Recovering stable isotope time-series in tooth enamel: a new method

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Introduction

Stable isotopes are non-radioactive elemental species that differ by mass and widely used as an archive of ecological information. Ratios of stable carbon $^{13}C/^{12}C$ ($\delta^{13}C$) and oxygen $^{18}O/^{16}O$ ($\delta^{18}O$) from tooth enamel are commonly used to understand the diets and environments of modern and fossil animals. Isotope variation within the lifetime of individual animals can be recovered by microsampling along the direction of growth (Fig 1a). However, the prolonged nature of enamel development results in significant signal attenuation (Fig 1b).

Sampling along the rapidly mineralized innermost enamel layer (0.01-0.02 mm) may provide a less dampened isotope signal. To test this hypothesis, secondary ion mass spectrometry (SIMS) is used to sample the innermost enamel layer of a woodrat (*Neotoma cinera*) incisor (Fig 2) from a controlled water-switch experiment (drinking water $\delta^{18}O$ from 15.0‰ to -16.1‰; food constant at 24.0‰). SIMS values are compared with $\delta^{18}O$ values sampled from the enamel surface by laser ablation (attenuated signal) and breath CO_2 (primary signal).

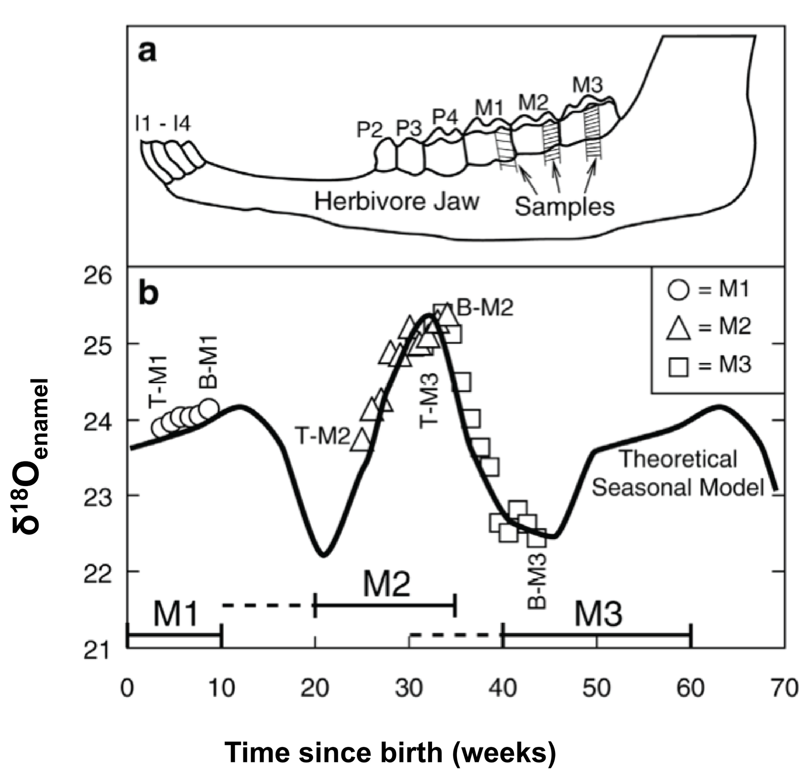

Figure 1a: Conventional enamel incremental sampling (Kohn and Cerling 2002)

