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ORIGINAL PAPER

Strontium isotope analysis of human tooth enamel from Barsinia: a late antiquity site in Northern Jordan

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Abstract The archaeological site of Barsinia represents a model of a mixed subsistence strategy in the late antiquity of Jordan. Contrary to historians' belief that the late antiquity economy was stagnated, archaeological evidence at the site of Barsinia points to wealth accumulation as mirrored by the local wine industry and trade. As the economic growth may enhance population dynamics, the study tests the population mobility at the site using strontium isotope ratios from the human tooth enamel. The study comprised 12 right upper third molars and 12 rodent teeth samples. The results confirm that all of the sampled individuals were local to the area (raised in the area) and whose diets were probably obtained from spatially restricted localities in the region.

Keywords Strontium · Late antiquity · Barsinia · Mobility · Jordan

Introduction

Owing to the sense of security, trade, and economic networks, the late antiquity period in Jordan witnessed a peak of population and a climax of settlement (Rose et al. 2004) followed by economic prosperity (Kingsley and Decker 2001), especially the sites that were located on the Trajan road (Parker 1986: 143–47). The road, one of the greatest international trade routes of the ancient world, ran from the southern port of Aqaba all the way to the Syrian city of Bosra, hence extending nearly 500 km.

The beginning of the late antiquity in Jordan (around 300 AD to the end of the Byzantine period) witnessed the establishment of about 211 new late Roman sites (never occupied before), 62 Early Byzantine sites, and 143 Late Byzantine sites. Accordingly, the movements of goods from and into towns might have been accompanied by an intense mobility of people (Freeman 2001). On the other hand, the late antiquity had witnessed huge immigration movements from large urban centers to rural areas (Bar 2004). The result was an expansion of the rural landscape toward either areas with good soil by the higher social class or marginal areas by the lower social class (Safrai 1994). In marginal areas in terms of society and geography, people had to be self-sufficient, relying on land as the main source of food production and improvisation (Garnsey and Saller 1987).

One of these recently excavated rural sites is Barsinia in the north of Jordan. The site represents a model of mixed subsistence strategies: agriculture, industry, and trade. Barsinia is located west to the city of Irbid, occupying an area of about 112 km^2 (Figs. 1 and 2). The archaeological excavations at the site revealed an occupation that started during the Iron Age and continued till the Ottoman period. The uncovered remains at the site, however, showed great prosperity during the Hellenistic, Roman, Byzantine, and Umayyad periods in particular. The diversification in tomb types and grave goods as well as other recovered artifacts during the Late Roman/Early Byzantine point to a hierarchical society who subsisted on agriculture, animal

