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Migration and mobility in Roman Beirut: The isotopic evidence

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A B S T R A C T

Rescue excavations in Beirut, Lebanon, have uncovered large burial assemblages dating to the Roman period. As the first Roman colony in the Near East, the human skeletons from Beirut provide a unique opportunity to explore migration to the city using biomolecular analyses. This study applies strontium and oxygen isotope analysis to nineteen human skeletons and establishes primary local reference values through the analysis of human and faunal dentition and the utilisation of already available environmental and botanical data from Lebanon. Two possible incomers and two definite migrants – both male and female – were identified who originated from different parts of the Empire. The comparison of isotopic data with the material culture of the graves illustrates how migrant identity is not always expressed in burial, and also how archaeological data can supplement biomolecular results in identifying the type of migration involved in a colonial setting. The results from this study contribute to our understanding of the Roman colonization of Beirut, highlight female mobility during the Roman period, and establish local human isotope ratios which can be used in future research on migration to the city and in the region.

1. Introduction

1.1. Research background

The Levant, here narrowly defined (Fig. 1), constituted an important corridor for the movement of peoples across human history. While historical sources and material archaeology have contributed to our knowledge of movement in this area, the bioarchaeological evidence has not been as extensively utilized. Yet, the biological information obtained from ancient people themselves serves an important role in better understanding human interactions in this culturally and populationally diverse region (see Sheridan 2017).

This paper focuses on Lebanon and considers migration and mobility in Roman Beirut. The analysis that is presented forms part of a larger and multifaceted study of burials from the city that contextualizes skeletal and biomolecular data with the material features of the grave and the historical setting of the Roman Near East (Kalenderian 2020). This article discusses part of the strontium (Sr) and oxygen (O) isotope results from that study.

The aim of this paper is threefold. The first and main objective is to rectify the lack of local Sr and O isotope baselines for mobility studies on Beirut (and more broadly, Lebanon) through the compilation of published signatures, as well as the generation of new biologically available values. The second objective is to assess the geographic origins of the analysed individuals. This will contribute to answering long-standing questions on migration and patterns of settlement in Beirut during the Roman period. The third objective is to explore the interplay between the isotopic evidence and the archaeological burial data in expressions of migrant identities.

1.2. Historical background

Roman Beirut, or *Colonia Julia Augusta Felix Berytus*, was the first Roman colony in the Near East and was situated in the Empire's province of Syria that was annexed in 64 BC. The colonization of the city occurred during the reign of Augustus as part of the program to resettle and compensate demobilized soldiers from the battle of Actium. The influx of retired soldiers occurred between 31 and 27 BC, as well as ca.15

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BC when the colony was officially founded (Mouterde 1964; Sawaya 2002, 2009).

Veterans settled in the urban center of Berytus, and its *territorium* in the Lebanese hinterland, belonged to two Roman legions: *legio V Macedonica* and *legio VIII Augusta* (formerly known as *legio VIII Gallica*) (Millar 1993; Butcher 2003). The legions of the Roman army usually acquired their names in reference to the areas in which they served. In this case, Macedonia and Gaul. The names of the legions, as such, do not reflect the veterans' geographic origins. However, based on what is known of the Roman army, recruits serving in the legions were required to be Roman citizens. In the early Imperial Period when Beirut was colonized, citizenship was predominantly restricted to the Italian peninsula (Southern 2007). It is therefore assumed that the retired soldiers settled in the city originated from Italy. Furthermore, although they were denied legal conjugal rights, active Roman soldiers often cohabited with local women in the areas where they were stationed and raised children (Scheidel 2007; Southern 2007). Some veterans would consequently have moved to Berytus with their families and slaves.

Colonists, however, were not the only migrants to Berytus. Due to the increased connectivity between the provinces, movement to and from the Near East – as elsewhere in the Empire – was continuous throughout the Roman era. Local diversification was therefore not limited to colonization. Furthermore, it is not entirely clear what happened to the local population of the city upon the influx of veterans. Different archaeo-historical hypotheses have been presented on local-colonial dynamics and the patterns of veteran settlement in Berytus and its *territorium* (Rey-Coquais 1973; Hajjar 1977; Applebaum 1989; Millar 1993; Sawaya 2002, 2009; Newson 2015). Although the current consensus is that the local population was allowed to remain in the city, this has never been previously explored using biomolecular methods.

Biodistance studies employing dental and skeletal metric and non-metric traits have shown phenotypic population heterogeneity in multiple Roman cities along the Lebanese coast, including Berytus (Elias 2016; Mardini et al. 2023). While suggestive of genetic variation and supporting the hypothesis of a mixed local population, these osteological methods do not identify first generation migrants. This study focuses on identifying the people who participated in the original movement to Berytus and explores their potential places of origin through isotope analysis in order to better comprehend the nature and socio-cultural consequences of ancient mobility.

