**Supplementary S1 for:** Intra-tooth stable isotope profiles in warthog canines and third molars: implications for paleoenvironmental reconstructions

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**1. Rainy season onset, cessation, and duration using Mpala precipitation record**

The Mpala precipitation record ([Caylor et al., 2019](#_ENREF_2)) consists of daily manual rain gauge readings (from May 1998 to November 2015) and daily (0000 - 2400 hours) automatic weather station precipitation readouts (from April 2011 to March 2019). We used the manual rain gauge dataset for our seasonal duration calculation. The precipitation pattern of Mpala, Laikipia, generally consists of frequent rains from March to June (the long rainy season), from October to November (the short rainy season), and periodical rains from July to August (the boreal summer rains). Rainy season onset is defined as the first day of precipitation with at least 15 mm of cumulative rainfall received during five successive days ([modified from Ngetich et al., 2014](#_ENREF_12)). The onset typically falls between February 15 and April 15 each year for the long rainy season, and between September 15 and November 15 for the short rainy season. Periodic rains in July and August are excluded from the seasonal duration calculation to avoid complications. Rainy season cessation is defined as the last day of precipitation of the season with less than 2 mm of cumulative rainfall during the next 10 successive days. The number of days between the cessation of a rainy season and the onset of the next rainy season is the length of a dry season. Because the rains are distributed unevenly throughout a calendar year, the duration of seasonal cycles also follows a bimodal distribution, with one long cycle at *ca.* 205 days (one long rainy season + one dry season), and one short cycle at *ca.* 165 days (one short rainy season + one dry season; Table 5 of the main manuscript; Supplementary S2).

**2. Stable isotope sampling, pretreatment, and analysis methods**

Tooth enamel was sampled using a Dremel handheld drill with carbide (Brasseler) or diamond grit impregnated (Lasco) bits at low speed (~1000 RPM). Canine enamel was sampled using a cylindrical bit. Molar enamel was sampled using a 1 mm diameter spherical bit. Approximately 1 mm-wide grooves were drilled perpendicular to the greater curvature of the canine using a cylindrical bit, at ~5 mm intervals starting from the cervix and ending close to the tip of the tooth. Because the canine enamel is very thin, great care was taken to avoid the underlying dentine. For the molar enamel, 1 mm-wide grooves were drilled perpendicular to the growth axis of the tooth at ~2 mm intervals. The sampling depth was between 0.5 mm and 0.7 mm.

Collected sample masses were about 3-5 mg. Enamel powder was treated using 3 % H2O2 for 30 minutes in 1.5 ml centrifuge tubes that were stirred every 10 minutes on a vortex mixer. After the reaction period, samples were centrifuged, and the supernatant was removed. Each sample was then rinsed three times with distilled water. The rinse procedure involved adding de-ionized (DI) water, stirring on the vortex mixer, then centrifuging the sample and removing the supernatant. Next, samples were treated with 0.1 M Na-acetate buffered acetic acid for 30 minutes, as above. Following three DI water rinses, they were dried in a 60°C oven overnight. At the SIRFER facility of the University of Utah, enamel powder samples were reacted with >100 % H3PO4 at 50°C in individual glass vials for 8 hours using a Thermo Finnigan GasBench II. The resulting CO2 was extracted from the vials using a GC-TC PAL autosampler connected to a Conflo IV. 13C/12C and 18O/16O ratios of the CO2 were measured using a Thermo Finnigan MAT 253. Data were corrected with Carrara carbonate and internal laboratory carbonate standards. For δ18O, samples were corrected for the acid fractionation factor (α = 1.00930, at 50°C) that is dependent on reaction temperature ([Passey et al., 2007](#_ENREF_14); [Swart et al., 1991](#_ENREF_19)). Analytical precision was < 0.2 ‰ for δ13C and < 0.3 ‰ for δ18O (Supplementary S2).

**3. Methods for preparing thin sections**

The teeth were embedded in transparent epoxy resin (Presi MA2+) before being cut with a precision saw (Buehler - Isomet 5000), and a 15 LC Isomet Diamond Wafering Blade (178 × 0.6 mm). Upper third molars were cut axio-bucco-lingually through the second pair of main cusps for both the Souron1 and the NKU M3s. Due to curvature, the Souron2 lower canine was cut transversely along a labio-lingual axis into four segments before each part was cut longitudinally along a cervico-apical axis. A small amount of crown was lost due to the kerf. We estimate the kerf to be slightly wider than the Isomet blade thickness (0.6 mm) due to blade wobbling during the cuts. The total amount of crown height/length that was lost for each cut is estimated to be around 1 mm. This has minimal effects on our measurements of enamel histology or timeline reconstruction.