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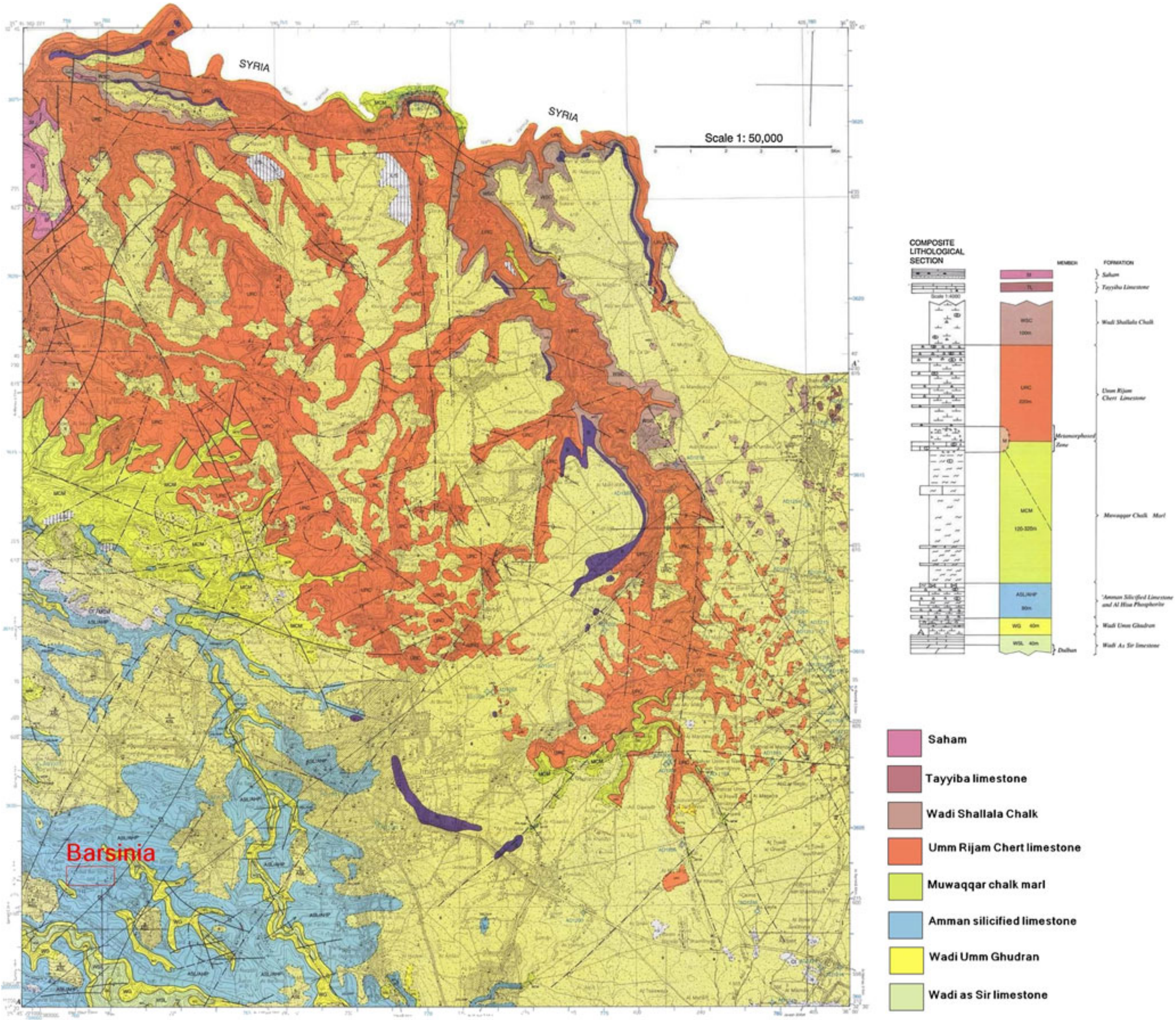

Fig. 1 A geological map of northern Jordan

husbandry, industry, and trade (Fig. 3). The presence of complex tombs and some fine industries like wine and metal infer wealth accumulation. The people of Barsinia practiced trade with Anatolia, North Syria, North Africa, and locally with the nearby urban centers such as Gerasa (Jerash) and Pella (Tabaqat Fahil). The archaeological records of the site remained silent on the interactions with other established settlements either locally or centrally, leading one to assume that Barsinia may have attracted non-local settlers or originally been established by people not originally from the region. The archaeological analysis did not introduce clues on population mobility and originality, which this study intends to investigate on through using strontium isotope analysis from human tooth enamel.

