SUPPLEMENTARY MATERIAL FOR:

Homogeneous life histories of *Anchitherium* in the face of Miocene climate changes

File index:

Supplementary Note: Fossil Sites

Carpetana

The Carpetana fossil site is located in the urban area of Madrid, near other classic Miocene sites (e.g. San Isidro, Hidroeléctrica, etc.). It was discovered in 2008 during palaeontological monitoring of the improvement works to the accesses to the Carpetana train station (47,48). The topographical elevation is 634 m above sea level. The sediments are brown clays with intercalations of manganese and sand. Bone remains are very abundant, but they are mostly isolated anatomical elements, with varying degrees of preservation, and frequent evidence of transport (breaks, erosion, rounding, etc.).

The macromammal fauna is largely dominated by the equid *Anchitherium*, but there are also abundant artiodactyl remains from species such as *Conohyus simorrensis*, *Hispanomeryx* sp., *Heteroprox moralesi*. On the other hand, the presence of rhinos and mastodons is quite rare. The rodent assemblage of this locality is characterised by the presence of two species of *Megacricetodon,* confirming the correlation of Carpetana (as well as other localities) to biozone F (49,50).

Calatayud-Daroca Basin (Munébrega and Alto del Valle)

The Calatayud-Daroca Basin is one of the largest intramontane sedimentary basins of the Iberian Range (NE of the Iberian Peninsula). This intraplate mountain chain developed from the intense Alpine deformation of Iberia microplate driven by the convergence with both Europe and Africa during the Cenozoic (51-55). The Calatayud-Daroca Basin is placed in its central zone (Aragonian Branch), separating two Palaeozoic-cored structural highs consequence of the re-folded during the Cenozoic compression with a NW-SE trend. In the Miocene, the compressional stress regime of the eastern Iberian plate began to change into an extensional one, but compressional macrostructures in the central-eastern Iberian Chain developed at least until Middle Aragonian (55). The basin was generated under this complex compressional-extensional regime (51,55).

Sedimentary basin filling was characterised by the development of three main sedimentary units (Lower, Intermediate and Upper units), separated by breaks in the sedimentation (56,57). The Early to Middle Miocene series mainly consists of clastic sediments (conglomerates, sandstones and shales), deposited in alluvial fans sourced in the uplifted Aragonian Branch, which grade to lacustrine (limestones and gypsum) sediments towards the basin centre, firstly with dominant evaporites (Lower unit) and later with carbonates (Intermediate unit). The sedimentary break between the Lower and Intermediate units is represented by a paleokarstic surface in the central sectors of the basin generated by the subaerial exposure of the evaporitic facies of the Lower Unit, as well as by changes in the arrangement of alluvial detrital deposits in the marginal sectors of the basin (56). The transition between these two units constitutes one of the most important moments in the evolution of sedimentation in the basin. The mineral assemblages of the Early-Middle Miocene lacustrine deposits evidence an evolutionary sequence from hypersaline to lowermoderated salinity lacustrine facies indicative of a progressive hydrochemical change in relation to a colder and wetter climate (56).

In the vicinity of Munébrega village, the classical Munébrega I (58) and the new Alto del Valle 1 mammal sites supplied large mammal remains, among them the *Anchitherium* tooth studied. Munébrega I is placed at the base of the Intermediate unit (59). At Munébrega I, an overlaying level (12) supplied small mammals. According to Oliver (59), the small mammal fauna made it possible to correlate Munébrega I site with local zone Dc (Middle Aragonian, ~15.6–14.81 Ma, García-Paredes et al. 2016) based on the co-occurrence of *Democricetodon jordensi* with *M. alvarezae,* a new form of *Megacricetodon* larger than *M. primitivus* and previously named as *Megacricetodon* n. sp. 2 by van der Meulen et al. (60). Alto del Valle 1 is placed south-eastern and topographically around 20 m higher than Munébrega I. The site was encountered during activities of palaeontological control in the area of Munébrega village. It has not been excavated yet, but some large mammal remains have been collected on the surface mainly during our 2023 fieldworks in the area. The presence of the minute biochronological marker *Cainotherium* indicates that Alto del Valle 1 still belongs to local zone D. The sediments of the basin fill show a general subhorizontal structure, with the most conspicuous tectonic deformations being found in the vicinity of the margins. At the SW boundary, two of the major faults (Munébrega E and W faults) delimited a trending NW-SE horst (53,54). Alto del Valle 1 is placed at the top of this prominent structure, while Munébrega I fall just east of the Munébrega E normal fault. Consequently, we cannot discard the faunas of both localities could have a similar age. In turn, Munébrega W Fault may result from the inversion of an Alpine thrust system (53,54), which could be contemporaneous to the Daroca thrust, one the major crustal-scale strike-slip faults roughly parallel to the Cenozoic structural trend (NW-SE) that cut across the Middle Aragonian infill (51,55) and constitutes the SE boundary of the basin in the vicinity of Daroca village.