The cut surface of each block was ground using a rotary motorized polisher (Presi - « LeCube ») with abrasive paper (Presi - Reflex NAC Type M P240), and then polished with diamond suspension liquid with a 54 µm particle diameter (Presi - IMAX R 54µ), and 18 µm particle diameter (Presi - IMAX R 18µ). The polished surface of each section was mounted onto a glass slide (26 x 76 mm or 30 x 45 mm, depending on the size of the sample). The samples were affixed to the slide with epoxy resin (Escil - Geofix) using a heating press (GBrot - Presse 1.04.02). The samples and glass slides were first heated to 65°C and then the resin was applied to the glass slide. The polished surface of the sample was gently placed onto the resin before being cured at 65°C for one hour. The mounted blocks were then sectioned to a thickness of about 500 µm to 800 µm before being ground to a final thickness of about 100 µm. To obtain the best surface quality with fewest possible defects, sections were polished using 9 µm, 3 µm, and finally 1 µm diamond suspension liquid.

**4. The possibility of contamination**

Because canine enamel is very thin, it is possible to introduce dentine into the enamel sample as a major contaminant. In addition, molar enamel has a thick coronal cementum cover externally. This cementum layer is formed after enamel is fully mineralized, but the rugose outer enamel surface of the molar intersects with cementum, giving it a “rough” appearance. This phenomenon is also observed in hypsodont equid teeth with coronal cementum, in which the rugose outer enamel surface is created via resorption of fully mineralized enamel by odontoclasts ([Sahara, 2014](#_ENREF_18)). While the outer 0.2 mm of molar enamel was carefully abraded using a low speed drill before sampling, it is possible that some “pockets” of cementum could still be a source of contamination. To investigate possibility of contamination, we bulk sampled MPL1 specimen for 1) canine dentine, 2) molar dentine, and 3) molar cementum, for a total of three samples. We divided each sample into two subsamples, each measured for δ13C with pretreatment (as in Supplementary S1.1) and without (untreated), which gave us six measurements in total. The measured δ13C values for MPL1 canine dentine were −1.5 ‰ treated and −2.0 ‰ untreated. δ13C values for MPL1 molar dentin were −1.1 ‰ treated and −2.3 ‰ untreated. δ13C values for MPL1 molar cementum were −2.6 ‰ treated, and −2.9 ‰ untreated (Supplementary S2).

The principle of mass balance is applied in a potentially contaminated sample, which is fundamentally a mixing process. A mixed sample can only have isotope values between the two endmember values. In our case, the canine enamel has the highest value and the molar cementum has the lowest value. We consider these as our endmember values, which does not rule out the possibility of canine being contaminated by dentine, but that would only make the theoretical pure canine enamel at a higher δ13C value, which increases the difference between canine and molar enamel δ13C values. If we consider the possibility that molar enamel is contaminated, then the amount of contaminant (cementum) that is needed to achieve the measured difference (~2 ‰) would be unrealistically large (i.e. > 70 %) in order to account for the difference. There are fundamental differences in the texture and color between the two types of dental tissue: enamel being white and resilient to abrasion using a low speed drill, cementum being yellow and soft. Therefore, we are confident in ruling out the possibility of any major dentin or cementum contamination in our analysis.

**5. Nominal** **%C4 calculation**

Because the isotopic enrichment factor between diet and enamel in the warthog is unknown, we used the isotopic enrichment factor between diet and enamel apatite (ε\*diet-enamel) value of 13.3 ‰ in *Sus scrofa* ([Passey et al., 2005b](#_ENREF_16)) and the following procedure to estimate the %C4 in the diet represented by the canine and third molar mean δ13C values in both MPL1 and MPL2 specimens. The application of the enrichment factor, ε\*diet-enamel, is from rearrangement of the following equation,

*ε\*= α\* – 1* (1)

from [Craig (1954](#_ENREF_4)), where alpha (α\*) is the apparent fractionation factor between diet and enamel, defined as

