New Tooth Growth Model for Studying Ancient Climate

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Seasonal climate impacts ecosystem productivity and human subsistence, and is hypothesized to have influenced early human technological development. Rainfall patterns are reflected by oxygen isotope ratios ($\delta^{18}O$ values) in tooth enamel, which records environmental chemistry during mineralization. Fossilized herbivore molars are used for climate reconstruction as seasonal variation in precipitation $\delta^{18}O$ results in spatial variation in tooth phosphate $\delta^{18}O$. However, this approach has been hampered by incomplete knowledge of tooth mineralization. Here we use synchrotron x-rays and MCMC methods to build a dynamic model of herbivore molar mineralization from sheep molars. We integrate tooth growth and blood oxygen isotope turnover to produce high-resolution isomap predictions, and test these using fine-scaled phosphate $\delta^{18}O$ measurements in a sheep subjected to a controlled water switch. Results demonstrate that enamel secretion and maturation waves advance at nonlinear rates with distinct geometries, and include isotopic shifts during enamel maturation from amorphous precursors. We produce an inverse system for reconstructing water $\delta^{18}O$ inputs from tooth isotopic measurements. This system reconstructs rainfall histories at different latitudes with striking fidelity. Results also indicate a revised mammalian phosphate-water offset. By accounting for nonlinear growth with our model, even simple conventional sampling approaches may yield accurate reconstructions. Tooth isotopic measurements have the potential to quantitatively reconstruct seasonal rainfall patterns and further exploration of the relationships between climate, behavior and human evolution.