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Focus article

Revisiting the strontium contribution of sea salt in the human diet

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ABSTRACT

Sea salt is getting increasing attention as a potential source of strontium incorporated into human tissues. One particularly interesting instance was published by one of us in 2005 in which sea salt was proposed as a possible reason why the stable strontium isotope ratios of ancient Maya human tooth enamel from Tikal, Guatemala, did not match the expected local strontium isotope signature. We revisit that analysis and identify a calculation error that led to an underestimate of the amount of salt required. Our revised mixing model increases the amount of salt required by 51 percent. We consider the implications of this for the case of the ancient Maya at Tikal and also discuss application of the mixing model in other circumstances.

1. Introduction

Strontium isotope ratio analysis is becoming common in archaeological investigations. When analyzed in archaeological human tooth enamel, strontium isotope ratios can identify individuals whose geographic location during childhood differs from their burial location and thereby reveal cultural practices such as migration or short-term travel patterns, postmarital residence patterns, and geographic relocation of victims of war or ritual sacrifice. The typical procedure is to compare strontium isotope ratios ($^{87}Sr/^{86}Sr$) in human tooth enamel to a burial area $^{87}Sr/^{86}Sr$ signature determined by ratios in fauna, geology, plants and drinking water sources (Bentley, 2006). In most pre-industrial cases where a non-local strontium ratio is found, it is assumed that it is the person who re-located rather than the source of strontium. That is, the result is interpreted based on an assumption that (at least during the period of enamel formation) children obtain most of their strontium from food and water procured locally. In many cases this is a reasonable assumption. An exception, however, may be cultures utilizing sea salt produced at coastal locations and either consumed locally or traded to inland settlements. Salt is a good candidate as a trade item because it has many important uses, can be easily transported long distances, does not quickly degrade, and without trade is often not readily available at inland locations. The production and trade of sea salt may have repercussions for our interpretation of strontium isotope ratios because sea salt has a significant amount of strontium and a strontium isotope ratio that may be substantially different than that found in terrestrial sources.

In 2005, one of us reported stable strontium isotope ratios in human remains from the ancient Maya city of Tikal (Wright, 2005; see also Wright, 2012). Most of the Tikal ratios did not closely match the local signature, even when outliers representing probable immigrants were removed. To assess whether sea salt may have contributed to this mismatch, a mixing model incorporating sea salt and lime-treated maize was created. Results indicated that about 6.1 g of sea salt daily could account for the difference. This result has been applied more widely as a reminder of the potential for sea salt to affect isotope ratios (e.g., Conlee et al., 2009; Laffoon et al., 2012). We revisited that analysis and determined that certain calculations included in the mixing model were incorrect. In particular, a term was inadvertently squared, producing the characteristic shape of a logistic equation when a simpler form was expected. Here we provide a revised mixing model. We have also taken this opportunity to review the parameters used in the model and in some cases provide updated values. Our results indicate that a given amount of sea salt provides less strontium than previously estimated but that it remains possible that sea salt made a significant contribution to raising the Tikal strontium isotope ratios above the expected local signature. We also discuss the potential contribution of sea salt to human strontium isotope ratios more generally.

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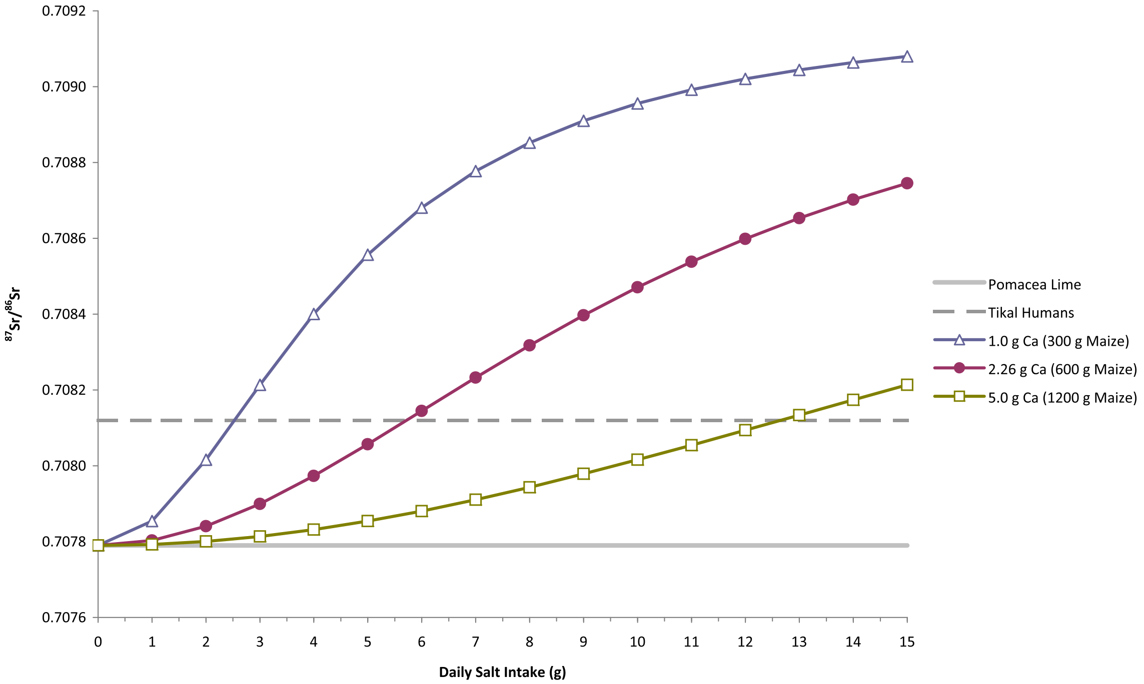

