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Local water resource variability and oxygen isotopic reconstructions of mobility: A case study from the Maya area

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ABSTRACT

Stable oxygen isotopic studies of migration and mobility using human tissue are based on the premise that $\delta^{18}O$ values of potable water sources are relatively stable over time and vary predictably across the landscape. Local variability of $\delta^{18}O$ is generally assumed to be negligible and negated by an averaging effect as oxygen is consumed primarily as imbibed liquid and incorporated into tissue. This study tests the assumption that variability of $\delta^{18}O$ ratios of water from within a region are insufficient to impact the reconstruction of ancient mobility using isotopic measures of human tooth and bone. This case study focuses on the Maya area of Guatemala and Mexico, a region where many analyses of oxygen isotopic ratios in ancient human tissue has been conducted. 71 water samples were obtained over the course of five years, from precipitation, streams, rivers, lakes, *aguadas* (watering holes), *civals* (perennial wetlands), and caves. Unlike most baseline studies, the objective here was the repeated testing of a diversity of sources from the same location. $\delta^{18}O_{VSMOW}$ values from surface and meteoric water range from −16.0 to +3.6‰. The precipitation range is −16.0 to 1.58‰ ($n = 22$) with the highest and lowest values measured at the same location (El Zotz, Guatemala). The surface water range is −9.2 to 3.6 ($n = 48$), the lowest value is the Usumacinta River at Yaxchilan and the highest value is from a lake located 65 kilometers away. The $\delta^{18}O$ values of local streams were remarkably stable over time. Major rivers, such as the Usumacinta River, have relatively constant values. Closed water basins (lakes, *aguadas*, and *civals*) demonstrated an evaporative effect and $\delta^{18}O$ was variable both between basins and in individual basins over time. In the Petén region, mean $\delta^{18}O$ of precipitation is statistically different than that of lake and *aguada* water. Local $\delta^{18}O$ differences in consumed water likely explain the variability observed in human tooth enamel at Tikal and other Petén region sites. This case study demonstrates that local isotopic values may be more diverse than is generally assumed in studies of human mobility that rely on little to no baseline data. Future studies of mobility based on oxygen isotopic measures of ancient human tooth and bone should include measures of both meteoric water and a diverse range of surface and groundwater to develop more robust interpretations of oxygen isotopic values in ancient human tissue.

1. Introduction

Stable oxygen isotope ratios have been widely employed in the archaeological sciences to reconstruct ancient climates (Brenner et al., 2003; Emery and Kennedy Thornton, 2008; Hodell et al., 1995, 2005, 2007; Kennett et al., 2012; Medina-Elizalde et al., 2010; Medina-Elizalde and Rohling, 2012; Repussard et al., 2014), childhood diets (Dupras and Tocheri, 2007; White et al., 2004a; Wright, 2013; Wright and Schwarcz, 1998, 1999b), and to measure mobility over the course of an individual's lifespan (Buzon et al., 2011; Dupras and Schwarcz, 2001; Eckardt et al., 2009; Evans et al., 2006a; Keenleyside et al., 2011; Knudson, 2009; Knudson et al., 2009; Müldner et al., 2011; Spence et al., 2004; Stuart-Williams et al., 1996; White et al., 1998, 2000, 2001, 2002, 2004b,c, 2007; Wright, 2012). The ratio of the relatively rare isotope, ^{18}O, is measured against the abundant ^{16}O and is reported relative to the ratio ($^{18}O/^{16}O$) of a reference standard as $\delta^{18}O$ per mil (‰). Vienna Standard Mean Ocean Water (VSMOW) is the most common standard used. $\delta^{18}O$ of animal tissue reflects the isotope ratios of ingested water, which for humans is water imbibed as liquid (Kohn, 1996; Longinelli, 1984; Luz et al., 1984).