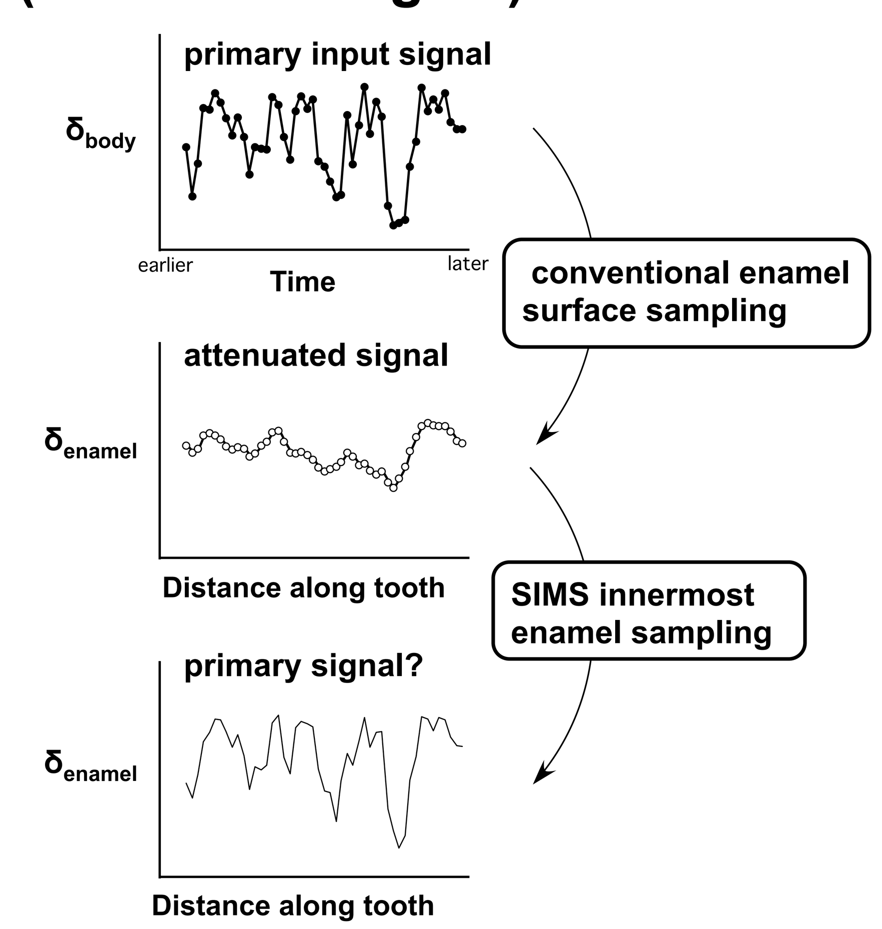

Figure 1b: Signal loss and sampling technique (Passey and Cerling 2002)

Methods

SIMS was performed with the WiscSIMS CAMECA ims-1280 high resolution, multi-collector ion microprobe using a $^{133}Cs^{+}$ primary ion beam focused to ~4 μm beam-spot size. Analytical conditions were similar to those previously reported for work at this facility (Kita *et al.* 2009). Reproducibility of the individual spot analyses of UWA-1 standard generally varies from approximately 0.5 to 1.3 ‰ (± 2 SD). After analysis at WiscSIMS, sample spots were examined with SEM to ensure each pit does not overlap with dentin, surface discontinuities, or epoxy resin (Fig 3). SIMS values are reported raw, as the apatite standard UWA-1 is not yet certified relative to VSMOW. Applying an offset of 2‰ brings SIMS values into rough alignment with laser enamel values.