Strontium isotopes

Strontium has four natural occurring isotopes, ^{88}Sr, ^{87}Sr, ^{86}Sr, and ^{84}Sr, that vary in an ecosystem based on the underlying geology (Faure and Powell 1972). Of these four isotopes, only ^{87}Sr is radiogenic; it is formed over time by radioactive decay from rubidium (^{87}Rb), which has a half-life of about 4.88×10^{10} years (Faure 1986). Strontium isotope data are reported as ^{87}Sr/^{86}Sr values. As strontium is very abundant in rocks and soils, it is absorbed by plants and thus passed on to animals and to humans (Ericson 1985, 1989). Strontium replaces Ca in hydroxyapatite in bones and teeth upon absorption (Rosenthal 1981; Nelson et al. 1986; Hillson 1996) and does not biologically

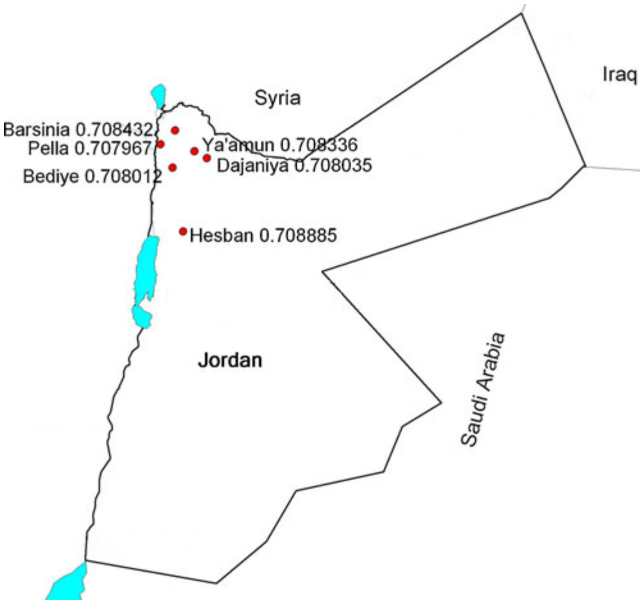

Fig. 2 A map showing the strontium isotope values in Jordan

fractionate because the mass difference between ^{87}Sr and ^{86}Sr is very small (Faure and Powell 1972; Graustein 1988). Consequently, the ^{87}Sr/^{86}Sr ratio of a human tooth and bone reflects the same signature in local plants and local geological substrate (Sillen et al. 1995; Sealy et al. 1995; Hoppe 1999).

Fig. 3 A photograph of tomb 2 from Barsinia

Unlike bone, tooth enamel is not remodeled after the completion of the crown development, which takes place during the early years of an individual's life (Hillson 1996). For this reason, the isotopic signature of enamel reflects the plant's and geology's signature in which a person lived (Carlson 1996; Evans and Tatham 2004; Evans et al. 2006). As bone is continuously remodeled (White and Folkens 1991) with a turnover of strontium of about 26% per year (Price et al. 2000), its strontium signature reflects that of the local flora and fauna of the last years of an individual's life (Beard and Johnson 2000; Knudson et al. 2004). Besides, bone is very often subject to diagenesis. Therefore, the local values of bones oftentimes are rather due to a diagenetic overprint than due to the turnover process during a lifetime. Comparing the strontium signature of teeth with the signature of local fauna such as rodents in the same site can be used to investigate the past residential behavior and mobility.

Geology of Barsinia

The rock stratigraphy of northern Jordan ranges from the Cretaceous Ajlun and Belqa groups to the Tertiary Jordan Valley super group and the Tertiary and Quaternary volcanic flows (Abed 2000). The studied area of Barsinia is covered by red-brown soil: Terra Rosa (Xerochrepts and Chromoxererts), which is formed of soft and highly plastic silty clay. It lies above Muwaqqar Chalk Marl Formation, the uppermost member of Belqa Group outcropping in the area. Of Belqa Group, Umm Gudran formation, Amman silicified limestone formation and Al-Hisa (Ruseifa) Phospherite formation outcrop also in the area (Abed 2000; Moh'd 2000; Shinaq and Bandel 1998). This sequence of rocks is clear in Wadi Sindian geological column studied by Shinaq and Bandel (1998).