1.3. Archaeological background

During development work in modern Beirut, rescue excavations uncovered a number of burial grounds linked to the Roman city. A total of six archaeological sites that were excavated between the years 2006 and 2015 are included in this paper. These sites were situated east of the ancient city and include the following land lots: RML 2385, MDWR 02, ASH 163, MDWR 466/468, ASH 002, and RML 778 (Fig. 2). Collectively, a total of 189 tombs and 286 skeletons dating to the Roman era were uncovered.

The limits of excavation were determined by the size of the urban plots being developed. Excavations were conducted using the single context recording system set by the Museum of London Archaeology Service, and a Harris matrix was employed to record the sequences of layers and deposits on each site. Sediments from the graves were sieved and removed for flotation to ensure that smaller bone fragments and burial artefacts were not lost.

In antiquity, these burial spaces were situated outside the Roman city walls and appear to have been part of a continuous and expansive burial ground flanking the urban center from the east, west, and south. Burials in the assemblages presented in this study largely involved simple pit graves. Pit graves with stone capping slabs, cist graves, and tombs built with carefully hewn masonry blocks were also occasionally present. A burial chamber and one funerary enclosure were also excavated.

The dead body was inhumed and typically placed in a wooden coffin or in a similar perishable container. The use of more durable burial receptacles such as terracotta and stone sarcophagi increased over the course of the Roman period. Cremation was a rare burial rite that was introduced into the burial record of Beirut following Roman annexation.

Fig. 1. Map of the Levant (highlighted) and some of its major cities.

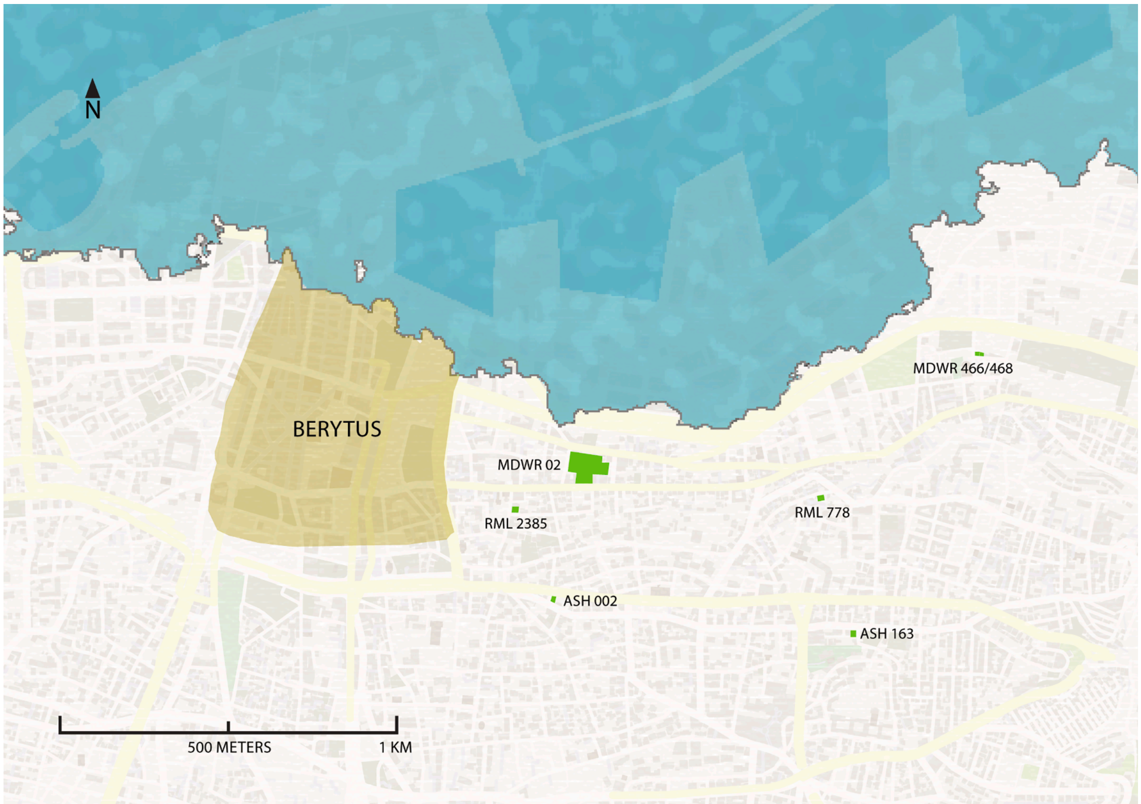

Fig. 2. Location of the burial sites outside of the approximate limits of the fortified Roman city (shaded area). The visible coastline is that of the ancient city. The faded outline within the Mediterranean Sea delineates the modern coastline.

Only two such burials were present in this study collection. Grave goods remained a continuous feature in burials throughout the Roman period and included unguentaria; vessels made of pottery, glass, bone, and metal; articles of personal adornment and dress; spinning implements; equipment such as toiletry items; coins; toys or gaming pieces; and other miscellaneous finds (Kalenderian 2020).