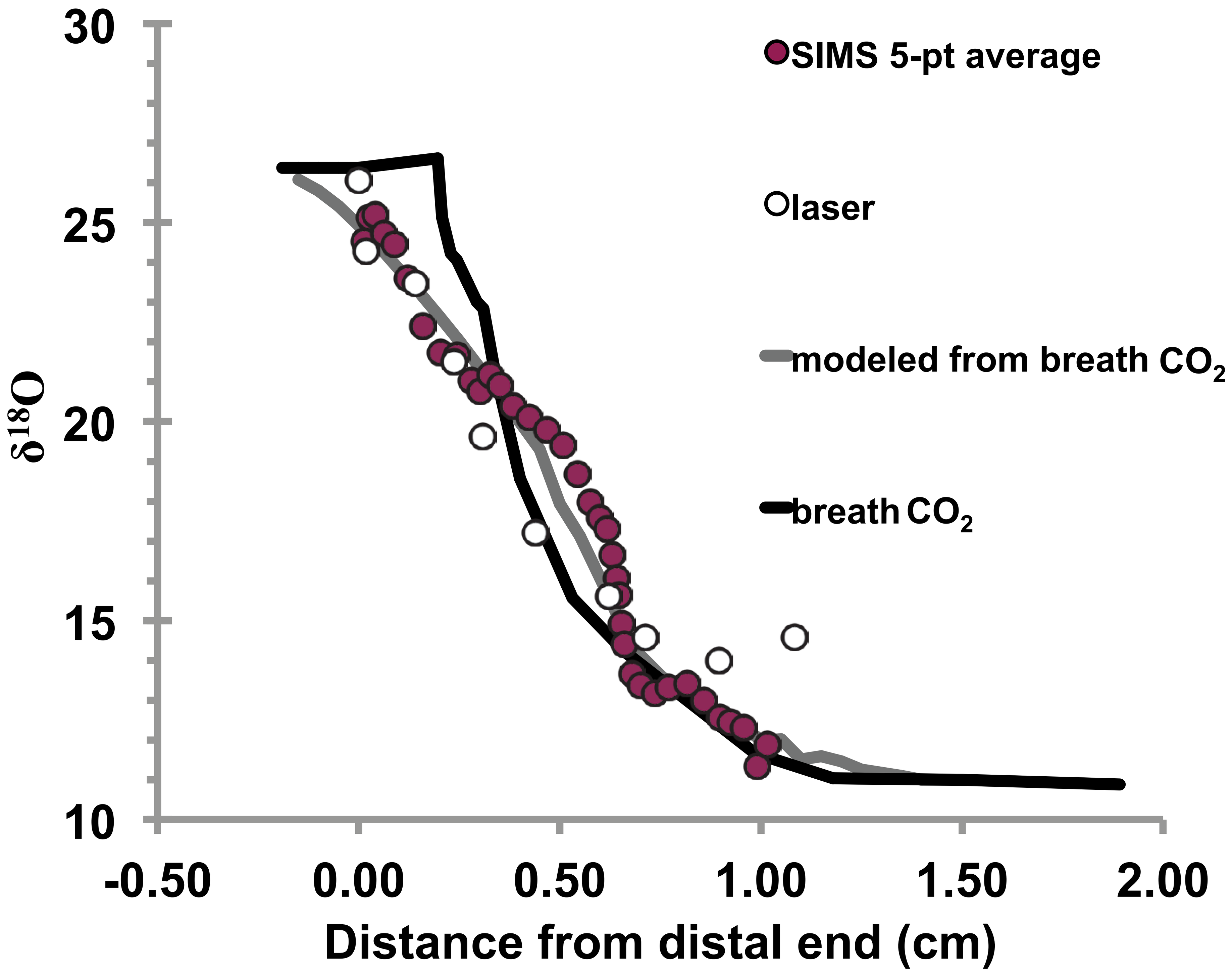

Figure 4: SIMS enamel, laser enamel, modeled enamel, and breath CO_2 $\delta^{18}O$ values (from Podelsak *et al.* 2008)