Georgensgmünd

The hill near Georgensgmünd is a classic fossil site from the 19th century. Although the current summit of the hill is ca. 400 m above sea level, it can be assumed that the hill was higher in the past and that a slightly lower summit plateau was created as a result of quarrying (61). The author mentions the presence of solid, thick and massive limestones, which were followed by layers with leaf remains and layered limestones (61).

Several plant and animal species have been identified there (62). The faunal composition suggests an assignment to the base of zone MN5 (62). Regarding mammals, small teeth from *Anomalomys minor* and *Megacricetodon bourgeoisi* are particularly important stratigraphically. On the other hand, *Bunolistriodon cf. lockharti*, *Plesiaceratherium cf. mirallesi*, *Hemicyon stehlini* and *Anchitherium aurelianense* are some of the large mammals found in the site (62).

Steinheim

The Steinheim Basin is situated on the Upper Jurassic limestone plateau of the Swabian Alb (Baden-Württemberg, Germany). It is an impact crater that probably formed around 14.0–14.3 Ma ago (63,64). The basin is filled with sediments of a lake that developed within the crater after the impact event, which occurred approximately 0.5 to 0.8 Ma after the formation of the larger Nördlinger Ries crater, located about 40 km further NE on the Swabian Alb (63,64). While the deposition of lake sediments at Steinheim am Albuch may have begun as early as the late MN 6 or during the MN 6/7 transition, the upper layers of the section, considered to date back to about 13.5 Ma (63,65), are rich in mammal remains and represent the reference site for the European Mammal Neogene Zone MN7 (66,67).

With around 90 plant and 230 animal species represented so far, including over 50 mammals, Steinheim am Albuch is one of the most important Miocene fossil sites in Europe (66,68,69). Small mammals include the pika *Prolagus oeningensis*, the hairy hedgehog *Galerix socialis*, and cricetids of great biostratigraphic value, such as *Megacricetodon* cf. *gregarius*, *Collimys transversus* and *Democricetodon affinis* (66,70,71). Large mammals encompass among the others *Gomphotherium steinheimense*, *Anchitherium aurelianense, Palaeomeryx eminens, Euprox* vel *Heteroprox*, *Listriodon splendens*, *Pseudocyon steinheimensis, Hemicyon goeriachensis, Paralutra jaegeri* and *Styriofelis lorteti* (65,66,69). Moschids are particularly abundant and include the most likely oldest true representative of the family *Micromeryx flourensianus* and the larger *Micromeryx*? *eiselei* (68).

The mammal community reflects a partly open woodland palaeoenvironment, with a combination of woodland dwellers, taxa adapted to more open and arid conditions, and semi-aquatic species 65,72,73). Palaeoclimatic reconstructions based on isotopic analyses of skeletal fossils of terrestrial and aquatic organisms, together with the fossil plant assemblage, indicate warm-temperate conditions that were drier and/or cooler than those of previous periods (65,74). According to Tütken et al. (65), the mean annual air temperature around the Steinheim basin was approximately 19 °C, with lake water temperatures ranging from 17 to 22 °C.