The dating of the burials was based on the typochronological analysis of the associated artefacts, primarily pottery sherds and objects, glass vessels, and coins. These dates were then confirmed, or further adjusted and refined, through the detailed assessment of the overall stratigraphic sequence of the site. For the purpose of this study, radiocarbon analysis was performed on select human skeletons from each site to further ascertain the relative dating obtained through the archaeological material and stratigraphic evidence.

2. Material and methods

Different isotope analyses were undertaken on skeletons from the burial assemblages described above to assess mobility and dietary practices. These include strontium (n = 40), oxygen (n = 17), lead (n = 40), nitrogen (n = 78), and carbon (n = 78). The results of these analyses will be published in a series of forthcoming articles. This paper focuses on the first set of results from the Sr isotope analysis (n = 19) and the complete results of the O isotope analysis (n = 17).

2.1. Material

Sr and O isotope analysis was carried out on nineteen adult and late adolescent skeletons. Since two of these skeletons consisted of cremated individuals, they were only analysed for Sr isotopes.

To analyse mobility patterns over time, skeletons were chosen from various sub-periods within the Roman era, which experienced different migration events. For instance, during the early Roman period, mobility to Berytus was predominantly driven by colonization. However, in the mid- to late Roman periods, movement may have been motivated by commercial and educational endeavours due to the increase in local trade and production activities, as well as the founding of prestigious schools of Roman Law and Latin literature in the city (Butcher 2003; Hall 2004).

Overall, the skeletons represent female and male individuals with surviving dentitions (and petrous bones for the cremated skeletons), different grave locations, and varying burial characteristics. The latter criterion included graves presenting features typical of local burials (n = 5), ones that displayed similar but more elaborate characteristics (n = 9), and those presenting atypical rites (n = 5).

The typicality of the burials was chronologically determined in order to account for the evolution of burial trends within the city, as certain features that were uncommon during the early phase of Roman rule became prevalent in burials during the mid- and/or late Roman periods. Generally, however, typical burial features consisted of inhumations made in simple pit graves that included wooden coffins or other perishable burial containers. They also contained minimal grave goods of the type frequently encountered in late Hellenistic and Roman Beirut, such as unguentaria and jewellery items. The slightly more elaborate burials were those that maintained the principal local practices, namely inhumation, but which displayed greater energy and resource expenditure on the physical features of the grave or tomb. For example, the employment of cist graves, the use of more durable burial receptacles such as terracotta or stone sarcophagi, and the provision of a greater number of grave goods that also included items made of more precious material such as gold. The atypical rites involved new treatments of the dead body, such as cremation, the use of prominent or monumental tomb structures, and the inclusion of (yet) uncommon grave goods.

To ensure the reliability of the temporal evaluation and confirm the relative dating obtained through the archaeological evidence, eighteen human skeletons were chosen for radiocarbon analysis. Skeletons were selected in such a way as to maximize the chronological information for the entire burial sequence. The position of the grave within the stratigraphic order of the burial phase, patterns of grave truncation, and the absence of reliably datable artefacts directed the selection of skeletons for radiocarbon dating. The following sections outline in detail the different methods of analysis.

2.2. Human osteological analysis

The sex of the skeletons was determined primarily through assessments of pelvic (Phenice 1969; Milner 1992; Buikstra and Ubelaker 1994; Klales et al. 2012) and cranial morphology (Acsádi and Nemeskéri 1970), and secondarily through measurements of sexually dimorphic skeletal elements when available (Stewart 1979; Buikstra and Ubelaker 1994; Bass 1995; Byers 2005). Sex was estimated as either Possible Male (PM), Male (M), Intermediate (I), Possible Female (PF), or Female (F).

Age estimation for the adults was based on the assessment of dental attrition (Brothwell 1981; Lovejoy 1985) and the examination of degenerative bony changes on the pubic symphysis (Todd 1920; Brooks & Suchey 1990), the auricular surface (Lovejoy et al. 1985; Buckberry and Chamberlain 2002), and when preserved, the sternal rib ends (Iscan et al. 1984, 1985). Cranial suture closure (Meindl and Lovejoy 1985) also served as a supplementary age indicator. Late epiphyseal fusion in the cranial and postcranial skeleton (Mckern and Stewart 1957; Webb and Suchey 1985; Buikstra and Ubelaker 1994; Albert & Maples 1995; Scheuer and Black 2000, 2004; Schaefer et al. 2009), as well as third molar development and eruption (Ubelaker 1989; AlQahtani et al. 2010), were used for the more precise age determination of late adolescents and young adults. The age categories were divided as follows: adolescents (12 – 20 years), young adults (20 – 35 years), middle adults (35 – 50 years), and old adults (50 + years) (Buikstra and Ubelaker 1994).

2.3. Radiocarbon dating

Bone samples from 18 inhumed skeletons were chosen from already fragmented skeletal elements and primarily from the dense bones of the legs, i.e. the femur and the tibia. When unavailable, fibula or humerus samples were selected instead. Radiocarbon dating was carried out at the Centre for Isotope Research (CIO) at the University of Groningen.