*α\*=* (*1000 + δ13Cenamel*) / (*1000 + δ13Cdiet*) (2)

With these equations, we calculated the δ13Cdiet values from mean δ13Cenamel in both canine and M3. The δ13Cdiet is then used in a linear mixing model to estimate %C4 in diet. The endmember values for C3 and C4 plants were taken from [Cerling and Harris (1999)](#_ENREF_3), with particular reference to Laikipia. The modal δ13C of −27.0 ± 1.7 ‰ was used to represent C3 browse in eastern Africa. The modal δ13C of −12.8 ± 0.8 ‰ was used to represent C4 NAP-PCK grasses found in Laikipia ([Cerling and Harris, 1999](#_ENREF_3)).

For a linear mixing model, the δ13C value of a mixed diet can be expressed in the following equation:

*δ13Cdiet = fC3 × δ13CC3 + fC4 × δ13CC4* (3)

Assuming *fC3 = 1 – fC4*, we can solve for *fC4*, where:

Nominal %C4 (*fC4*) = (*δ13Cdiet – δ13CC3*) / (*δ13CC4– δ13CC3*) × 100 (4)

We used three linear mixing lines to calculate the average nominal %C4 and its upper and lower range estimates. The modal values for C3 and C4 plants (−27.0 ‰ and −12.8 ‰, respectively) were used to produce the average value. A steeper slope was used for the higher end estimate, using the C3 end member value of −28.7 ‰ (−27.0 – 1.7 ‰, mean minus 1σ), and the end member C4 value of −12 ‰ (−12.8 + 0.8 ‰, mean plus 1σ). Similarly, a shallower slope was used for the lower end estimate, using the C3 end member value of −25.3 ‰ (−27.0 + 1.7 ‰, mean plus 1σ), and the end member C4 value of −13.6 ‰ (−12.8 − 0.8 ‰, mean minus 1σ).

For the mean δ13Cenamel reported in Table 2, we obtained a mean nominal %C4 for MPL1 canine at 108 % (103 % – 118 % range) and for MPL1 M3 at 92 % (89 % – 97 % range). Similarly, the mean nominal %C4 for MPL2 canine was at 103 % (98 % – 111 % range) and for MPL2 M3 at 89 % (86 % – 94 % range). Note that the nominal %C4 values calculated from canine enamel are consistently higher than 100 %, while those calculated from M3s fall within a reasonable range. This reflects the fact that the enrichment factor (ε\*diet-enamel = 13.3 ‰) being used here is an important assumption and that it may vary among individuals ([e.g., Warinner and Tuross, 2010](#_ENREF_21)). It seems to be suitable for dietary estimates of molar enamel, but not suitable for estimates of canine enamel. These results are also consistent with our finding that an isotope spacing exists between canine and molar enamel.

**6. Inverse modeling procedure**

The inverse model ([Passey et al., 2005a](#_ENREF_15)) requires input parameters related to tooth formation, isotope sampling geometry, and isotope analysis. The inverse model assumes a constant growth rate, a mineralization process that starts immediately after enamel matrix secretion, and a mineralization geometry that is identical to the appositional geometry. Based on the growth and mineralization data of the canine, these assumptions are acceptable. Input parameters relevant to tooth enamel formation, or amelogenesis, include initial enamel density (*finit*), enamel appositional length (*la*), and maturation length (*lm*) ([Passey and Cerling, 2002](#_ENREF_13)). We used the initial enamel density of the third molar: *finit* = 0.45 (Table 4). Enamel appositional length was calculated using average canine appositional angle (enamel formation front angle) and average canine enamel thickness (~200 µm). This resulted in an *la* = 4.66 mm. A second estimate of *la* was made by measuring the distance from the tip of the dentin formation front to the edge of enamel that is preserved. This approach resulted in an *la*’ = 5.02 mm. Since these two independent estimates are very similar, we used the average value *la* = 4.8 mm as our model input. *lm* was measured from the beginning of the canine enamel edge to the 90 % added mineral density line, corresponding to about 95 % density of the fully mature canine enamel, which is ~ 12 mm. We used *lm* =12 mm. Sample input variables, including isotope measurement precision, distance between samples, depths, and their respective errors, are listed in Supplementary S2.