Supplementary figures

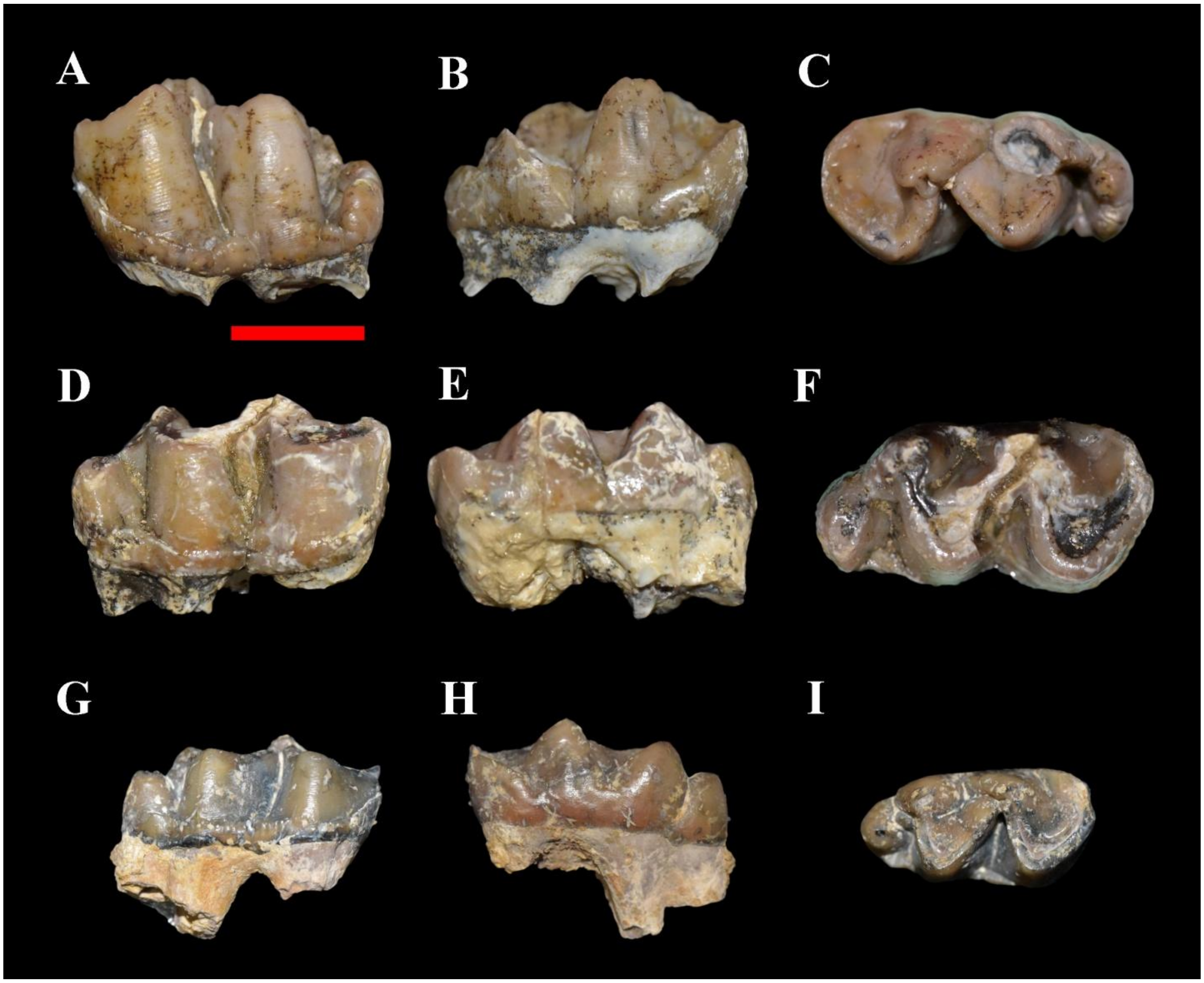

Figure S1. Detailed images of the lower third molars analysed. Specimen 8/17/0212.HC.3 (A-C), 8/17/2548.HC (D-F), and MLU.GeoS.7897 (G-I) in its labial (A,D,G), lingual (B,E,H) and occlusal (C,F,I) views. Scale-bar: 1cm.