100 to 1000 mg of bone samples were physically prepared for chemical pre-treatment through washing in ultrapure water and careful surface scraping with a scalpel to remove surface soil concretions and any other extraneous particulates. They were next treated for collagen extraction using methods outlined in Dee et al. (2020). This involved a modified Longin protocol (Longin 1971; Mook and Steurman 1983) consisting of an acid-base-acid pre-treatment with 4% HCl and 1% NaOH. The collagen fraction was then denatured to gelatin in acidified distilled water (pH 3) at 80 °C for 18 h. The dissolved gelatin was filtered through a 50 μm mesh and thoroughly dried. The crystalline collagen product was then collected. 5.5 mg of the material was weighed into tin capsules and combusted with an Elemental Analyser coupled to an IRMS and an automated cryogenic collection system. The resulting CO_2 was thereafter graphitised to solid carbon and subsequently pressed in targets and measured for carbon isotopes (^{12}C, ^{13}C, ^{14}C) through an Accelerator Mass Spectrometer (AMS).

Most of the samples were measured with a Tandetron AMS system of HVEE (van der Plicht et al. 2000) and were given a Lab-ID code 'GrA'. A few samples were measured with a MICADAS AMS system of Ionplus (Synal et al. 2007; Salehpour et al. 2016). These were given a Lab-ID code 'GrM'. The main difference between the measurement results of both AMS-systems is the lower measurement uncertainty obtained with the MICADAS system. All measurement results were standardized, normalized for isotope fractionation, and background corrected (Stuiver and Polach 1977). The reliability of the AMS-measurements was verified with measured reference standards run in the same AMS batches as the samples. Additional checks were applied to ascertain the quality and purity of the obtained collagen fractions, which were based on the collagen yield and the carbon and nitrogen composition of the collagen samples.

The uncalibrated dates obtained through measurements of the radiocarbon content of the bones are presented with the unit 'yr BP' (year before present), while the calibrated date (Bronk Ramsey 2009; van der Plicht et al. 2020) is given with the unit 'cal. BP', or as BC/AD.

2.4. Isotope analysis

Isotopes are different structural forms of an element that share the same number of protons but have different numbers of neutrons in their nucleus. These elemental variations are naturally occurring in the environment and are continuously incorporated into living organisms through the intake of food and water. The basic principle of isotope analysis for mobility studies rests on the understanding that the isotopes that are deposited in the living skeleton during life will reflect the isotopic signature of the ingested diet. Provided that the diet is predominantly locally sourced, the isotope signature will in turn be characteristic of the locale within which the individual resided at the time of tissue formation (Larsen 2003; Eriksson 2013; Price 2015).

Strontium and oxygen are two isotope systems, often jointly used in research on ancient mobility, that respectively reflect local geology and climate. This paper uses strontium and oxygen isotope analysis to establish local baselines for Beirut and to explore migration to the city during the Roman period.

2.4.1. Environment and Mobility: Strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\delta^{18}O$) isotopes

Naturally occurring strontium isotopes are most abundantly found in geological material, particularly bedrock. Through the natural weathering of this latter, strontium is released into the soil and water, and journeys through the food chain to eventually be incorporated into human skeletal tissues. Since it is a heavy isotope, it does not readily fractionate in biological processes as it passes through the biosphere and into the human skeleton. Consequently, strontium isotope ratios ($^{87}Sr/^{86}Sr$) incorporated into the living organism remain mostly characteristic of the underlying geology in which the individual was found when the bones and teeth were formed (Graustein 1989; Montgomery 2002; Bentley 2006; Price 2015).

Oxygen is incorporated into the skeleton primarily through ingested fluids, with minor contributions from solid foods and atmospheric oxygen. The main source of fluids usually consists of drinking water which is ultimately of meteoric origin; rain or snow (Daux et al. 2008; Leach et al. 2009; Chenery et al. 2010; Müldner et al. 2011; Eriksson 2013; Price 2015; Eckardt et al. 2015). The oxygen isotope ratio ($\delta^{18}O$) contained in precipitation varies according to different geographic and climatic factors including latitude, elevation, temperature, amount of precipitation, and distance from the source water of the precipitation (e.g. sea, lake, etc.) (Dansgaard 1964; Longinelli 1984; Daux et al. 2008; Leach et al. 2009; Chenery et al. 2010; Chenery et al. 2011; Price 2015; Killgrove & Montgomery 2016).

As a light stable isotope, and unlike strontium, oxygen ratios are subject to change through a series of metabolic stages between ingestion and incorporation into skeletal tissues. A number of conversion equations have been developed that allow the calculation of the drinking water value ($\delta^{18}O_{dw}$) from the ratios measured in skeletal phosphate ($\delta^{18}O_{phos.}$) (Longinelli 1984; Luz et al. 1984; Levinson et al. 1987; Daux et al. 2008). The estimated drinking water isotope composition can then be compared to known regional values in order to assess mobility (Müldner et al. 2011; Price 2015; Eckardt et al. 2015). Since this involves a regression procedure, errors are associated with the estimated $\delta^{18}O_{dw}$ from human skeletons that can lead to imprecise geographical attributions (Pollard et al. 2011). Pollard et al. (2011) advise instead the implementation of direct comparisons of measured $\delta^{18}O_{phos.}$ due to the significantly smaller ranges of measurement error. However, in the absence of the needed hydrological $\delta^{18}O_{phos.}$ data from Lebanon, this paper maintains comparisons of measured meteoric and estimated dental enamel $\delta^{18}O_{dw}$ values. It uses Daux et al.'s (2008) equation 6 to convert the $\delta^{18}O_{phos.}$ values calculated from measured enamel $\delta^{18}O_{carb.}$ (Chenery et al. 2012) into $\delta^{18}O_{dw}$ (see Section 2.4.4.1.1).

