A Stable Isotope Aridity Index for Terrestrial Environments

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The terrestrial oxygen isotopic record from East Africa is underutilized because it has been difficult to distinguish the influences of evaporation (aridity), ^{18}O composition of precipitation, and physiology, on $\delta^{18}O$ values of fossil teeth and soil carbonate. Here we present a simplified approach to using bioapatite $\delta^{18}O$ values as environmental indicators. In this approach, we account for physiological and behavioral differences between animals, and we isolate the effects of meteoric water ^{18}O composition and evaporation on tooth enamel $\delta^{18}O$ values. During evaporation, the $^{18}O/^{16}O$ ratio in residual waters increases and functions as an isotopic label for evaporated waters. If evaporated and non-evaporated water sources can be identified, then the isotopic difference between these sources can be used to quantify the degree of evaporative enrichment, and thereby serve as a proxy for aridity. Using a large isotopic dataset of East African mammal teeth (> 1000 teeth), we classify mammals by their isotopic sensitivity to environmental aridity and place them into two groups, evaporation sensitive (ES) and evaporation insensitive (EI). ES animals ingest evaporated waters and have tooth enamel $\delta^{18}O$ values that increase linearly with aridity, whereas EI animals ingest relatively unevaporated waters and their tooth enamel ^{18}O composition tracks that of local meteoric water. Data from modern East African mammals show that bioapatite $\delta^{18}O$ values of animals with different behaviors track different aspects of the same environment. The difference between tooth enamel $\delta^{18}O$ values of ES and EI animals records the degree of ^{18}O enrichment between evaporated water and source water, which increases with environmental aridity as described in Craig and Gordon's 1965 model. By recognizing the ES-EI distinction, $\delta^{18}O$ values of tooth enamel can be used as a quantitative proxy for terrestrial aridity. The aridity index has immediate application to evaluating how aridity affected human evolution in East Africa.