For each canine profile, a measured error term, *Emeas*, is computed from measurement uncertainties in isotope values and sample measurements. This term is used to determine an appropriate damping factor (*ε2*) for the inverse model. We matched the model output of estimated error (*Emeas*) and propagated error for the inverse predictions (*Epred*) by choosing an appropriate damping factor for each canine profile (Supplementary S2). Model code was adopted from [Passey et al. (2005a)](#_ENREF_15) and run in MATLAB (v. R2019b).

**7. Sensitivity test of inverse model output using different *finit***

One of the major assumptions in the inverse model for the canine isotope data is that the initial mineral density of canine enamel matrix is the same as molar enamel matrix. To further investigate how sensitive the inverse model is to different initial mineral densities, we applied a range of *finit* (from 0.25 to 0.55 as a reasonable range of *finit* values) to the inverse model while keeping the other parameters constant using the MPL2 canine dataset. The average 100 model solutions are reported in Supplementary S2 and plotted in Figure S3. The average solutions of all other *finit*values fall within the confidence interval (± 2σ) of the solutions with *finit* = 0.45, suggesting that our assumption about canine enamel matrix density should not significantly influence our interpretation of canine isotope variation and seasonality.

**8. The relationship between appositional angle and enamel extension rate**

Previous studies of hypsodont molars observed an exponential decrease in the appositional angle (enamel formation front angle) as enamel extends close to the cervical margin ([Hoppe et al., 2004](#_ENREF_7); [Nacarino-Meneses et al., 2017](#_ENREF_11); [Uno et al., 2020](#_ENREF_20)*;* [Zazzo et al., 2012](#_ENREF_22)). A similar pattern is also observed in the warthog M3, but not in the warthog canine (Supplementary S2). We further explored the relationship between the enamel extension rate and the appositional angle, which are both dependent upon the location of the EDJ. We found that there is no relationship between the appositional angle and enamel extension rate in the canine, but a significant exponential decrease (using a generalized linear model with a link function of natural log, *p* < 0.0001) in the enamel extension rate relative to the appositional angle in the molars (Figure S5), after pooling both the Souron1 and NKU molar data. This indicates that appositional angle can be used to predict enamel extension rate, and vice versa ([McGrath et al., 2019](#_ENREF_10)). One potential application of this finding would be to estimate enamel extension rates based on the angles of laminations at broken enamel surfaces via confocal scanning optical microscopy ([e.g., Bromage et al., 2009](#_ENREF_1)). This potential application can avoid the damaging of a specimen due to the destructive nature of thin section preparation. This is especially valuable for fossil specimens because they are subject to the rules and regulations of the country of origins in which destructive data collection methods are strongly discouraged. Another implication of this relationship is that calculating enamel extension rates may not have to depend on crown height measurements. This is potentially useful in teeth that are worn and whose original crown height is difficult to reconstruct. One last potential application of this finding would be building simpler mathematical models in reconstructing the isotopic input in body water, since this relationship is related to both growth and mineralization geometry. More data on this relationship in other taxa would help to improve our understanding of tooth formation and mineralization, as well as modeling efforts in environmental reconstruction.

**9. Enamel daily secretion rates in warthog M3s and canines**

In order to provide additional information on how warthog M3s and canines form, we measured daily secretion rates (DSRs) using the same thin sections in which enamel extension measurements were made. Digital images were taken using a 50x objective lens (1 pixel = 0.34 μm), supplemented by images taken with a 20x objective lens (1 pixel = 0.84 μm), using the same microscope setup as in Section 2.2 of the main manuscript. Only the buccal side of each tooth was measured for DSR, due to low visibility of the enamel microstructure on the lingual side. In each tooth, the enamel was divided into three crown regions along the EDJ: the upper third (close to the cusp tip), the middle third, and the lower third (close to the cervix). For the M3s, DSR was measured in three zones: the inner (close to the EDJ), middle, and outer (close to the outer enamel surface) enamel ([following Kierdorf et al., 2014](#_ENREF_8)). For the Souron2 canine, due to the thin enamel, it was divided into only inner and outer zones. DSR was recorded as distance (in μm) along the prism pathway from one lamination to another. DSRs were measured in five different locations in a single enamel zone and the arithmetic mean of the five was used to represent the DSR of the respective zone.