2.4.2. Environmental baselines vs. Biologically available baselines

Despite geology being the main determinant of strontium values, differential weathering of bedrock, sediment formation and drift, as well as strontium transfer through dust, rainfall and sea-spray, may also markedly contribute to the "local" $^{87}Sr/^{86}Sr$ signature (Montgomery 2002; Bentley 2006; Eckardt et al. 2015). Additional biosphere samples, such as plants and tooth enamel from archaeological animals that lived locally (usually small animals, such as rodents), are therefore better suited to characterizing the biologically available strontium values (BASr) of a given area (Price et al. 2002; Bentley et al. 2004; Bentley 2006; Montgomery 2010; Chenery et al. 2010; Eckardt et al. 2015; Holt et al. 2021). This study utilizes published plant data from Beirut and the Mount Lebanon range, and measures strontium ratios in faunal dentition from Roman Beirut to establish local BASr baselines for the city.

Establishing local oxygen baselines is more challenging. Environmental and faunal measurements of oxygen isotopes cannot be directly applied onto humans (Daux et al. 2008; Killgrove & Montgomery 2016). Moreover, natural variation exists even among individuals from the same population who consume the same drinking water. This variation in particular is not very well understood, but is likely due to the unique metabolic processes affecting oxygen within individual bodies (Chenery et al. 2010).

Furthermore, cultural practices associated with food and more importantly, drink preparation and consumption, can alter the isotope composition of ingested oxygen. These include the cooking, stewing, and boiling of certain foodstuffs such as cereals, legumes, and meat; the brewing and fermenting of beverages (e.g. beers, ale, wine); the preparation of hot drinks with boiled water (e.g. herbal teas); as well as the consumption of milk from animals (Daux et al. 2008; Brettell et al. 2012; Lamb et al. 2014). Because of these complexities, oxygen isotope analysis is considered less robust in identifying human mobility. Nonetheless, it is useful in complementing the information obtained from the strontium isotopes. Local oxygen ranges are thus cautiously estimated based on the available hydrological data from Beirut.

Other human or faunal mobility isotope values from Roman Beirut or Roman Lebanon are not available. Stantis et al. (2022) recently analyzed Sr and O isotope ratios in human remains from Bronze Age Sidon (Fig. 1). The results from Sidon are listed in Section 3.4.2 as comparative values for Sr and O isotope ratios on the Lebanese coast.

2.4.3. Sample selection

2.4.3.1. Human samples. Given that skeletal tissues form and remodel at different rates, it is possible through the analysis of different elements from the same skeleton to track individual mobility patterns at different stages of life (Larsen 2003; Eriksson 2013; Price 2015). The primary types of tissue used in mobility studies involve tooth enamel and calcined bone apatite. Since the aim of this study is to identify individuals who moved to Beirut, the preferred analytes are those that reflect the isotope composition of their place of residence during the early years of life.

Dental enamel once formed and mineralized during childhood and early to late adolescence in the case of third molars, does not undergo further changes during the lifetime of the individual (Ericson 1985; Eriksson 2013; Price 2015). It is also largely resistant to post-depositional contamination and retains both its Sr and O isotope ratios. For this reason, it is usually the sample of choice in migration studies (Montgomery 2002; Chenery et al. 2010; Price 2015). Dental enamel was sampled for the majority of the skeletons included in this study. Permanent second molars and second premolars were chosen in order to avoid the effects of breastfeeding (Wright and Schwarz 1998; Montgomery 2002; Prowse et al. 2008) which in the Roman world is estimated to be between birth and three years of age (Dupras and Schwarcz 2001; Fuller et al. 2006; Prowse et al. 2008). Both the second molar and second premolar crowns have a period of enamel mineralization between the ages of 3 and 7 (Ubelaker 1989; AlQahtani et al. 2010), which relates to early childhood.