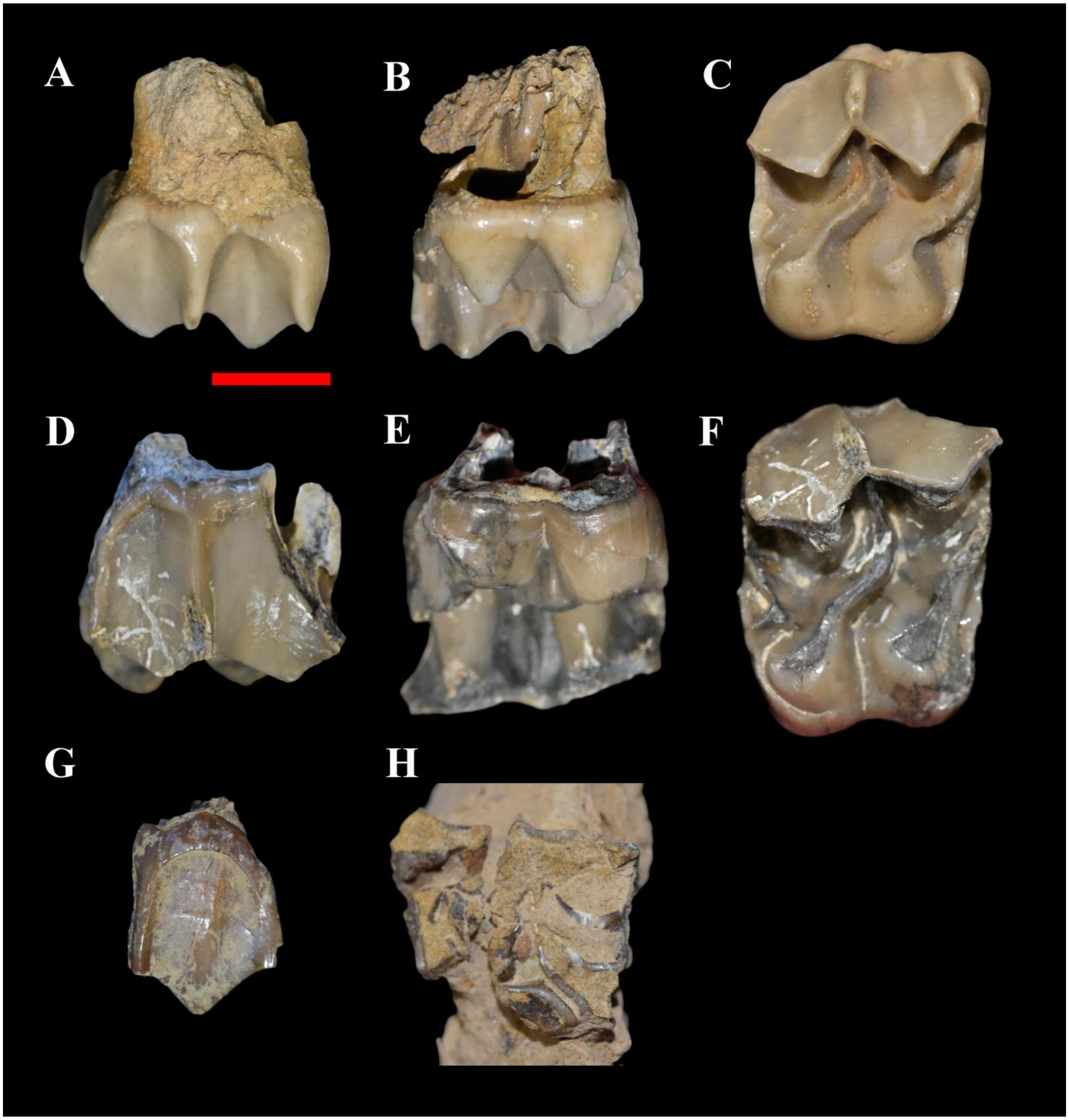

Figure S2. Detailed images of the upper first/second molars analysed. Specimen MLU.GeoS.7898 (A-C), 8/17/10308.HC (D-F), MPZ 2005/471 (G) and MPZ 2005/472 (H) in its labial (A,D,G), lingual (B,E) and occlusal (C,F,H) views. Scale-bar: 1cm.