Daily secretion rates (DSRs) of warthog M3 enamel fall between 12 μm/day and 27 μm/day. In comparison, DSRs of canine enamel is much lower, between 8 μm/day and 16 μm/day (Table S6). The Souron1 M3 exhibits significantly higher DSRs compared to the NKU M3. In general, DSR increases from the inner zone to the outer zone along the enamel prism in both the M3 and the canine enamel. Within a single tooth and within each enamel zone, DSRs show a slight decrease from the cuspal region to the cervical region along the EDJ, while DSRs between enamel zones are significantly different. Compared to the DSRs of the wild boar (*Sus scrofa*) M3s ([Kierdorf et al., 2019](#_ENREF_9)), the DSRs of the warthog M3s share a similar pattern of variation among enamel zones.

The significant difference in DSRs between the Souron1 and the NKU M3s is likely due to the different developmental stages of the two teeth, with the Souron1 M3 being only slightly worn and the NKU M3 being moderately worn and with roots formed. It is also possible that the differences relate to inter-individual variation or sexual dimorphism, which we do not have enough information to discern. Future studies that sample a wider range of developmental or wear stages of warthog M3s with known sexes will help to resolve this concern. In terms of absolute DSR, warthog M3s have overall higher DSRs (*ca.* +20 % on average) than those of the wild boar M3s. This observation suggests that the striking difference in crown height between the warthog and the wild boar is only partially due to higher DSRs, but to a greater extent due to the high enamel extension rates that are associated with low appositional angles (EFF angle) in the warthog. This has also been observed in apes ([McGrath et al., 2019](#_ENREF_10)), hominins ([Dean, 2009](#_ENREF_5)), and fossil equids of different crown heights ([Nacarino-Meneses et al., 2017](#_ENREF_11)). The results here reinforce the importance of the relationship between the appositional angle and enamel extension rate discussed before.

**10.** **Additional discussion on the carbon isotope spacing between canine enamel and enamel of other tooth types**

A carbon isotope spacing between canine and incisor (*Δ*c-i13C) profiles was also found in domestic pigs ([Frémondeau et al., 2012](#_ENREF_6)). The authors observed that the amplitude of change in the canines are larger than those in other teeth. Isotope profiles of M3s are also available in [Frémondeau et al. (2012)](#_ENREF_6). However, it was difficult to match the variation patterns of the M3 to those of the canines in the same individual because of a much more attenuated signal in the M3. Nevertheless, the incisors (both I1 and I2 combined) show similar patterns of variation in δ13C compared to those of the canines. Figure S6 shows four out of five domestic pig incisor and canine profiles. The one specimen that is omitted here has isotope profiles that lack characteristic seasonal patterns, making it difficult to interpret. The differences between the overlapping portion of the canine and incisor profiles are summarized in Table S3. Due to the different sampling intervals between I1 and I2, resampling (2,000 iterations) was performed to account for skewness when combining the two profiles for comparison. Therefore, the means and medians reported in Table S4 are results based on resampling and marked with an asterisk (\*). The differences in the range between the I1 + I2 combined profiles and the canine profile are consistently smaller than the differences between the means and the medians. This suggests that the shift between the incisors and the canine is larger than the difference in the “amplitude”.

**11. Linear regression combining both the Souron1 and NKU enamel extension rate data**

The timeline reconstructions based on MPL1 and MPL2 molar profiles are based on the Souron1 growth regression only. This is because the enamel in both specimens is still growing and it is relatively straightforward to estimate the amount of enamel lost due to dental wear. However, in the published M3 profiles by [Reid et al. (2019)](#_ENREF_17), only the distance from the enamel-root junction (cervix) is reported and most of the specimens have high crowns that are beyond the predictive range of the NKU regression. To provide more meaningful estimates for enamel extension rates and timeline reconstructions, we decided to combine the Souron1 and the NKU dataset and use one regression model for section 4.4 (Discussion) only. The main rationale behind this is based on the nearly identical slopes in the Souron1 and NKU regressions.

Enamel extension rates in the warthog molars are referenced to the length of EDJ from the estimated dentine horn location in the thin sections. We combined the two datasets by adding 35 mm to the EDJ measurement of the NKU dataset, making 58.5 mm the maximum EDJ length measurement of the dataset and 8.3 mm the minimum. The most significant effect of using this combined dataset is a smaller 95 % prediction interval of the model compared to either Souron1 or NKU, due to a higher *R2* value and lower residual error. To compensate for this effect, we chose 98 % prediction interval to estimate error in the timeline reconstruction. The regression is plotted in Figure S7.

