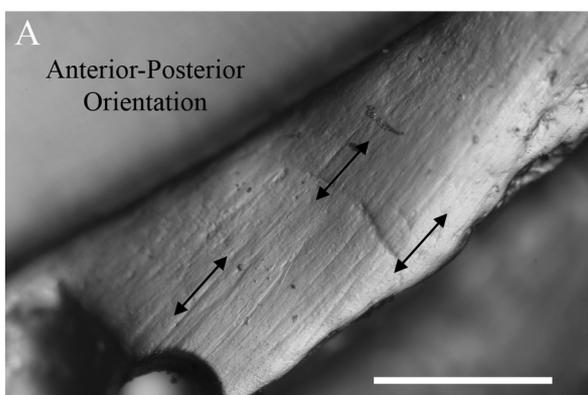


Epoxy resin replica of a teeth
(lower M2)

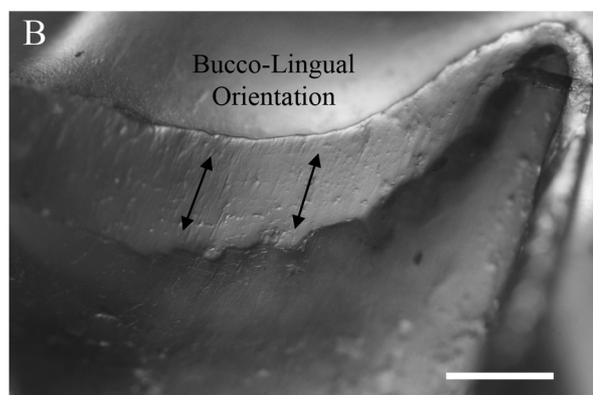


Steremicroscope (Leica MZ 16)
used to make the observations

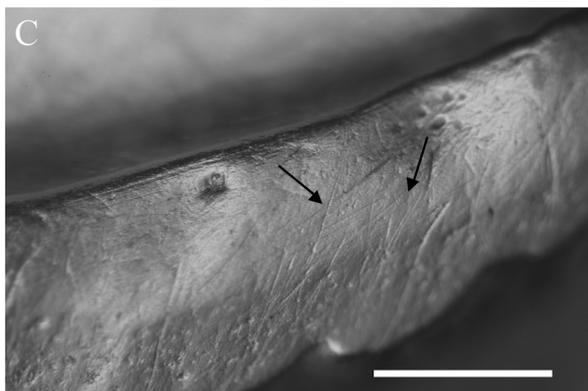
Scratch Orientation



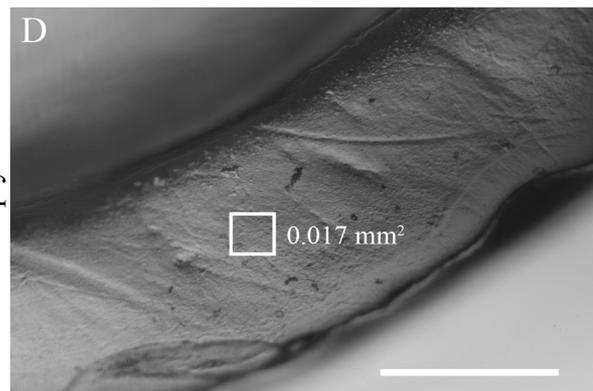
Scratch Orientation



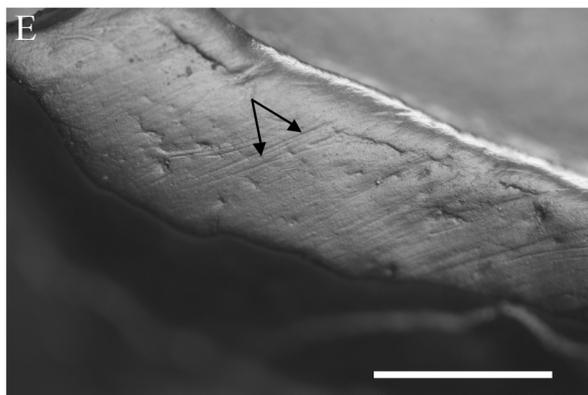