Fig. 1. Original mixing model results. Adapted from Wright (2005) Figure 5.

2. Material and methods

2.1. Tikal strontium isotope ratios

The ancient city of Tikal is located in the heartland of the southern Maya lowlands, in northern Guatemala, some 120 km from the Caribbean Sea to the east, and 230 km from the Gulf of Mexico to the northeast. As the focus of one of the earliest intensive excavation programs in the 1950s and 60s by the University Museum of the University of Pennsylvania, Tikal has played a key role in shaping archaeological reconstructions of ancient Maya society, settlement, agriculture and political systems (Sabloff, 2003). Among the most populous of Maya states, Tikal saw exponential growth in the Early and Late Classic periods, reaching perhaps 62,000 persons or more in its epicentre by AD 700 (Culbert et al., 1990). Political interactions among Tikal's royal dynasties and those of distant Maya cities are recorded on hieroglyphic monuments, both at Tikal and elsewhere, some of which imply long distance interaction with the central Mexican city of Teotihuacan, some 900 km to the northwest. The role of migration into the city, and its possible contribution to the rapid population growth, together with the possibility of foreign intervention in its Early Classic dynastic history (Stuart, 2000) make the site a prime candidate for study of ancient migration (Wright, 2005, 2012).

Wright (2005) analyzed strontium isotope ratios in enamel from 83 skeletal remains recovered from the Tikal area, 11 of whom were identified as immigrants based on their outlying stable strontium isotope ratios, which are characteristic of distant geological regions and/or can be identified as statistical outliers. The ^{87}Sr/^{86}Sr mean of the apparent locals (0.70812 ± 0.00019) was, however, substantially different than the local signature predicted by snail shell

Table 1
Parameters used in the mixing model.

Id	Description	Value	Units	Reference
Terrestrial parameters				
F	Food amount consumed (lime-treated dry maize)	300, 600 or 1200	g/day	600 g/day: Benedict and Steggerda, 1936: 174
Ca$_f$	Calcium concentration in food	0.00196	g Ca/g Food	Wu Leung, 1961: 15 (item 25)
[Sr]$_f$	Sr:Ca proportion in food	0.000559	g Sr/g Ca	Average of 2 *Pomacea flagellata* and 2 *Pachychilus glaphyrus* modern shells in Wright (1994) App E p. 435
R_f	^{87}Sr/^{86}Sr in food	0.70779		Wright, 2005: 561 Table 2
Sea Salt Parameters				
S	Daily salt intake	0 to 15	g/day	Per Wright, 2005: 562 Figure 5
Ca$_s$	Calcium concentration in sea salt	0.0012	g Ca/g salt	Horne, 1969: 419 Table 12.24
[Sr]$_s$	Sr:Ca proportion in sea salt	0.018	g Sr/g Ca	Assumed the same as in seawater. Culkin and Cox, 1966: 801
R_s	^{87}Sr/^{86}Sr in sea salt	0.7092		Assumed the same as in seawater. Elderfield, 1986: 76
Computational parameters				
87$_f$	^{87}Sr contributed from food		g ^{87}Sr/day	
86$_f$	^{86}Sr contributed from food		g ^{86}Sr/day	
87$_s$	^{87}Sr contributed from sea salt		g ^{87}Sr/day	
86$_s$	^{86}Sr contributed from sea salt		g ^{86}Sr/day	
R_h	^{87}Sr/^{86}Sr measured in Tikal humans			