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Geographic origins of a War of 1812 skeletal sample integrating oxygen and strontium isotopes with GIS-based multi-criteria evaluation analysis

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ABSTRACT

The oxygen and strontium isotope composition of human bones and teeth are used to investigate human geographic origins and mobility in the archaeological record. We measured the oxygen ($^{18}O/^{16}O$) and strontium ($^{87}Sr/^{86}Sr$) isotope ratios in 14 teeth and 22 bone sections from 19th century soldiers who died in the Battle of Stoney Creek, Ontario, and were buried in a commingled mass grave at Smith's Knoll. To spatially locate the tooth isotope data we generated overlay maps of the eastern United States and Great Britain based on regional $^{87}Sr/^{86}Sr$ and meteoric precipitation $\delta^{18}O$ variation. To do this, we employed a new method to visualize the isotopic information using GIS-based Multi-Criteria Evaluation analysis (GIS-MCE), a computational algorithm yet to be applied to stable isotope migration research. Our data confirm historic information concerning the areas from which American and British soldiers originated or were recruited, namely from the mid- to northerly latitude United States and Great Britain. This approach revealed the probable identity of at least one British soldier, and possibly one American soldier within the Smith's Knoll assemblage, making it the first archaeological study to provide substantial evidence for the identity of individuals interred in a mass grave. Our analysis highlights a new way to integrate isotopic and geophysical data through GIS-MCE technology to locate the most likely place of origin of individuals in a skeletal sample.

1. Introduction

The use of oxygen and strontium isotope analysis to identify human mobility and origins has widespread applications in bioarchaeological research (e.g. Ericson, 1985; Dupras and Schwarcz, 2001; Budd et al., 2003; Prowse et al., 2007; Buzon and Bowen, 2010; Hemer et al., 2014; Laffoon et al., 2017). This study presents the strontium ($^{87}Sr/^{86}Sr$) and oxygen ($^{18}O/^{16}O$) isotope ratios from 22 bones and 14 teeth from the remains of soldiers recovered from a War of 1812 battlefield site in Stoney Creek, Ontario, known as Smith's Knoll. Previous investigations of the Smith's Knoll sample have added further bioarchaeological data to the growing body of literature concerning diet, health, and trauma of the participants of the War of 1812 (e.g. Schwarcz et al., 1991; Blyth, 2003; Lockau et al., 2013, 2016; Emery et al., 2015; Brickley et al., 2016). Further, we use a GIS-based (Geographic Information System) Multi-Criteria Evaluation (MCE) approach to determine the regions of origin of the Smith's Knoll soldiers. Our study is the first to geo-spatially provenance isotope data recovered from teeth using GIS-MCE analysis.

The Battle of Stoney Creek was a military confrontation that took place in the early morning of June 6th, 1813, between the Upper Canadian-based British regiments and the United States army during The War of 1812 (Fig. 1) (Caffrey, 1977; Hickey, 1981, 1989; Dale, 2001). Historic documents report that approximately 800 British soldiers and a dozen First Nation warriors attempted a night attack on the larger American force, estimated between 3000 and 4000 men (Elliott, 2009: 75, 157). British soldiers surprised the American army as they were camped closed to Stoney Creek, and created enough disorder among the Americans to force them into retreat (Elliott, 2009). According to Elliott (2009: 157), official British casualties were upwards of 213 soldiers dead, wounded, or missing. The American casualty figure was estimated to be lower, at 17 dead and 38 wounded, however this is probably an underestimate of the actual number of American soldiers killed in action (Elliott, 2009: 153–154).

2. Oxygen and strontium isotope analysis

2.1. Bone composition and turnover

Living bone is structurally composed of inorganic apatite (70%), collagen (20%), and water (10%), whereas mature tooth enamel has a

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Fig. 1. Map showing the location of Smith's Knoll (modified from Lockau et al., 2013 and Brickley et al., 2016).

smaller proportion of organic matter (~0.5%), and is instead predominantly composed of apatite (i.e. > 96%) (Hill, 1998; Szostek et al., 2015). Strontium (Sr) is incorporated into bone via chemical substitution for calcium (Ca) in apatite due to its similar ionic radius and charge, while oxygen is captured either as phosphate (PO_4) or carbonate (CO_3) (Dupras and Schwarcz, 2001; Hoppe et al., 2003). The isotope ratios of food and water are preserved in teeth at the time of their formation. Tooth enamel of permanent teeth is formed during infancy through early adolescence, reflecting the food and water consumed during early development. Second permanent molar crowns terminate mineralization by the age of 8, so the isotope composition of M2s will represent the foods consumed during this period of childhood development (Scheuer and Black, 2000). Bones, on the other hand, remodel throughout life and reflect the average isotope composition of the water and food consumed before death (Katzenberg, 2008). While there is a general consensus that turnover rates differ between skeletal elements and that remodelling rates decrease with age, it is generally accepted that bones, and adult long bones in particular, completely remodel every 10–20 years (Manolagas, 2000; Hedges et al., 2007).