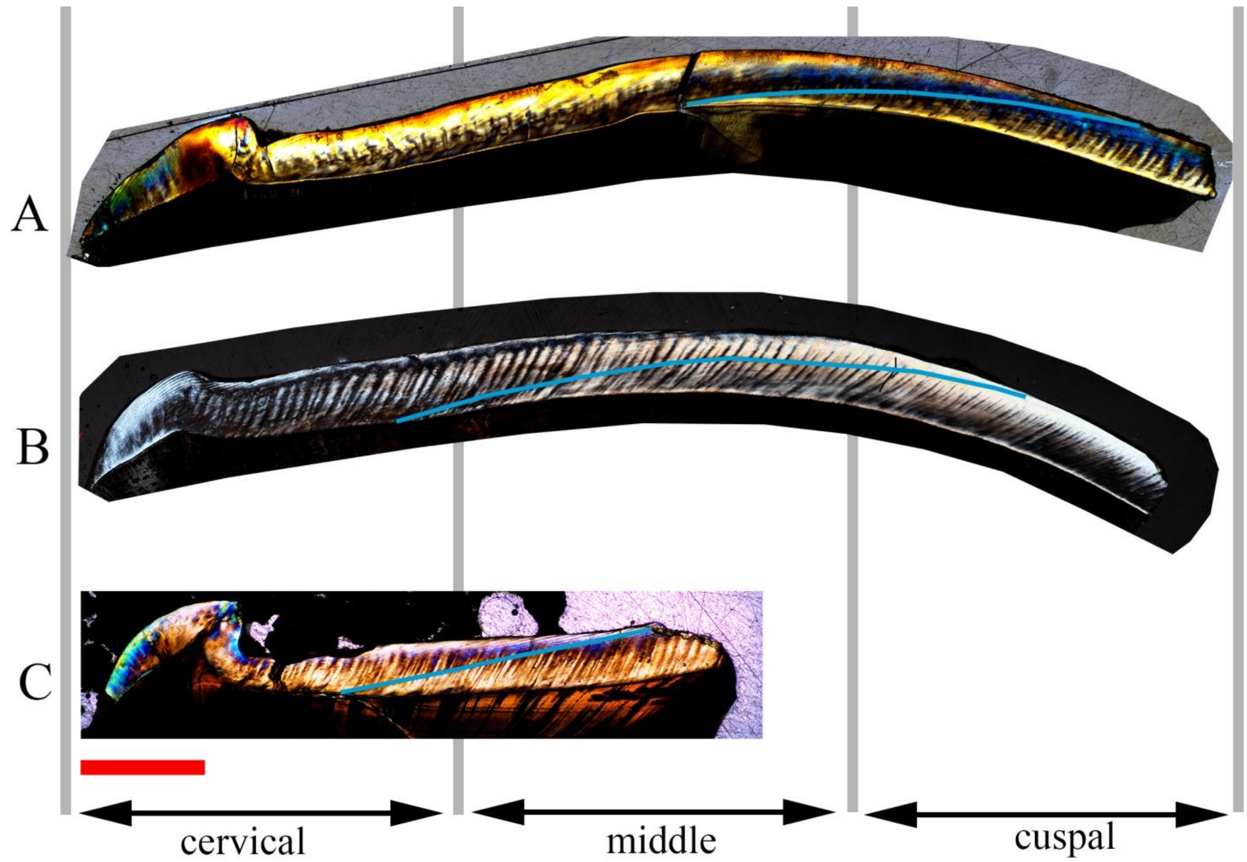

Figure S3. Histological composition of the labial part of the M1/2 paracone representing non-periodic marks (in blue) in the enamel of specimens (A) MPZ 2005/471, (B) 8/17/10308.HC and (C) MPZ 2005/472. Scale-bar: 2mm.

Supplementary Tables

Table S1. Mean DSR values (in µm/day) for the different parts of the crown of m3 and M1/2 from the different European populations and statistical results for the comparison between enamel regions (Kruskal-Wallis test). Characters in bold indicate statistical significance (p-value < 0.05).

population	molar	part	count	mean	sd
Carpetana (MN6)	m3	inner	10	11.6	0.839
		central	5	11.9	0.775
		outer	17	11.7	0.322
	chi-squared = 0.4856, df = 2, p-value = 0.1492				
	M1/2	inner	9	11.1	1.26
		central	1	9.58	NA
		outer	1	11.9	NA
	chi-squared = 1.6364, df = 2, p-value = 0.4412				
Alto del Valle (MN5)	M1/2	inner	9	11.5	0.971
		central	4	10.6	0.703
		outer	17	11.1	0.688
	chi-squared = 3.9830, df = 2, p-value = 0.1365				
Munébrega 1 (MN5)	M1/2	inner	7	10.3	0.554
		central	3	10.7	0.686
		outer	3	11.1	0.447
	chi-squared = 3.9874, df = 2, p-value = 0.1362				
Steinheim (MN7/8)	M1/2	inner	5	10.4	0.626
		central	9	10.5	0.586
		outer	14	10.4	0.343
	chi-squared = 0.7074, df = 2, p-value = 0.7021				
Georgensgmünd (MN5)	m3	inner	11	9.94	0.308
		central	1	9.62	NA
		outer	6	10.3	0.233
	chi-squared = 5.6124, df = 2, p-value = 0.0604				
population	**molar**	**part**	**count**	**mean**	**sd**
Carpetana (MN6)	m3	cuspal	13	11.8	0.705
		middle	16	11.7	0.455
		cervical	3	11.1	0.527
	chi-squared = 3.8047, df = 2, p-value = 0.1492				
	M1/2	cuspal	6	11.6	1.16
		middle	1	11.2	NA
		cervical	4	10.1	1.16
	chi-squared = 4.5833, df = 2, p-value = 0.1011				
Alto del Valle (MN5)	M1/2	cuspal	15	11.4	0.622
		middle	5	10.5	0.376

		cervical	10	11.1	1.05
	chi-squared = 5.0284, df = 2, *p*-value = 0.8093				
Munébrega 1 (MN5)	M1/2	cuspal	NA	NA	NA
		middle	7	10.8	0.651
		cervical	6	10.3	0.549
	chi-squared = 1.6531, df = 1, *p*-value = 0.1985				
Steinheim (MN7/8)	M1/2	cuspal	4	10.3	0.385
		middle	10	10.5	0.447
		cervical	14	10.5	0.486
	chi-squared = 1.1179, df = 2, *p*-value = 0.5718				
Georgensgmünd (MN5)	m3	cuspal	NA	NA	NA
		middle	7	10.1	0.395
		cervical	11	9.97	0.276
	chi-squared = 0.7403, df = 1, *p*-value = 0.3896				