Due to the fact that the regression is based on EDJ measurement from the dentine horn, we converted the isotope sampling measurement into EDJ length measurement using this equation:

EDJL = 58.5 + 3 ̶ sampling distance (mm) (5);

A value of 3 mm is added to the maximum length of EDJ based on the length of the first decile measured in the thin section of the NKU specimen (see Supplementary S2).

**12. List of data available in Supplementary S2**

a) Stable isotope raw data for MPL1 and MPL2

b) Souron2 canine extension rate and appositional angle raw data

c) Souron1 molar extension rate and appositional angle raw data

d) NKU molar extension rate and appositional angle raw data

e) Inverse model parameters

f) Inverse model output

g) Reconstructed timelines

h) Lengths of seasonal cycles at Mpala

**Supplementary Tables**

Table S1. Test of normality using Shapiro-Wilk normality test.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Profile | *W* | *p*-value | Profile | *W* | *p*-value |
| MPL1C δ13C | 0.980 | 0.938 | MPL2C δ13C | 0.926 | 0.072 |
| MPL1C δ18O | 0.948 | 0.365 | MPL2C δ18O | 0.943 | 0.169 |
| MPL1M δ13C | 0.910 | 0.074 | MPL2M δ13C | 0.927 | 0.150 |
| MPL1M δ18O | 0.939 | 0.248 | MPL2M δ18O | 0.972 | 0.815 |

Table S2. Comparing canine and molar stable isotope values. For δ13C profiles, Mann-Whitney *U* test is used because the Shapiro-Wilk normality test shows that some of the δ13C profiles are approaching statistical significance in deviating from a normal distribution. For δ18O profiles, Shapiro-Wilk normality test yielded insignificant results. Therefore, Welch’s *t*-test was used (see table S1 for more details). Comparisons that reach statistical significance are bolded.

|  |  |  |  |
| --- | --- | --- | --- |
| Profiles | *W* | | *p*-value |
| MPL1C δ13C vs MPL1M δ13C | 361 | | **<0.0001** |
| MPL2C δ13C vs MPL2M δ13C | 475 | | **<0.0001** |
|  |  | |  |
| Profiles | *t* | *Df* | *p*-value |
| MPL1C δ18O vs MPL1M δ18O | 3.418 | 35.689 | **<0.01** |
| MPL2C δ18O vs MPL2M δ18O | 0.503 | 41.631 | 0.618 |

Table S3. Comparison of reconstructed seasonality based on local high and low δ18O values in model output and measured M3 profiles; Δ18O is the difference between the high and low points, which is used in calculating the percentage signal preserved in molar profiles; the duration of seasonality is reported with the 95 % confidence interval (CI); consistent seasonal durations between the model output and molar timelines are bolded; asterisks (\*) indicate timeline reconstruction based on inverse model output.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | MPL1 \*modeled | MPL1 M3 | MPL2 \*modeled | MPL2 M3 |
| Season 1 | Dry | Dry | Dry | Dry |
| Δ18O (‰) | +3.3 | +2.1 | +3.9 | +1.9 |
| Duration [95 % CI] (days) | 151 [120 – 206] | 203 [175 – 240] | 79 [63 – 107] | 104 [88 – 126] |
| Season 2 | Rainy | Rainy | Rainy | Rainy |
| Δ18O (‰) | −0.5 | −0.4 | −4.2 | −2.5 |
| Duration [95 % CI] (days) | 49 [39 – 68] | 25 [21 – 31] | 111 [87 – 151] | 83 [68 – 105] |
| Season 3 | Dry | Dry | Dry | Dry |
| Δ18O (‰) | +3.0 | +1.6 | **+5.3** | **+3.5** |
| Duration [95 % CI] (days) | 48 [37 – 66] | 76 [64 – 95] | **124 [97 – 172]** | **120 [96 – 159]** |
| Season 4 | Rainy | Rainy | Rainy | Rainy |
| Δ18O (‰) | −2.5 | −0.8 | −2.7 | −1.0 |
| Duration [95 % CI] (days) | 83 [65 – 117] | 56 [46 – 72] | 42 [33 – 59] | 75 [57 –111] |
| Season 5 | - | - | Dry | Dry |
| Δ18O (‰) | - | - | +2.8 | +0.7 |
| Duration [95 % CI] (days) | - | - | 56 [43 – 80] | 35 [26 – 54] |
| Season 6 | - | - | Rainy | Rainy |
| Δ18O (‰) | - | - | −**3.9** | −**2.3** |
| Duration [95 % CI] (days) | - | - | **102 [78 – 149]** | **120 [86 – 198]** |