Enamel, however, rarely survives the process of cremation as high temperatures lead to the shattering of the dental crowns. An equivalent tissue with a similar period of early formation would be the otic capsule of the petrous bone which is an element that endures well the burning process and tends to maintain its original morphology. The otic capsule is one of the densest bones of the body and is formed in utero (16–18 weeks gestation) primarily through endochondral ossification (Scheuer and Black 2004). It is fully ossified around the time of birth and ceases to remodel after the age of two. Unlike regular bone, the calcined skeleton is resistant to external contamination and thereby retains its original strontium isotope signature (Harbeck et al. 2011; Harvig et al. 2014; Snoeck et al. 2015; Veselka et al. 2021). Its oxygen values, however, are not reliable indicators of hydrological sources due to the chemical changes occurring during the burning process that affect the biogenic $^{18}O/^{16}O$ ratios of bone (Snoeck et al. 2016). Since the isotope signature of the otic capsule reflects the diet during the period between utero and two years of age, it includes contributions from the mother's diet during gestation and throughout the breastfeeding period. Although the interpretation of this data is not as straightforward as that of dental enamel, it does not necessarily constitute an impediment to mobility assessment. By considering also the contextual and historical background, the isotopic contribution from the mother reflecting her own geographical location can help infer later mobility in her offspring.

2.4.3.2. Animal samples. Three faunal samples from Beirut were analyzed in this study to characterize local bioavailable strontium values. These samples were obtained from archaeological sites within the city: SFI 1056 and BEY 198. All three samples dated to the Roman period and were contemporary with the human population included in this study. Since smaller animals were not available for analysis, enamel samples were obtained from the permanent dentition of an equid (P4; SFI 1056 – Skeleton 806), caprine (sheep/goat) (M3; SFI 1056 – Skeleton 820), and cattle (M1; BEY 198 – Skeleton 368).

Through the practice of transhumance, these animals are assumed to have grazed in the general area of Beirut. As such, they offer a proxy for the biologically available strontium in and within the vicinity of the city. Based on their respective weaning patterns and the age at mineralization of the teeth, the isotope signatures of the equid and caprine samples reflect those attained solely from their grazing activity, while that of the cattle consists of a mixture of isotope ratios originating from nursing and grazed food sources (Hoppe et al. 2004; Brown et al. 1960; Weinreb & Sharav 1964; Milhaud & Nézit, 1991; Kierdorf et al. 2012). It is, however, important to note the possibility of these larger animals to have been imported to Beirut from further away through, for instance, trade activities.

2.4.4. Chemical preparation and analysis

2.4.4.1. Dental enamel. Teeth were cleaned of all altered surfaces using dental burs, and enamel samples were cut from the dental crowns using diamond edged dental saws. Adhering dentine was then removed from the enamel chips using the dental burs.

2.4.4.1.1. Strontium isotopes. The chemical treatment and analysis of the enamel samples for strontium isotopes was undertaken at the Arthur Holmes Isotope Geology Laboratory at Durham University. The pre-cleaned enamel chips (0.01 g – 0.1 g) were weighed into clean

Teflon beakers and dissolved in 0.5 ml Teflon distilled (TD) 16 M HNO_3, dried down, and re-dissolved in 0.5 ml TD 3 M HNO_3. Sr fractions were extracted from the sample matrix using an Eichrom Sr-Spec exchange resin column following the procedure in Font et al. (2008).

The Sr fraction, eluted from the column in 400 ml of ultrapure (MQ) H_2O, was acidified with TD 16 M HNO_3 to make a 3% HNO_3 solution ready for isotope analysis by Multi-Collector ICP-MS (MC-ICP- MS) using a ThermoFisher Neptune. Prior to analysis, the Sr fraction was tested to determine the Sr concentration and ensure the major isotope of Sr (^{88}Sr) did not exceed the maximum voltage (50 V) for the detector amplifiers. Any samples that exceeded this limit were diluted to yield an ^{88}Sr signal of ~25 V.

A Sr isotope measurement comprised a static multi-collection routine of 1 block of 50 cycles with an integration time of 4 s per cycle; a total analysis time of 3.5 min. Instrumental mass bias was corrected for using an ^{88}Sr/^{86}Sr ratio of 8.375209 (the reciprocal of the accepted ^{86}Sr/^{88}Sr ratio of 0.1194) and an exponential law. Corrections were also applied for Kr interferences on ^{84}Sr and ^{86}Sr and the Rb interference on ^{87}Sr. The average ^{83}Kr intensity throughout the analytical session was ~0.38 mV, which is insignificant considering the Sr beam size (average ^{88}Sr beam size of 19.2 V). The average ^{85}Rb was slightly greater at ~0.6 mV, but similarly, given the Sr beam size, the correction on the ^{87}Sr/^{86}Sr was very small (<0.00001) and is accurate.

Samples were analyzed during a single analytical session during which the average ^{87}Sr/^{86}Sr and reproducibility for the International Reference Material (IRM) NBS 987 was 0.710275 ± 0.000012 (2σ, n = 11). All sample data are reported relative to an accepted ^{87}Sr/^{86}Sr ratio of 0.710240 for NBS 987.

2.4.4.1.2. Oxygen isotopes. The oxygen isotope analysis was carried out at the NERC Isotope Geosciences Laboratory at the British Geological Service in Keyworth. Approximately 3 mg of prepared enamel was loaded into a glass vial and sealed with septa. The vials were transferred to a hot block at 90 °C on the GV Multiprep system. They were subsequently evacuated, and four drops of anhydrous phosphoric acid were added. The resultant CO_2 was collected cryogenically for 14 min and transferred to a GV IsoPrime dual inlet mass spectrometer. The resultant isotope values were treated as a carbonate.