Crossed Scratches



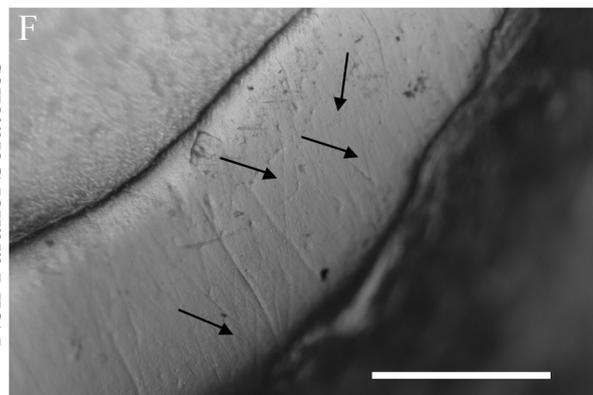
Empty Areas

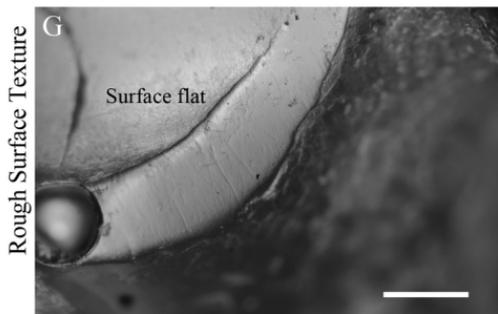
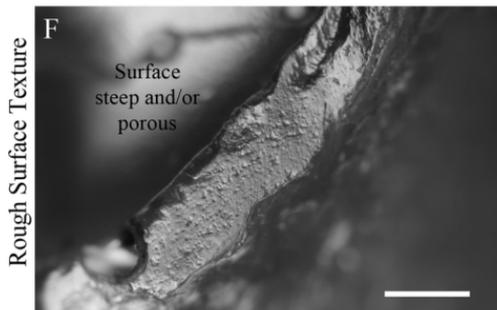
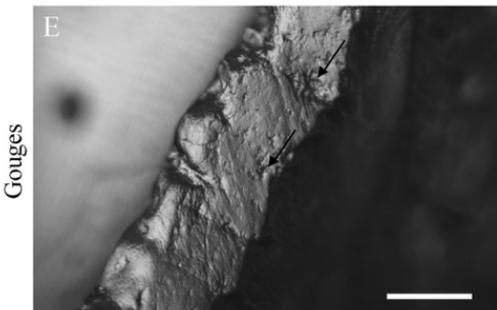
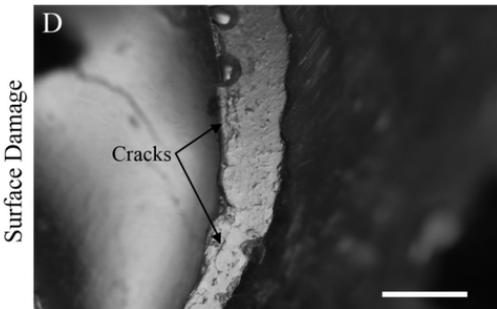
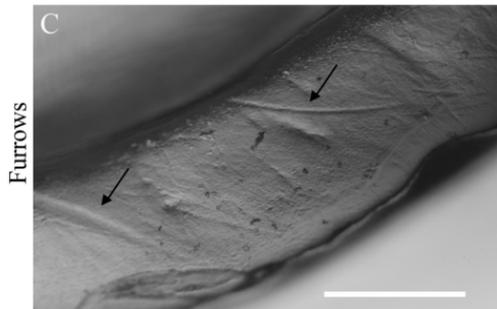
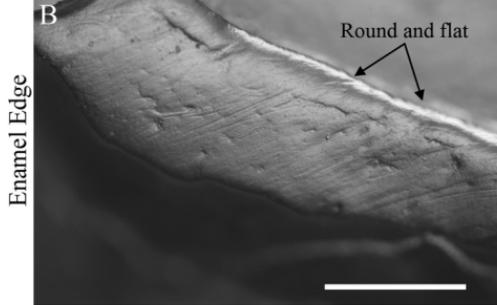
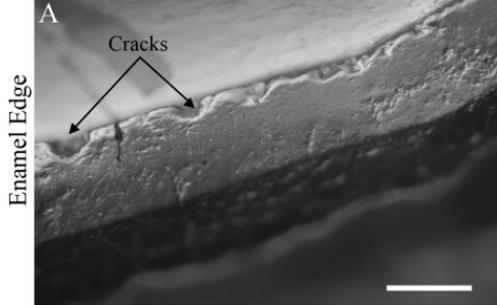