Table S4. Summary of canine and incisor isotope profiles reported in [Frémondeau et al. (2012)](#_ENREF_6); asterisks (\*) indicate mean of resampled data (2,000 iterations), to account for the skewness in the dataset.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Specimen | Tooth | Mean δ13C (‰) | Median δ13C (‰) | Min δ13C (‰) | Max δ13C (‰) | Range (Max – Min, ‰) | Δ mean δ13C (‰) | Δ median δ13C (‰) | Δ range δ13C (‰) |
| PCR1 | canine | −11.5 | −11.6 | −12.9 | −10.1 | 2.8 | 0.9 | 0.8 | 0.1 |
| I1 + I2 | −12.4\* | −12.4\* | −13.8 | −10.9 | 2.9 |
| PCR2 | canine | −9.7 | −10.0 | −12.3 | −7.7 | 4.6 | 1.4 | 1.1 | 0.4 |
| I1 + I2 | −11.1\* | −11.1\* | −13.3 | −9.1 | 4.2 |
| PCR3 | canine | −9.1 | −9.5 | −11.3 | −6.2 | 5.1 | 1.0 | 0.5 | 0.3 |
| I1 + I2 | −10.1\* | −10.0\* | −12.5 | −7.7 | 4.8 |
| PCR5 | canine | −7.7 | −7.3 | −10.7 | −5.5 | 5.2 | 1.3 | 1.3 | 0.5 |
| I1 + I2 | −9.0\* | −8.6\* | −12.0 | −7.3 | 4.7 |

Table S5. Duration of seasonality interpreted from reconstructed M3 timelines, based on intra-tooth sampling data published in [Reid et al. (2019)](#_ENREF_17); the durations that likely represent unimodal pattern of rainfall are bolded (365 days within the range, which is calculated using 95 % confidence interval). R = rainy season; D = dry season.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Specimen | B 58.2 | B384 | B33 | B56.1 | 4035 | 4032 |
| Season | - | R + D | R + D | R + D | - | - |
| Duration  [Range] (days) | - | 276  [238 – 330] | 242  [208 – 291] | 284  [238 – 352] | - | - |
| Season | **D + R** | D + R | D + R | - | D + R | D + R |
| Duration  [Range] (days) | **387**  **[306 – 528]** | 211  [178 – 259] | 159  [134 – 195] | - | 237  [199 – 294] | 172  [147 – 207] |
| Season | - | R + D | R + D | - | - | R + D |
| Duration  [Range] (days) | - | 260  [209 – 346] | 122  [100 – 156] | - | - | 228  [188 – 291] |
| Season | - | - | - | - | - | **D + R** |
| Duration  [Range] (days) | - | - | - | - | - | **291**  **[233 – 390]** |

