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Paleodiet in northern Chile through the Holocene: extremely heavy $\delta^{15}N$ values in dental calculus suggest a guano-derived signature?

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ABSTRACT

Dental calculus extracted from the teeth of 28 prehistoric human skeletons from coastal and valley archaeological sites in northern Chile that date from the Archaic period (~2300 BC) to the Late Intermediate period (AD 1476) was analyzed for stable isotope ($\delta^{15}N$, $\delta^{13}C$) compositions. $\delta^{15}N$ compositions were extremely heavy (+17.8 to +33.1‰), but comparable to some studies using conventional human biomaterials (hair, nail, muscle) at other prehistoric sites in northern Chile. There was a negative correlation between $\delta^{15}N$ and $\delta^{13}C$ for coastal sites, but a positive correlation for valley sites. Results for the valley sites point to a diet that was influenced by marine resources throughout all time periods. The unusually heavy $\delta^{15}N$ values for the coastal sites require a dietary component with a $\delta^{15}N$ composition significantly heavier than that of marine resources. The hyper-aridity at the study area (mean annual rainfall of 0.5–0.6 mm/year) is a likely contributing factor to the production of heavy $\delta^{15}N$ values, but is unlikely to account for the heaviest $\delta^{15}N$ values (>+30‰). One possible explanation for the heaviest $\delta^{15}N$ values is that dietary components were impacted by isotopically-heavy guano, which is abundant in the region. Guano may have been used as a fertilizer during crop cultivation at the onset of the Formative period, continuing through the Historic period after Spanish contact. The indirect impact of guano from abundant bird habitats in the region may have influenced wild foodstuffs harvested throughout the pre-agricultural period. Results provide support for the utility of dental calculus as a proxy for obtaining stable carbon and nitrogen isotope signatures for use in paleodietary studies.

1. Introduction

Stable carbon and nitrogen isotopes ($\delta^{15}N$ and $\delta^{13}C$) have long been used to qualify and/or quantify dietary compositions for humans and other organisms because they are an effective determinant of possible food sources (e.g. Schoeninger, 2009, 2010; Schwarcz and Schoeninger, 1991). Stable isotope analysis of all sample material types is destructive, consumes a finite amount of sample material, and may not be allowed when laws designed to protect cultural remains, such as the Native American Graves Protection and Repatriation Act in the United States, preclude the destruction of primary biomaterials (i.e. bone, hair, nails, muscle tissue). In a recent study, Scott and Poulson (2012) suggested that dental calculus might serve as a new proxy for estimating stable carbon and nitrogen isotope ratios with application to paleodietary studies. Although stable isotope analysis of dental calculus is also destructive, consideration of calculus as a secondary (or "add-on") biomaterial rather than a primary biomaterial may alleviate curatorial concerns regarding the destruction of sample material in some cases.

Dental calculus is a biomineral derived from plaque, a biofilm that forms on tooth surfaces as a byproduct of microbial activity in the mouth (Scott and Poulson, 2012). If this plaque biofilm is not removed, it hardens to form calculus after approximately ten days. Calculus continues to accrete onto teeth over the course of an individual's lifetime. In the absence of modern dental hygiene practices that remove plaque and calculus, the presence of dental calculus in prehistoric teeth is a common occurrence. In contrast to

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other body tissues (e.g. collagen, muscle tissue, hair, fingernails) that have been used for stable isotope analysis, and consist of proteins with C/N weight ratios that lie within a relatively narrow range (e.g. 2.9–3.6 for collagen, 2.9–3.8 for hair; DeNiro, 1985; O'Connell and Hedges, 1999), calculus is not a conventional 'tissue' with a fixed C/N weight ratio. Mineralogical investigation reveals that calculus is composed primarily of various calcium phosphate minerals, including brushite, whitlockite, octacalcium phosphate, and hydroxyapatite (Hayashizaki et al., 2008; White, 1997), although organic components such as proteins, carbohydrates, lipids, and glycoproteins comprise 15–20% of the dry weight of calculus (Lieverse, 1999), and these organic components provide enough carbon and nitrogen to facilitate stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$). To the best of our knowledge, only one previous study (Scott and Poulson, 2012) has analyzed the stable isotopic composition of dental calculus.

Stable isotope analysis of dental calculus was performed for a suite of samples from the desert region of northern Chile to investigate paleodiet. The study area was selected for its abundant skeletal collections, excellent preservation, and broad temporal sequence, which covers the Archaic period (~2300 BC) to the end of the Late Intermediate period (AD 1476), just prior to the expansion of the Inca Empire into the region. In contrast to the European study by Scott and Poulson (2012), the later prehistoric populations in this desert region of northern Chile subsisted on maize, a C_4 plant, and utilized marine resources intensively (Muñoz Ovalle and Focacci, 1985; Santoro et al., 2003; Watson et al., 2011).