Muwaqqar Chalk-Marl Formation is about 7-m thick and consists of soft, thick-bedded chalky marl, marl, and chalky limestone. It also has hard limestone and chert beds and nodules that are common in its upper part. The colors of the formation are gray and pink at the base and greenish gray towards its top (Moh'd 2000; Shinaq and Bandel 1998). Ruseifa Formation that underlies Muwaqqar is about 5-m thick and distinguished by phosphatic sand intercalated with thin layers of limestone at its base followed by beds of chert at its upper parts. Limestones are chalky and rich in vertebrate teeth and bones (Shinaq and Bandel 1998). Amman silicified limestone formation, which underlies Ruseifa Formation, is about 14-m thick. It consists of an alternation of medium to thick layers of hard massive gray–brown–white chert and gray micro-crystalline limestone and marly limestone. Umm Gudran Formation outcrops at the base of the sequence. The Umm Ghudran Formation is about 7-m thick and consists of white, fossiliferous, highly bioturbated marl chalk and thin layers of fractured chert.

Materials and methods

This study investigates the sum of all the recovered skeletal remains during the 2006 excavation. The skeletal remains were recovered from four Late Roman/Byzantine tombs; dating was accomplished based on pottery and glass typologies. The recovered skeletons were comingled but in a very good preserved condition. Age was classified as adults and non-adults based on the epiphyseal union of long bones after Baker et al. (2005) and White and Folkens (2005). The minimum number of individuals is estimated after sorting the bones according to bone type and side of the body (left or right). Each bone was examined visually for the presence of pathological lesions. The total number of recovered teeth is 212, which were examined for dental caries and dental wear using the scoring system of Buikestra and Ubelaker (1994).

The study comprises the enamel of 12 human teeth and the enamel of 12 archaeological rodent teeth from the same site. All of the sampled human teeth were right upper third molars to ensure the representation of a maximum number of individuals (12). As the crown of the third molar starts to initiate at an age of about 7 years and ends at about 16 years (Hillson 1996: 123), the strontium signature will thus represent the childhood intake and residence. All of the sampled teeth were in very good preserved condition, free of caries, and of minimal dental wear (no occlussal exposure of dentine). The teeth were prepared after Knudson et al. (2004); they were cleaned with distilled water in an ultrasonic bath to remove any adhering dirt, left to dry at room temperature, and then cleaned with alcohol swabs; then, a wedge-shaped sample was cut of the crown using a diamond pit, and the attached dentine was removed using a carbide burr. The samples were treated with acetic acid 5% for 5 min then rinsed with distilled water, ashed at 750°C for 8 h, and powdered. The ash was dissolved in 500 µl of 5 M HNO_3, evaporated in 250 µl of 5 M HNO_3, and then purified. The samples were then redissolved in 2 µl of 0.1 M H_3PO_4 and 2 µl of $TaCl_5$ and loaded on to degassed Re filaments for analysis by thermal ionization mass spectrometry (TIMS). The rodent teeth were taken from the tombs and other archaeological strata at the site, ensuring enough spatial distribution, and prepared using the same procedure.

A Micromass Sector 54 thermal ionization multiple collector mass spectrometer was used to measure the $^{87}Sr/^{86}Sr$ of the samples (at the University of North Carolina-Chapel Hill), which were mounted on zone-refined tantalum filaments. Mass fractionation in the instrument was corrected using the exponential mass fractionation law, with $^{86}Sr/^{88}Sr$ equal to 0.1194. The long-term average for $^{87}Sr/^{86}Sr$ analyses of the NIST SRM strontium carbonate standard is 0.710262 (no. 81), and the standard error of analyses at UNC-CH is typically 0.00009–0.000012.