The $\delta^{18}O$ of surface and groundwater is largely determined by the $\delta^{18}O$ of local meteoric water. Generally, as air masses move inland from the ocean they become depleted in ^{18}O as the heavier isotope is lost in precipitation. ^{18}O depletion is affected by temperature and the fraction of moisture removed from the air mass (Raleigh distillation) (Dansgaard, 1964). Nevertheless, $\delta^{18}O$ of water from a given location can vary and the extent of that variability will be dependent on the specifics of local climate, topography, and hydrology (Geyh, 2000:358, Różański et al., 2000:256,259,283). Surface water may become enriched in ^{18}O as a result of an evaporative effect. This effect is most pronounced

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in ponds and lakes in hot or arid regions. Input from riverine or groundwater may counteract the effect. $\delta^{18}O$ of groundwater, especially in cooler regions, is closely correlated to mean meteoric water. Groundwater and precipitation are the primary inputs of rivers and streams and riverine $\delta^{18}O$ is generally correlated to meteoric water. Rivers are more resistant to the evaporative effect and any difference will be most evident in rivers in hot, arid regions. Larger rivers have greater catchment areas and so their isotopic values can differ from that of mean local precipitation. Generally, $\delta^{18}O$ differences along a river become more pronounced when the catchment area involves greater elevation changes, especially in regions with seasonal meltwater of ice and snow. River headwaters reflect local precipitation values while $\delta^{18}O$ further down a river's course reflect the mean contribution of its tributaries. Overall, seasonal and annual variation in temperature and precipitation will effect $\delta^{18}O$ values of meteoric and surface water.

$\delta^{18}O$ of human tissue reflects an average of $\delta^{18}O$ in water imbibed at the time the tissue formed. Consumption of water from a variety of sources (for example, rivers, lakes, captured precipitation) that approximates a region's total $\delta^{18}O$ variability should result in tissue $\delta^{18}O$ that is statistically comparable to that area's mean. At localities with particularly diverse $\delta^{18}O$ among its available water sources, we may expect greater variability in $\delta^{18}O$ among the humans sample. As a result, variability in $\delta^{18}O$ in human tissue among skeletons from an archaeological site may indicate mobility among the population or could reflect the variance of $\delta^{18}O$ in potable water available to a population. The potential for $\delta^{18}O$ variability in local water is, however, generally disregarded (or only given brief consideration) in most oxygen isotopic studies of human migration.

A brief survey of prior research on ancient human $\delta^{18}O$ shows a fair amount of variation as to how researchers do (or do not) engage with baseline water $\delta^{18}O$ from their area of study. For example, in the British Isles, researchers generally rely on Darling and colleagues' study of British surface and groundwater $\delta^{18}O$ (Darling et al., 1999; Darling and Talbot, 1999). They found surface water to vary between −10.6‰ and −1.3‰. Ancient mobility researchers, however, generally ignore the surface water data and cite the more restricted range for groundwater (−9‰ to −4‰) as the expected values for water consumed on the British isles (Eckardt et al., 2009; Evans et al., 2006a:2818). Some studies rely less on the baseline ranges and instead distinguish local and foreign individuals in their archaeological samples based on comparison to the distribution of tooth and bone $\delta^{18}O$ from various sites in Britain (Müldner et al., 2011:284). When studying migration within the British Isles, researchers often cite both Darling and colleagues' groundwater range and the distribution of ancient human tissue data $\delta^{18}O$ (Budd et al., 2004; Evans et al., 2006b:317).

In the South American Andes, although relatively few mobility studies have been conducted utilizing oxygen isotope data, the general focus has been to identify movement between different environmental zones (coastal, mid-altitude, high altitude) (Buzon et al., 2011; Gil et al., 2014; Knudson, 2009; Knudson et al., 2009; Toyne et al., 2014; Turner et al., 2009). Researchers in the Andes generally define local signatures largely based on sample distribution of $\delta^{18}O$ in human bone and teeth, coupled with some comparison to meteoric and surface water data. In some cases, human $\delta^{18}O$ data from archaeological sites demonstrate mean $\delta^{18}O$ that accord with expected values based on measured water data, yet in other studies the human distribution deviates from the expected $\delta^{18}O$ values (Buzon et al., 2011; Knudson, 2009:185, Knudson et al., 2009:252). Most Andean sites demonstrate a high degree of human $\delta^{18}O$ variability that resists easy interpretation. Some scholars attribute the observed variability to a high degree of mobility among Andean populations (Gil et al., 2014; Toyne et al., 2014; Turner, 1990) while others caution that the complexity of Andean hydrology and water use may complicate the reconstruction of human mobility using oxygen isotopic data (Knudson, 2009). Diverse sources of drinking water in the Andes included rivers, canals, spring-fed fountains, and rainwater collected in cisterns (Turner et al., 2009:324).