2. Environment – the extreme north of Chile

The extreme north of Chile is broadly divided into three ecological zones: (1) the Pacific coastal zone; (2) the intermediate zone with oases and valleys that transect the arid Atacama Desert; and (3) the puna, precordillera, and altiplano, which make up the Andean highlands (Rivera, 1991). Microclimates found within these zones foster some plant and animal diversity, but human survival in northern Chile during prehistoric times was difficult due to the hyper-arid environment (see Bryson et al., 2001 for paleoclimatic evidence). During the prehistoric period, human survival depended upon settling in valleys and valley openings where fresh water sources were located. Despite the dearth of terrestrial plants and animals in the Atacama Desert, the cold waters of the Pacific Humboldt Current supported an abundance of marine resources (Arriaza et al., 2008; Llagostera, 1979). These microclimates and ecological zones were interconnected throughout prehistory, providing groups with extensive trade networks and access to natural resources (Rivera, 1991).

The study area is the modern city of Arica and the adjacent Azapa Valley, just a few kilometers south of the modern political border with Peru (Fig. 1). The coastal city of Arica and the Azapa Valley have extensive, well-preserved archaeological deposits that appear as early as 7000 BC (Standen et al., 2004). Scholars have argued that mild annual temperatures, fresh water supply in neighboring valleys, and diverse marine and bird life made this an attractive area for human occupation in an otherwise hostile environment (Arriaza, 1995a, 1995b; Arriaza et al., 2008; Bryson et al., 2001; Dillehay, 2008).

Throughout the Archaic period, people who lived on the extreme north coast of Chile were thought to have relied heavily on marine resources (Arriaza et al., 2008, 2010; Aufderheide et al., 1993; Standen et al., 2004). Recent research indicates that these early coastal populations were not fully nomadic, but instead, lived in year-round camps along the coast (Arriaza et al., 2008). Following the Archaic period, settlements increased in size at the coast, while people began to form permanent settlements in the

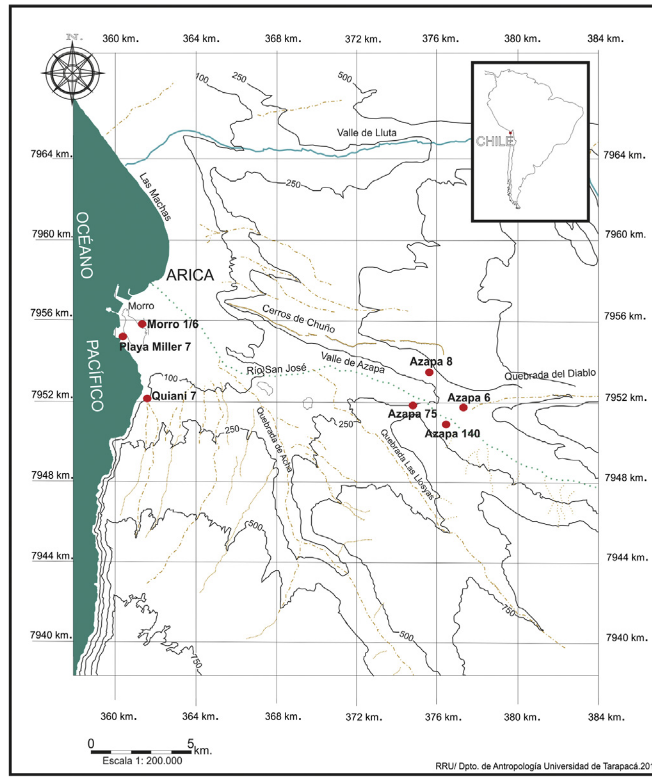

Fig. 1. Location of samples from sites in Arica and the Azapa Valley, Chile.

Azapa Valley (Muñoz Ovalle, 2004; Sutter and Mertz, 2004). Plant domestication began in the region at approximately 1500 BC (the beginning of the Formative period), possibly as a response triggered by a climatic shift (Bryson et al., 2001; Marquet et al., 2012). During the Middle Horizon (AD 750–1100), the Azapa Valley and adjacent coast experienced further regional development, influenced by the Tiwanaku culture, increased village formation, and more extensive irrigation systems (Rivera, 1991). The Middle Horizon also appears to have been a time of increased textile and pottery production and trade route expansion between the coast, valleys, and highland zones (Rivera, 1991; Roberts et al., 2013). The Late Intermediate period (AD 1100–1476) is characterized by continued exchange networks between ecological zones and the emergence of regional chiefdoms with ceramic styles from the San Miguel (1100–1200 AD) and Gentilar (~AD 1400) cultures who inhabited coast and valley sites (Sutter and Mertz, 2004). The final Prehispanic cultural sequence at coast and valley sites was dominated by the expansion of the Inca Empire (~AD 1500) into Chile, which led to the development of outposts and roads that facilitated access to mineral resources, continued craft production, and exchange of goods throughout the region (Rivera, 2008; Roberts et al., 2013).

Several dietary patterns are apparent at the coastal and Azapa Valley sites throughout the prehistoric period. Evidence of a heavily marine-based diet through the Archaic period is supported by good dental health and intestinal parasites associated with marine food consumption (Arriaza, 1995a; Arriaza et al., 2008; Kelley et al., 1991; Reinhard and Urban, 2003). After the Archaic period, people transitioned from their near-exclusive dependence on ocean foods to a mixed diet of cultivates, marine foods, and domesticated animals (Bryson et al., 2001; Rivera, 1991; Watson et al., 2010). Bioarchaeological research conducted by Watson et al. (2010) revealed more dental decay among Azapa Valley inhabitants during the Formative period, consistent with an increase in cariogenic foods, such as maize. However, despite the introduction of tubers,