Results and discussion

The minimum number of individuals is 20 for adults based on the highest count of the left femur and 17 for non-adults based on the highest count of the left humerus. Non-adults account for about 46% of the total sample, which is within the non-adult representation in similar sites in the region (Williams et al. 2004; Al-Shorman 2003). The visual examination of the adult skeletal remains revealed trivial pathologies, mild but few osteophytosis in some vertebrae. Osteophytosis is a disease that is common among ancient populations caused by aging and hard labor. Periostitis was evident in six non-adult bones; it usually represents a reaction to pathologic changes of the underlying bone, either primary or secondary (Ortner and Putschar 1981). Primary periostitis is most often the result of infection and trauma, while secondary periostitis (among non-adult limb bones and joints) is a reaction to a specific disease process (Putschar 1966; Aufderheide and Rodriguez-Martin 2005). As the periostitis cases belong to sub-adults of about 2 years old, the likelihood of a primary pathology was excluded. As the frequency of periostitis among the non-adults was very low; the infection was probably not endemic.

The upper and the lower jaw of almost all examined specimens suffered an obvious alveolar bone loss, which is sometimes accompanied by alveolar abscesses. The rate of dental caries is 18%, which is within the frequency of other Roman/Byzantine sites in the region that varies from 11% to 20% (Smith et al. 1992; Hershkovitz et al. 1995; Williams et al. 2004). Carious lesions were mostly on the position of the first molars. Dental wear was moderate on all of the teeth with two cases of oblique dental wear, where the latter might have been caused by using the teeth as tools. A significant number of cupped wear was also noted on most of the examined teeth. Cupped wear (the hollow erosion of dentine) is usually caused by acids and/or acidic drinks (Khan et al. 2001; Young 2001). The deciduous teeth were free of dental caries; some of them were not completely developed, which consequently indicates the very young age at death of the non-adults in the sample.

The adult population at Barsinia during the Roman/Byzantine period was healthy. The dental pathology refers to the poor dental hygiene and the excessive intake of sugar-containing and acidic food items. The sub-adult infectious disease probably put an end to the life of this age group. Further excavations may reveal more tombs and probably a higher mortality rate.

The strontium isotope results for the human and rodent teeth are shown in Table 1 below.

Table 1 The $^{87}Sr/^{86}Sr$ isotope ratios for human tooth enamel and rodent tooth enamel

Sample type	Sample no.	Sex	87/86 Exp Corr (−Rb)
Human tooth enamel	T01-01	Male	0.708428
	T01-02	Male	0.708420
	T01-03	Male	0.708270
	T01-04	Male	0.708656
	T02-01	Male	0.708303
	T02-02	Male	0.708324
	T02-03	Male	0.708506
	T02-04	Female	0.708477
	T04-01	Female	0.708376
	T04-02	Female	0.708490
	T04-03	Female	0.708459
	T04-04	Female	0.708473
	Average	–	0.708432
	Standard deviation	–	0.00011
Rodent tooth enamel	1	–	0.708160
	2	–	0.708100
	3	–	0.707820
	4	–	0.707900
	5	–	0.708100
	6	–	0.708068
	7	–	0.708527
	8	–	0.708622
	9	–	0.708160
	10	–	0.708129
	11	–	0.708548
	12	–	0.708358
	Average	–	0.708208
	Standard deviation	–	0.00025

The strontium isotope ratios of rodent teeth from the site of Barsinia are used to determine the local strontium isotope values. Any of the 12 individuals is identified as local to the area if the strontium isotope value is within the range of the mean of Barsinia's rodent signature ±2 standard deviations (Price et al. 2002). The mean of strontium ratio of Barsinia's rodents is 0.708208 and the standard deviation is 0.000254, yielding a range from