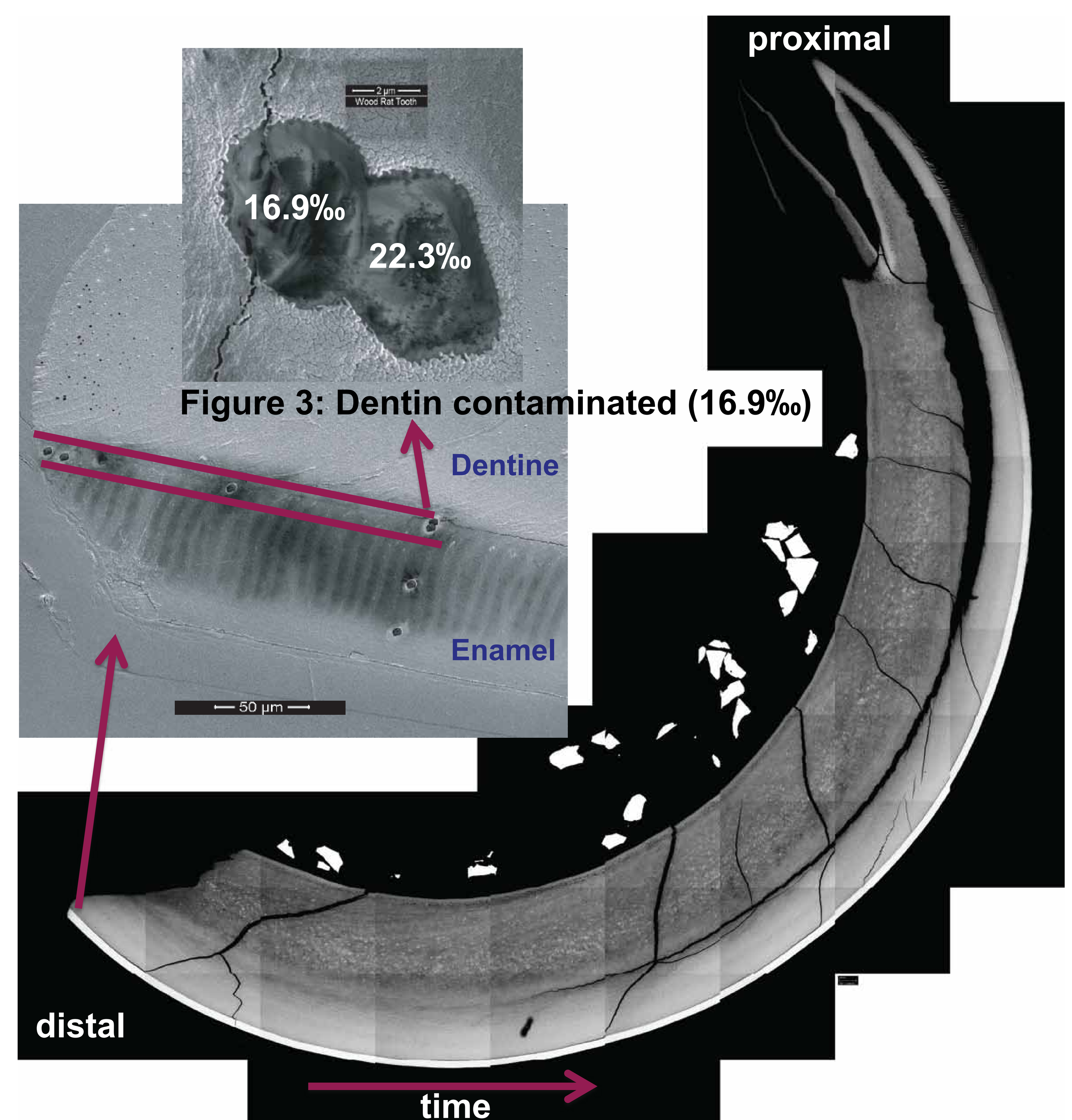

Figure 3: Dentin contaminated (16.9‰)

Figure 2: Woodrat incisor section; innermost enamel layer (inset)

Results and discussion

The range in $\delta^{18}O_{SIMS}$ values is 15.9‰, capturing the full abrupt shift in $\delta^{18}O$ recorded in breath CO_2 (a proxy for body water). $\delta^{18}O_{SIMS}$ values from sample spots in close proximity exhibited idiosyncratic variability, which was smoothed with a 5-point moving average (Fig 4). Enamel $\delta^{18}O$ values predicted with a forward model based on breath correspond closely with the SIMS profile. While $\delta^{18}O_{laser}$ values obtained from the enamel surface recover an attenuated signal, sampling the innermost enamel layer captures the primary input signal with high fidelity.

Conclusions

The rapidly mineralizing innermost enamel layer records the most unaltered archive of isotope variability in tooth enamel. This narrow zone should be targeted in isotope studies where recovering the full amplitude of environmental input variability is critical. This technique holds particular promise for efforts directed at reconstructing seasonal shifts in diet and climate.

Future work will focus on understanding changes in seasonality characterizing the past six million years of human evolution. Analyses of enamel from modern animals derived from habitats characterized by contrasting patterns of rainfall seasonality will provide a framework for interpreting oxygen isotope profiles from fossil herbivores.

Acknowledgments

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