δ^{18}O was reported as per mil (‰) (^{18}O/^{16}O) normalized to the PDB scale using a within-run calcite laboratory standard (KCM) calibrated against SRM19, NIST reference material, and were converted to the SMOW scale using the published conversion equation of (Coplen 1988): SMOW= (1.03091 × $\delta^{18}O_{VPDB}$) + 30.91. Analytical reproducibility for this run of laboratory standard calcite (KCM) was ± 0.02‰ (1 σ, n = 7) for $\delta^{18}O_{SMOW}$, and ± 0.01‰ (1 σ, n = 7) $\delta^{13}C_{PDB}$. The reproducibility of the tooth enamel, based on ten replicate analyses, was ± 0.06 (1σ) for $\delta^{18}O_{SMOW}$ and ± 0.04 (1σ) for $\delta^{13}C_{PDB}$. The carbonate oxygen results $\delta^{18}O_{carb.}$ were converted to phosphate values $\delta^{18}O_{phos.}$ using the equation of Chenery et al. (2012) ($\delta^{18}O_{phos.} = 1.0322*\delta^{18}O_{carb.} - 9.6849$). $\delta^{18}O_{phos.}$ values were then converted into $\delta^{18}O_{dw}$ using Daux et al.'s (2008) equation 6, as explained in Section 2.4.1.

2.4.4.2. Petrous bone. The calcined petrous bone was cleaned of any surface contaminants using dental burs and then sectioned using a dental saw. The sectioning followed the anatomical descriptions illustrated by Pinhasi et al. (2015) to best isolate the otic capsule. The subsequent chemical treatment and strontium isotope analysis of the bones were undertaken at the Université Libre de Bruxelles Analytical, Environmental and Geo-Chemistry lab following the procedures outlined by Snoeck et al. (2015).

The samples were measured on a Nu Plasma MC-ICP Mass Spectrometer (Nu015 from Nu instruments, Wrexham, UK). During the course of this study, repeated measurements of the NBS987 standard yielded ^{87}Sr/^{86}Sr = 0.710246 ± 0.000045 (2SD for > 300 analyses), which is, for our purposes, sufficiently consistent with the mean value of 0.710252 ± 0.000013 (2SD for analyses) obtained by TIMS (thermal ionization mass spectrometry) instrumentation (Weis et al. 2006). All the sample measurements were normalized using a standard bracketing method with the recommended value of ^{87}Sr/^{86}Sr = 0.710240. Procedural blanks were considered negligible (total Sr (V) of max 0.02 vs. 7–8 V for analyses; i.e. ≈0.3%). For each sample, the ^{87}Sr/^{86}Sr is reported with a 2σ error (absolute error value of the individual sample analysis—internal error).

3. Results

3.1. Osteological analysis

The results of the osteological analysis of the skeletons chosen for isotope analysis are presented in Table 1. Also indicated are the dentition sampled for each individual.

3.2. Radiocarbon dating and chronological subdivision of the Roman burials

Of a total of eighteen bone samples, ten yielded collagen of good quality and the measured ^{14}C results are considered to be reliable. The remaining eight samples did not yield any or sufficient collagen (<0.5% of the pre-treated bone material), or the extracted collagen was of low quality and not suitable for analysis. The latter assessment was based on the measured %C, %N and the ratio C:N. Acceptable values involve %C > 30%; %N > 10%; C:N between 2.9 and 3.5 and preferably between 3.1 and 3.3 (van Klinken 1999).

^{14}C ages (yr BP) were calibrated to calendar years using OxCal version 4.4 (Bronk Ramsey 2009) and the IntCal-20 calibration curve (Reimer et al. 2020). Results are reported within the 95.4% probability range (2σ uncertainty range for measured ^{14}C age) (Fig. 3).

The combined results from the archaeological and radiocarbon dating are what generated the final dates relied upon in this paper (Table 2). Overall, burials ranged from the late 1st c. BC to the 4th c. AD. They were divided into sub-periods involving burial sites dating to the early Roman period (1st c. BC – early 2nd c. AD): RML 2385, MDWR 02, and ASH 163; and others to the mid- and late Roman periods (late 1st c. AD – 4th c. AD): MDWR 466/468, ASH 002, and RML 778.

Table 1
List of skeletons sampled for isotope analysis (*after Kalenderian 2019).