Table S6. Daily secretion rates (DSR) measured along the prism path in different enamel regions; inner = close to EDJ, outer = close to outer enamel surface; upper = close to cusp tip, lower = close to cervix; Mean and SD values are italicized.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| DSR (μm/day) | Souron1 UM3 Buccal | | | NKU UM3 Buccal | | | Souron2 Canine Buccal | |
| Crown region | Inner | Middle | Outer | Inner | Middle | Outer | Inner | Outer |
| Upper third | 19.08 | 20.85 | 26.58 | 14.98 | 15.5 | 16.64 | 11.19 | 15.69 |
|  | 17.86 | 24.71 | 21.75 | 15.58 | 15.76 | 16.93 | 12.61 | 15.2 |
|  | 19.19 | 22.44 | 25.21 | 14.38 | 15.77 | 16.99 | 12.46 | 15.17 |
|  | 18.06 | 24.35 | 22.38 | 13.98 | 15.63 | 18.12 | 11.95 | 15.18 |
|  | 18.26 | 20.71 | 26.35 | 15.06 | 15.9 | 19.34 | 11.58 | 14.77 |
| Mean | *18.49* | *22.61* | *24.45* | *14.80* | *15.71* | *17.60* | *11.96* | *15.20* |
| SD | *0.61* | *1.88* | *2.25* | *0.62* | *0.15* | *1.12* | *0.59* | *0.33* |
| Middle third | 16.6 | 20.6 | 22.98 | 13.71 | 15.79 | 16.07 | 11.53 | 14.33 |
|  | 16.52 | 21.45 | 25.65 | 14.82 | 15.57 | 17.68 | 11.17 | 14.02 |
|  | 17.5 | 23.43 | 24.07 | 15.5 | 15.1 | 18.22 | 11.35 | 14.88 |
|  | 15.47 | 20.62 | 23.85 | 13.96 | 14.47 | 18.96 | 11.68 | 15.01 |
|  | 15.69 | 21.86 | 24.42 | 14.55 | 14.43 | 18.21 | 9.87 | 15.36 |
| Mean | *16.36* | *21.59* | *24.19* | *14.51* | *15.07* | *17.83* | *11.12* | *14.72* |
| SD | *0.81* | *1.16* | *0.97* | *0.71* | *0.62* | *1.08* | *0.72* | *0.54* |
| Lower third | 16.99 | 19.01 | 26.93 | 12.97 | 16.09 | 18.53 | 10.87 | 15.3 |
|  | 17.81 | 19.51 | 23.4 | 12.58 | 15.54 | 17.27 | 10.02 | 14.6 |
|  | 17.76 | 21.93 | 21.34 | 12.79 | 14.64 | 16.78 | 11.19 | 14.42 |
|  | 16.5 | 19.57 | 22.55 | 13.83 | 16.5 | 18.58 | 9.48 | 14.28 |
|  | 15.54 | 19.69 | 22.63 | 14.52 | 15.04 | 16.01 | 8.25 | 13.65 |
| Mean | *16.92* | *19.94* | *23.37* | *13.34* | *15.56* | *17.43* | *9.96* | *14.45* |
| SD | *0.95* | *1.14* | *2.12* | *0.81* | *0.76* | *1.12* | *1.17* | *0.59* |

**Supplementary Figures**



Figure S1. Souron2 canine mineralization pattern based on micro-CT grayscale values using transects perpendicular to the enamel-dentine junction (EDJ); panel a) shows the relative density of dental tissue as fractions of mature enamel along the transects shown in panel b); note that the initial enamel matrix is not preserved in this specimen, marked by the presence of EDJ towards the cervix while only dentine is visible.



Figure S2. Souron1 molar mineralization pattern based on micro-CT grayscale values using transects perpendicular to the enamel-dentine junction (EDJ); panel a) shows the relative density of dental tissue as fractions of mature enamel along the transects shown in panel b).



Figure S3. Inverse model output using different *finit* values; gray shaded area is ±2σ of the 100 solutions when *finit* is set at 0.45; V-PDB = Vienna Pee Dee Belemnite; ERJ = enamel-root junction.



Figure S4. Warthog canine (Souron2) enamel appositional angle (enamel formation front angle) along the EDJ; dark gray shaded area: 95 % CI for regression; light gray shaded area: 95 % prediction interval for regression.



Figure S5. A logarithmic decrease in molar extension rate as enamel appositional angle increases; gray shaded area represents 95 % confidence interval of the best fit line.



Figure S6. Stable carbon isotope profiles of canine and incisors in four out of five specimens reported in [Frémondeau et al. (2012)](#_ENREF_6); data points were aligned manually to ensure maximum overlap in the shapes of the curves; black squares represent canine isotope data; open circles and diamonds represent isotope data from I1 and I2, respectively.



Figure S7. Linear regression combining both the Souron1 and NKU datasets; dark gray shaded area: 98 % CI for the best fit line; light gray shaded area: 98 % prediction interval of the regression.



Figure S8. Reconstructed timelines of M3 based on intra-tooth sampling data published in [Reid et al. (2019)](#_ENREF_17); Rec. = reconstructed; CI = confidence interval; V-PDB = Vienna Pee Dee Belemnite; D = dry season; R= rainy season.

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