Parallel Scratches

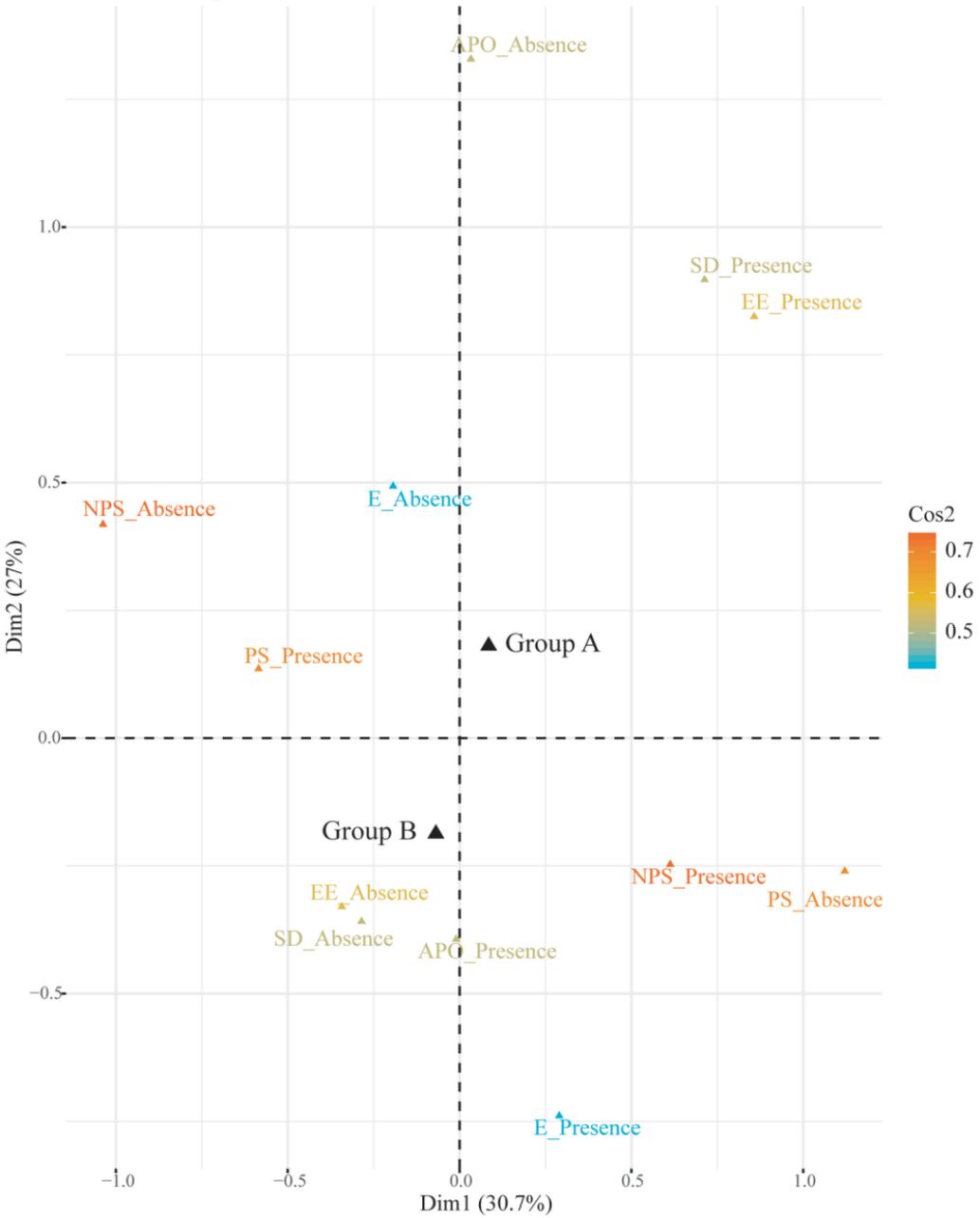


Non-Parallel Scratches

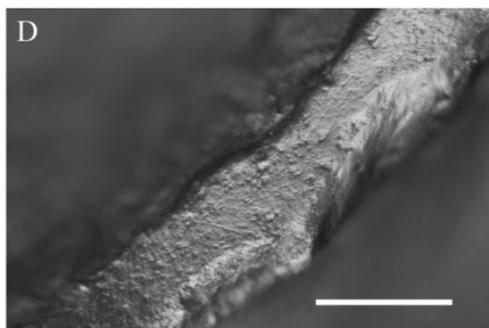
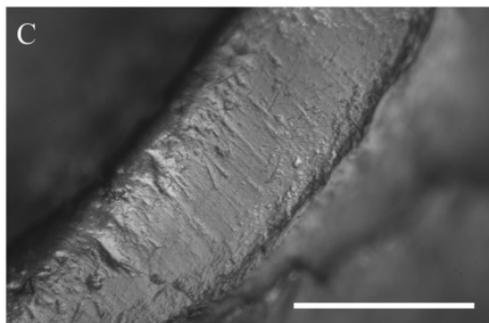
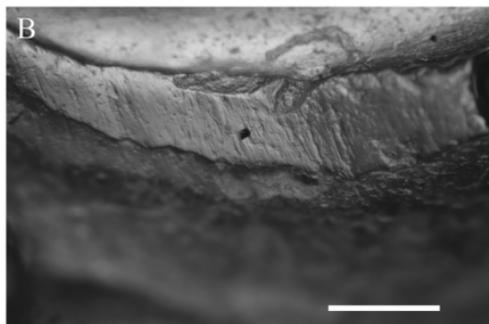
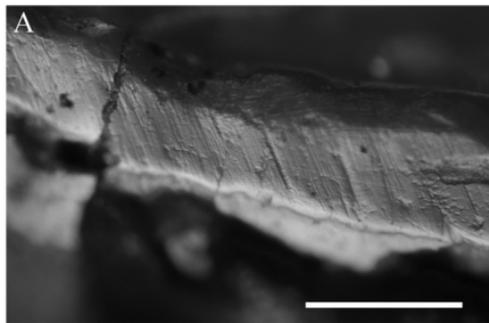