In the Maya area, the focus of oxygen isotopic research has been the identification of mobile individuals, especially people who migrated between the lowlands, the Guatemalan highlands, and with other parts of Mesoamerica, especially Teotihuacan in Central Mexico. Most scholars infer the expected local range for humans based on the observed distributions of enamel oxygen ratios in tooth and bone samples, coupled with a few measures of area water $\delta^{18}O$. As a result, the breadth of the expected local ranges can vary substantially between studies. At Kaminaljuyu, Guatemala, Wright et al. (2010:169) proposed a local $\delta^{18}O$ range of −6.0 to −4.0‰ for enamel carbonate (Pee Dee Belemnite [PDB]). At Copan, Price et al. (2010:24) suggest a very narrow local range of −4.8‰ and −3.8‰ for enamel carbonate (PDB). For Tikal, Wright (2012:343) recognizes a relatively broad range of −5.0 to −1.0‰ for enamel carbonate (PDB). Local enamel phosphate ranges (reported in VSMOW) are given as 17.8 to 19.5‰ at Altun Ha, 18.3–20.4‰ at Rio Azul/Rio Bravo, and 15.6–17.7‰ at Kaminaljuyu (White et al., 2000:69). The proposed local ranges for Maya area sites vary between 1.0‰ (Copan) and 4.0‰ (Tikal). Since the method for defining local ranges in the Maya area has generally relied on the distribution of human enamel $\delta^{18}O$ in a particular study, the breadth of the proposed local ranges is dependent on sample size. The greater breadth of the local ranged proposed for Tikal enamel carbonate reflects the relatively large sample size ($n = 89$) of that study in comparison to the work at Copan ($n = 32$; the Copan local range was defined based on the assumption that eight non-elite skeletons represented the local $\delta^{18}O$ range). In no Maya study has the actual variability of water $\delta^{18}O$ at a given archaeological site been used to define an expected local range for oxygen isotope ratios in human tooth or bone.

As this brief review of prior publications suggests, there is marked variability in regards to the degree to which ancient isotope specialists incorporate data on baseline water $\delta^{18}O$ into their reconstructions of ancient mobility. The study reported here proceeds from the assumption that a better understanding of variability in potable water $\delta^{18}O$ should lead to more robust interpretations of $\delta^{18}O$ in ancient human tissue samples. Although the challenges of interpretation vary in each part of the world, there is a common reality that the $\delta^{18}O$ of water consumed by ancient humans may not always have been consistent with that of groundwater $\delta^{18}O$, which tends to have low intra-regional variability. Instead, depending on region, technology, and accepted practice, humans may have utilized lakes, streams, rivers, precipitation, and other sources that are generally more variable in $\delta^{18}O$. Long-term storage of water in cisterns, ceramic vessels, and other devices may further introduce $\delta^{18}O$ variability as a result of the evaporative effect. Boiling and other food preparation techniques can further alter $\delta^{18}O$ values and milk is enriched in ^{18}O relative to imbibed water (Roberts et al., 1988b; Wright and Schwarcz, 1999a). As a result of this potential intra-regional variability, it is problematic to infer the local range from the human data alone (as is typical of work in Maya area) or to proceed from the assumption that local groundwater was the primary source of potable water (as in the British Isles) without considering other sources of water that may have been exploited. This is especially true of contexts where enriched water (e.g., lakes, stored water, boiled water) may have been systematically employed for drinking purposes.

As a case study of the potential effect of variability in $\delta^{18}O$ of local water sources, this paper reports on meteoric and surface water data in Guatemala and Mexico, measured over a span of five seasons of archaeological fieldwork (Fig. 1). This region comprised the heartland of Classic period Maya (AD 350–900) society, the subject of numerous studies of mobility and migration based on oxygen isotopes (Freiwald, 2011; Price et al., 2010; White et al., 2000, 2001; Wright, 2012, 2013; Wright and Schwarcz, 1998, 1999b; Wright et al., 2010). The majority of data come from two areas: the Petén Lakes region of Guatemala and the Usumacinta River Basin (part of the modern border between Mexico and Guatemala). $\delta^{18}O$ was measured in samples of precipitation, rivers, streams, lakes, *civales* (perennial wetlands), and *aguadas* (watering holes).

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