Table S2. Mean DSR values (in µm/day) for m3 and M1/2 from the different European populations and statistical results for the comparison between two or more populations (Wilcoxon test / Kruskal-Wallis test, respectively). Characters in bold indicate statistical significance (*p*-value < 0.05) while the asterisk (*) indicates that only data from cervical and middle regions were taken.

population	**molar**	**count**	**mean**	**sd**
Carpetana (MN6)	M1/2	11	11.0	1.25
	m3	32	11.7	0.589
	W = 139.5, *p*-value = 0.3163			
Alto del Valle (MN5)	M1/2	15	10.9*	0.913
Munébrega 1 (MN5)	M1/2	13	10.6*	0.624
	W = 118.5, *p*-value = 0.3449			
Alto del Valle (MN5)	M1/2	15	10.9*	0.917
Carpetana (MN6)	M1/2	5	10.9*	1.96
Munébrega 1 (MN5)	M1/2	13	10.6*	0.624
	chi-squared = 0.70172, df = 2, *p*-value = 0.7041			
Alto del Valle (MN5)	M1/2	15	10.9*	0.917
Carpetana (MN6)	M1/2	5	10.9*	1.96
Munébrega 1 (MN5)	M1/2	13	10.6*	0.624
Steinheim (MN7/8)	M1/2	24	10.5*	0.461
	chi-squared = 1.6799, df = 3, *p*-value = 0.6414			
Steinheim (MN7/8)	M1/2	24	10.5*	0.447
Georgensgmünd (MN5)	m3	18	10.0*	0.363
	W = 340.5, *p*-value = **0.001621**			
Carpetana (MN6)	m3	21	11.4*	0.814
Georgensgmünd (MN5)	m3	18	10.0*	0.324
	W = 340, *p*-value = **4.335E-06**			
Alto del Valle (MN5)	M1/2	31	10.9*	0.917
Munébrega 1 (MN5)	M1/2	13	10.6*	0.624
Georgensgmünd (MN5)	m3	18	10.0*	0.324
	chi-squared = 10.831, df = 2, *p*-value = **0.0044**			

Table S3. EER values (in μm/day) for the different parts of the crown of m3 and M1/2 from the different European populations and statistical results for the comparison between enamel regions (Kruskal-Wallis test). Characters in bold indicate statistical significance (p-value < 0.05).

<table>
<tr><th>population</th><th>molar</th><th>location</th><th>count</th><th>mean</th><th>sd</th></tr>
<tr><td rowspan="8">Carpetana (MN6)</td><td rowspan="3">m3</td><td>cuspal</td><td>1</td><td>105</td><td>NA</td></tr>
<tr><td>middle</td><td>5</td><td>51.5</td><td>16.5</td></tr>
<tr><td>cervical</td><td>16</td><td>14.7</td><td>4.53</td></tr>
<tr><td colspan="5">chi-squared = 12.7, df = 2, p-value = 0.00175</td></tr>
<tr><td rowspan="3">M1/2</td><td>cuspal</td><td>2</td><td>117</td><td>7.68</td></tr>
<tr><td>middle</td><td>2</td><td>78.4</td><td>2.81</td></tr>
<tr><td>cervical</td><td>5</td><td>26.4</td><td>14.3</td></tr>
<tr><td colspan="5">chi-squared = 6.5333, df = 2, p-value = 0.03813</td></tr>
<tr><td rowspan="4">Alto del Valle (MN5)</td><td rowspan="3">M1/2</td><td>cuspal</td><td>3</td><td>101</td><td>20.4</td></tr>
<tr><td>middle</td><td>4</td><td>55.1</td><td>12.7</td></tr>
<tr><td>cervical</td><td>6</td><td>23.5</td><td>8.9</td></tr>
<tr><td colspan="5">chi-squared = 10.385, df = 2, p-value = 0.00556</td></tr>
<tr><td rowspan="4">Steinheim (MN7/8)</td><td rowspan="3">M1/2</td><td>cuspal</td><td>1</td><td>119</td><td>NA</td></tr>
<tr><td>middle</td><td>2</td><td>83.6</td><td>7.59</td></tr>
<tr><td>cervical</td><td>9</td><td>33.6</td><td>15.5</td></tr>
<tr><td colspan="5">chi-squared = 6.3462, df = 2, p-value = 0.04187</td></tr>
<tr><td rowspan="4">Georgensgmünd (MN5)</td><td rowspan="3">m3</td><td>cuspal</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td>middle</td><td>2</td><td>51.4</td><td>14.7</td></tr>
<tr><td>cervical</td><td>10</td><td>16.1</td><td>10.4</td></tr>
<tr><td colspan="5">chi-squared = 4.6154, df = 1, p-value = 0.03169</td></tr>
</table>