2.2. Oxygen isotopes

Oxygen isotope analysis of the human dentition can provide information about dietary shifts early in life such as weaning or trace the origins of a single individual (Wright and Schwarcz, 1998; Britton et al., 2015). The oxygen isotope composition of the human skeleton is a function of the $^{18}O/^{16}O$ content of body water, which in turn largely reflects the $^{18}O/^{16}O$ composition of water ingested from the environment, although H_2O in the diet can play a role as well (Daux et al., 2008; Knudson, 2009; Knudson et al., 2009; Brettell et al., 2012). For most pre-modern populations, drinking water was largely derived from local meteoric precipitation (i.e., rain and snow). A number of environmental factors contribute to the observed global $^{18}O/^{16}O$ ratios in rainwater including; distance from the coast, altitude, latitude, evapotranspiration, and temperature (Dansgaard, 1964; Gourcy et al., 2005). Rainwater surveyed at GNIP (Global Network for Isotopes in Precipitation) stations across the planet provides information about the global distribution of oxygen isotopes in rainfall (Gat, 2005; Schwarcz et al., 2010).

Oxygen isotope ratios are expressed as delta (δ) values in per mil (‰), and are calculated using the following equation, and standardized to VSMOW (Hoefs, 2004):

$$\delta^{18}(\text{sample}) = \left(\frac{R(sample) - R(sample)}{R(standard)}\right) \times 1000$$

where $R = {}^{18}O/{}^{16}O$. Luz et al. (1984), Longinelli (1984), and Daux et al. (2008) developed equations that expressed the relationship between the oxygen isotope composition of human skeletal phosphate (PO_4) and precipitation ($\delta^{18}O_{DW}$), but required an additional step to convert carbonate values ($\delta^{18}O_C$) to phosphate values that potentially increased error in the final $\delta^{18}O_{DW}$ estimates. In order to reduce this margin of error, we used the regression equation developed by Chenery et al. (2012) to calculate $\delta^{18}O_{DW}$ values directly from bone or tooth carbonate ($\delta^{18}O_C$) values: $\delta^{18}O_{DW} = 1.590 \times \delta^{18}O_C - 48.6$ (‰ VSMOW).

2.3. Environmental $^{87}Sr/^{86}Sr$ mapping

The $^{87}Sr/^{86}Sr$ ratio is particularly useful in migration studies since the strontium isotope signature of the geological substrate is taken up into the tissues of plants and passed unaltered throughout the food chain (Burton et al., 2003). As a result, it is possible to determine geographic residency by matching teeth $^{87}Sr/^{86}Sr$ values to maps delineating the spatial variation of strontium in specific regional locations (Flockhart et al., 2015). A number of studies documenting $^{87}Sr/^{86}Sr$ spatial variation exist (e.g. Bataille and Bowen, 2012; Evans et al., 2010; Laffoon et al., 2012, 2017; Willmes et al., 2013, 2014); however, not all land masses on the planet have been mapped. By measuring the strontium isotope composition of the local biosphere (i.e. flora and fauna), the ratios will reflect the actual average strontium isotope composition of the biomass (and thus the soils on which they feed), generating more accurate data to produce baseline $^{87}Sr/^{86}Sr$ variation maps (e.g. Evans et al., 2010). Where bioavailable data are missing, lithic- or bedrock-age, and water-catchment (and tap water) strontium isotope maps have been modeled to fill in large geographic $^{87}Sr/^{86}Sr$ spatial gaps (Beard and Johnson, 2000; Bataille and Bowen, 2012; Chesson et al., 2012; Hartman and Richards, 2014).

3. Materials and methods

3.1. Sample description

Excavations of the Smith's Knoll site were carried out in 1998 and 1999 revealed several commingled assemblages of human remains (Liston, 2000). The skeletal remains were then placed within the Smith's Knoll stone monument until 2011, when the skeletal collection was loaned to Dr. Megan Brickley (McMaster University) by the City of Hamilton in order to conduct more detailed analyses. During re-analysis of the human remains in 2011, 2701 identifiable fragments were recorded and the MNI (Minimum Number of Individuals) of 24 that was established during the initial assessment by Liston (2000) was confirmed (Brickley et al., 2016). Skeletal elements large enough for sex estimation showed morphological features consistent with males. Brickley et al. (2016) estimated age-at-death using 19 right innominates, each element representing one individual. Age-at-death ranges followed the categories defined by Buikstra and Ubelaker (1994): Adolescent (12–20 years) $n = 3$, Young Adult (20–35) $n = 7$, Middle Adult (45–50 years) $n = 4$, and Old Adult (50 + years) $n = 1$, one individual is estimated to have been a young adult, and age could not be estimated for the three remaining cases.

Age-at-death estimates using the femur were limited to the fusion of proximal and distal epiphyses. According to Schafer et al. (2009) the earliest age for fusion of the femoral head and distal epiphysis in males is 16 years. Of the total femoral sample, 9 individuals were classified as over the age of 16 at the time of death on the battlefield, based on the fusion of the femoral head. The age-at-death for 9 individuals could not be determined since both proximal and distal epiphyses were missing (Table 2). A total of 21 left femora, one mandibular fragment, and 14