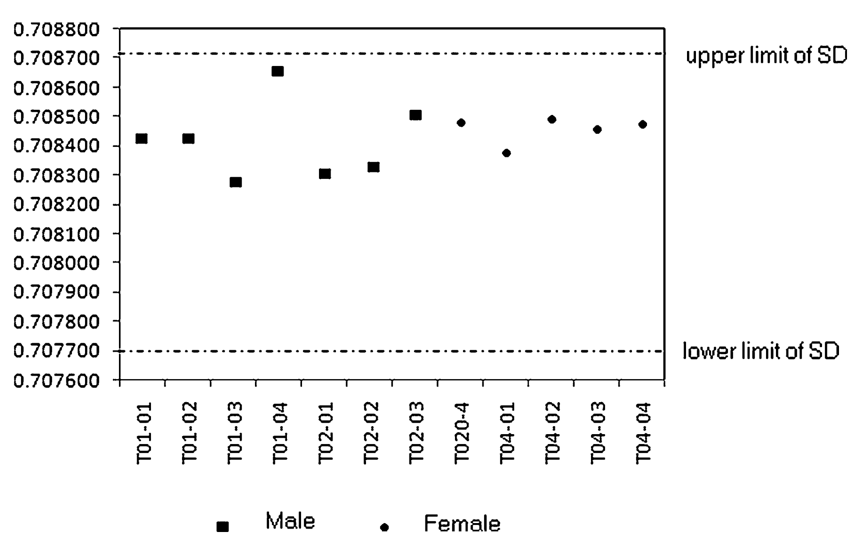

Fig. 4 Strontium isotope ratios for human tooth enamel from the archaeological site of Barsinia

Table 2 Single ANOVA test comparing the means of strontium ratios between males and females

Groups	Count	Sum	Average	Variance		
Males	7	4.958907	0.708415	1.81E-08		
Females	5	3.542275	0.708455	2.07E-09		
Source of variation	SS	df	MS	*F*	*P*-value	*F* crit
Between groups	4.6E-09	1	4.6E-09	0.394209	0.544166	4.964603
Within groups	1.17E-07	10	1.17E-08	–		
Total	1.21E-07	11	–			

0.707700 to 708716 (2 SD dotted lines in Fig. 4). According to Fig. 4, all of the sampled teeth are local to the area of Barsinia or the nearby northern region. The very low standard deviation among the teeth results indicates that the dietary sources of Barsinia's people might have come from a very limited geographical area, not abroad. Imported food items may alter the strontium isotope signature (Burton and Wright 1995) as well as the food production technique, such as imported grinding stones (Aberg et al. 1998; Wright 2005). These factors were excluded as the enamel strontium isotope signature was interpreted according to the local faunal signature, not the soil signature.

The case in Barsinia mirrors a model of a locally self-sufficient economy; the landscape is very fertile and the amount of rainfall during the Roman period supported a wide array of crops (Issar and Yakir 1997) triggered by ample amounts of rainfall (Furmkin et al. 1991; Yakir 1994). Although the variation in the local strontium isotope ratios in Barsinia is minimal, it was also noticed in other archaeological sites in the surrounding area. For example, the mean strontium ratios at tomb 181 and 182 in Ya'amun archaeological site are 0.708230 and 0.708336, respectively (Perry et al. 2008). This variation is in consonant with the geological variation as earlier studies have shown (Shewan 2004). The single ANOVA test was used to compare the means of strontium ratios between males and females. The results (Table 2) indicated that the difference in the two means is not significant since the P value of 0.54 is larger than 0.05. Consequently, none of the females and/or males was raised outside Barsinia, thus excluding the possibility of exogamy.

Conclusions

All of the sampled individuals were raised in Barsinia and confined to their territory either in living and/or subsisting. Barsinia had received little if any immigrants from the nearby areas, where the locals were resilient in subsisting and living in a society where land is the main mode of production and the agent of survival. The rain-fed agriculture has been very sensitive to rainfall shortages and infrequent droughts, which probably explain the desertion of the site in the latter periods. Except for sub-adults, the population in Barsinia was healthy. The migration process and/or population dynamics in the late antiquity of northern Jordan might have favored areas other than Barsinia, a site which was socially homogenous as exogamy was excluded. The archaeological sites in northern Jordan have strontium isotope values that lie within the range of the local fauna (the farthest site in the north is about 20 km away). Barsinia could not have received immigrants from the site of Hesban, for example, which has a strontium isotopic signature outside the range of Barsinia's local fauna.

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