Table S4. EER values (in µm/day) for m3 and M1/2 from the different European populations and statistical results for the comparison between two or more populations (Wilcoxon test / Kruskal-Wallis test, respectively). Characters in bold indicate statistical significance (*p*-value < 0.05). n=count.

molar	**population**	**cuspal**			**middle**			**cervical**		
		n	**mean**	**sd**	**n**	**mean**	**sd**	**n**	**mean**	**sd**
M1/2	Carpetana (MN6)	2	117	7.68	2	78.4	2.81	5	26.4	14.3
m3	Carpetana (MN6)	1	105	NA	5	51.5	16.5	16	14.7	4.53
		W = 2, *p*-value = 0.6667			W = 10, *p*-value = 0.0952			W = 61, *p*-value = 0.09101		
M1/2	Carpetana (MN6)	2	118	7.72	2	78.8	2.81	5	26.6	14.3
	Alto del Valle (MN5)	3	101	20.4	4	55.1	12.7	6	23.5	8.9
	Steinheim (MN7/8)	1	119	NA	2	83.6	7.59	9	33.6	15.5
		$\chi2$ = 0.428, *p*-value = 0.8071			$\chi2$ = 5.5, *p*-value = 0.064			$\chi2$ = 2.104, *p*-value = 0.3654		
m3	Carpetana (MN6)	NA	NA	NA	5	51.5	16.5	16	14.7	4.53
	Georgensgmünd (MN5)	NA	NA	NA	2	51.4	14.7	10	16.1	10.4
		NA			W = 5, *p*-value = 1			W = 94, *p*-value = 0.4838		

Table S5. Mean specimen dimensions (in millimetres) from the different European locations included in the study.

		Iberian (MN5)	**Iberian (MN6)**	**Georgensgmünd (MN5)**	**Steinheim (MN7/8)**
m1/2	length	22.66	23.37	18.35	NA
	width	14.74	15.12	12.33	NA
m3	length	23.56	23.79	19.99	NA
	width	12.15	12.25	10.51	NA
M1/2	length	22.45	22.97	18.80	20.30
	width	28.05	28.87	21.79	25.27
P4	length	22.70	24.94	19.93	21.21
	width	27.06	30.45	22.93	26.36

Table S6. Results from the statistical comparison of dental dimensions among the different populations. Characters in bold indicate statistical significance (*p*-value < 0.05). P.unadj = *p*-value unadjusted; P.adj = *p*-value adjusted.