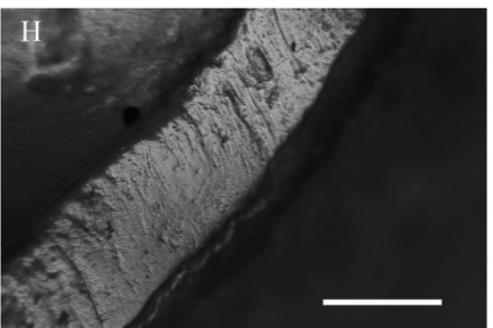
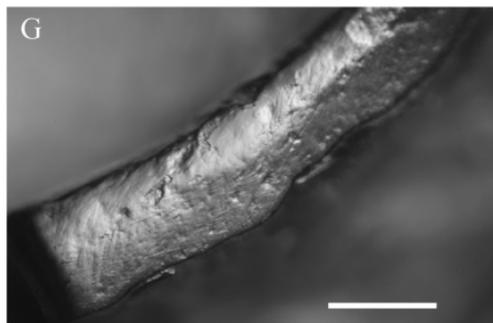
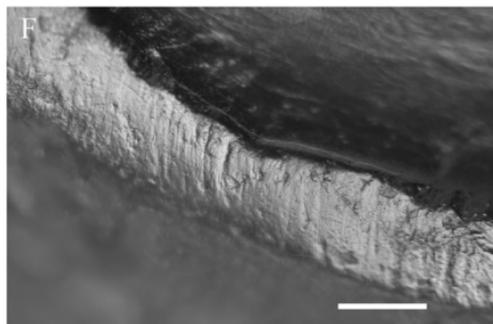
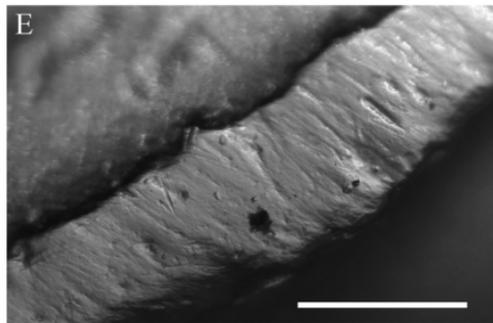
Variable categories – MCA



La Ramasse



Lattara



Individuals – MCA