m1/2 length			
Kruskal-Wallis test			
chi-squared = 42.574, df = 2, *p*-value = **5.691e-10**			
Dunn test			
Comparison	Z	P.unadj	P.adj
Georgensgmünd (MN5) - Iberian (MN5)	-4.5942293	**4.34e-06**	**1.30e-05**
Georgensgmünd (MN5) - Iberian (MN6)	-5.9605749	**2.51e-09**	**7.54e-09**
Iberian (MN5) - Iberian (MN6)	-0.7994721	4.24e-01	1.00e+00
m1/2 width			
Kruskal-Wallis test			
chi-squared = 39.603, df = 2, *p*-value = **2.514e-09**			
Dunn test			
Comparison	Z	P.unadj	P.adj
Georgensgmünd (MN5) - Iberian (MN5)	-4.5693255	**4.89e-06**	**1.47e-05**
Georgensgmünd (MN5) - Iberian (MN6)	-5.6655188	**1.47e-08**	**4.40e-08**
Iberian (MN5) - Iberian (MN6)	-0.5743424	5.66e-01	1.00e+00
M1/2 length			
Kruskal-Wallis test			
chi-squared = 34.508, df = 3, *p*-value = **1.548e-07**			
Dunn test			
Comparison	Z	P.unadj	P.adj
Georgensgmünd (MN5) - Iberian (MN5)	-5.0308619	**4.88e-07**	**2.93e-06**
Georgensgmünd (MN5) - Iberian (MN6)	-4.4138309	**1.02e-05**	**6.09e-05**
Iberian (MN5) - Iberian (MN6)	-0.1469918	8.83e-01	1.00e+00
Georgensgmünd (MN5) – Steinheim (MN7/8)	-2.0731792	**3.82e-02**	2.29e-01
Steinheim (MN7/8) - Iberian (MN5)	2.40594	**1.61e-02**	9.68e-02
Steinheim (MN7/8) - Iberian (MN6)	2.2633772	**2.36e-02**	1.42e-01
M1/2 width			
Kruskal-Wallis test			
chi-squared = 45.006, df = 3, *p*-value = **9.224e-10**			
Dunn test			
Comparison	Z	P.unadj	P.adj
Georgensgmünd (MN5) - Iberian (MN5)	-5.6543349	**1.56e-08**	**9.39e-08**
Georgensgmünd (MN5) - Iberian (MN6)	-5.1244272	**2.98e-07**	**1.79e-06**
Iberian (MN5) - Iberian (MN6)	-0.3146394	7.53e-01	1.00e+00
Georgensgmünd (MN5) – Steinheim (MN7/8)	-3.1277207	**1.76e-03**	**1.06e-02**

Steinheim (MN7/8) - Iberian (MN5)	1.9903775	**4.65e-02**	2.79e-01
Steinheim (MN7/8) - Iberian (MN6)	2.0591183	**3.95e-02**	2.37e-01
m3 length			
Kruskal-Wallis test			
chi-squared = 20.325, df = 2, *p*-value = **3.86e-05**			
Dunn test			
Comparison	Z	P.unadj	P.adj
Georgensgmünd (MN5) - Iberian (MN5)	-3.9147632	**9.05e-05**	**2.71e-04**
Georgensgmünd (MN5) - Iberian (MN6)	-3.2457644	**1.17e-03**	**3.51e-03**
Iberian (MN5) - Iberian (MN6)	-0.2926896	7.70e-01	1.00e+00
m3 width			
Kruskal-Wallis test			
chi-squared = 17.833, df = 2, *p*-value = **0.00013**			
Dunn test			
Comparison	Z	P.unadj	P.adj
Georgensgmünd (MN5) - Iberian (MN5)	-3.76767463	**1.65e-04**	**4.94e-04**
Georgensgmünd (MN5) - Iberian (MN6)	-2.88912699	**3.86e-03**	**1.16e-02**
Iberian (MN5) - Iberian (MN6)	-0.06192361	9.51e-01	1.00e+00
P4 length			
Kruskal-Wallis test			
chi-squared = 23.764, df = 3, *p*-value = **2.798e-05**			
Dunn test			
Comparison	Z	P.unadj	P.adj
Georgensgmünd (MN5) - Iberian (MN5)	-3.320254	**8.99e-04**	**5.40e-03**
Georgensgmünd (MN5) - Iberian (MN6)	-4.466189	**7.96e-06**	**4.78e-05**
Iberian (MN5) - Iberian (MN6)	-1.496463	1.35e-01	8.07e-01
Georgensgmünd (MN5) – Steinheim (MN7/8)	-1.244405	2.13e-01	1.00e+00
Steinheim (MN7/8) - Iberian (MN5)	1.861408	6.27e-02	3.76e-01
Steinheim (MN7/8) - Iberian (MN6)	3.10375	**1.91e-03**	**1.15e-02**
P4 width			
Kruskal-Wallis test			
chi-squared = 23.357, df = 3, *p*-value = **3.402e-05**			
Dunn test			
Comparison	Z	P.unadj	P.adj
Georgensgmünd (MN5) - Iberian (MN5)	-3.0343075	**2.41e-03**	**1.45e-02**
Georgensgmünd (MN5) - Iberian (MN6)	-4.7204471	**2.35e-06**	**1.41e-05**
Iberian (MN5) - Iberian (MN6)	-2.00648	4.48e-02	2.69e-01
Georgensgmünd (MN5) – Steinheim (MN7/8)	-2.2179905	**2.66e-02**	1.59e-01
Steinheim (MN7/8) - Iberian (MN5)	0.6203442	5.35e-01	1.00e+00

Steinheim (MN7/8) - Iberian (MN6)	2.4627217	**1.38e-02**	8.27e-02