Site Code	Skeleton Number	Sex	Age (years)	Tooth Sampled
RML 2385 (3)	1902	Indeterminate	30–55	Maxillary Right (R.) P4
	2284	PF	35–39	Mandibular R.P4
	2469	PF	30–50	Calcined Petrous Bone
MDWR 02 (6)	2722	F	14–17	Maxillary R.P4
	1420	M	35–55	Mandibular Left (L.) P4
	1925	Indeterminate	16–25	Maxillary R.P4
	2090	Indeterminate	30+	Mandibular R.P4
	3790	I	40+	Mandibular L.P4
	3804	Indeterminate	Adult	Calcined Petrous Bone
ASH 163 (1)*	107	PF	15 (+/-3)	Maxillary L.P4
MDWR 466/ 468 (2)	78	F	25–29	Maxillary R.M2
	105	M	25–29	Mandibular L.P4
ASH 002 (6)	444	Indeterminate	18–30	Maxillary L.M2
	178–2	PF	18–22	Maxillary R. P4
	263	PF	20–30	Mandibular M2
	160	Indeterminate	40+	Mandibular R.M2
	11	PF	17–25	Mandibular M2
	21	PF	25–40	Maxillary P4
RML 778 (1)	114	F	30+	Mandibular R.M2

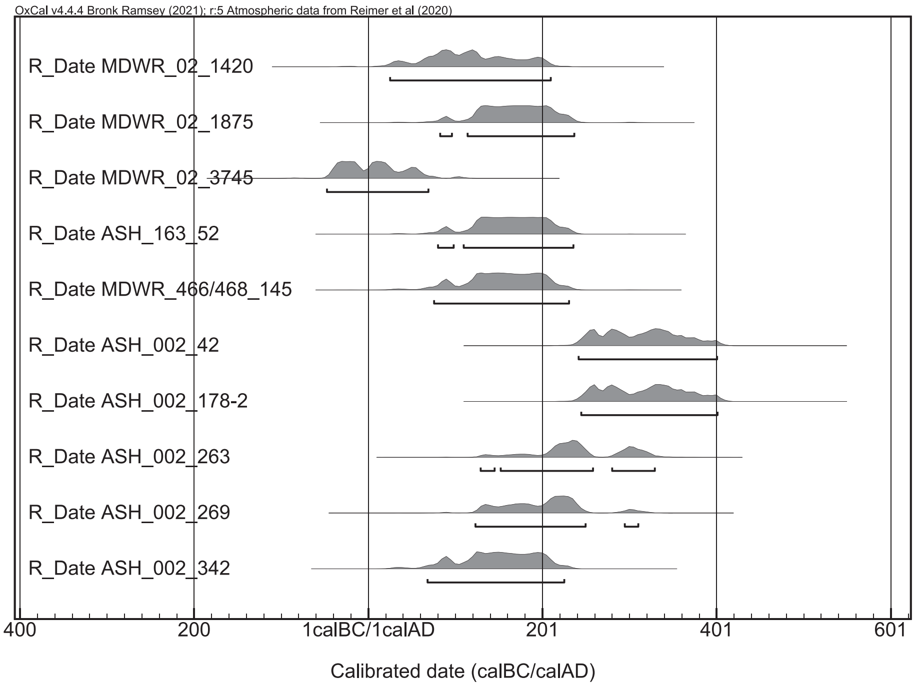

Fig. 3. Calibrated radiocarbon dates of the Beirut samples using OxCal version 4.4. (Bronk Ramsey 2009) and the IntCal-20 calibration curve (Reimer et al. 2020).

Table 2
List of archaeological sites included in this study, and the archaeological and radiocarbon dating of the burials.

Site Code	Archaeological Dating of the Burials	Skeleton Number	Radiocarbon Dating							
			Bone Sample	Lab-ID	Collagen Yield (%)	%C	%N	C:N	^{14}C age (yr BP± 1σ)	^{14}C Calibrated Calendar Date (95.4% probability)
RML 2385	late 1st c. BC – mid-1st c. AD	1902	Left Tibia	x	x	x	x	x	x	x
		2318	Right Humerus	GrA-69585	3.44	24.2	8.8	3.2	x	x
		2442	Left Tibia	GrA-69586	0.13	22.1	8.1	3.2	x	x
MDWR 02	late 1st c. BC – early 2nd c. AD	1420	Right Fibula	GrA-69579	0.74	42.3	15.5	3.2	1920 ± 30	AD 26 – AD 210
		1875	Right Femur	GrA-69580	7.51	46.0	16.9	3.2	1875 ± 30	AD 83 – AD 237
		3745	Right Femur	GrM-10350	0.76	35.4	13.1	3.2	2005 ± 22	48 BC – AD 70
ASH 163	late 1st c. BC – 2nd c. AD	52	Left Tibia	GrA-69578	1.26	41.8	15.1	3.2	1880 ± 30	AD 81 – AD 236
MDWR 466/468	mid-1st c. AD – 4th c. AD	145	Left Tibia	GrA-69576	1.14	33.9	12.2	3.2	1890 ± 30	AD 76 – AD 231
		193	Right Tibia	GrA-69541	0.01	39.8	14.9	3.1	x	x
ASH 002	1st c. AD – 4th c. AD	11	Right Femur	x	0.26	5.1	1.8	3.4	x	x
		42	Femur	GrA-69587	3.04	40.7	14.7	3.2	1745 ± 30	AD 242 – AD 401
		178–2	Femur	GrA-69588	1.64	37.8	13.7	3.2	1740 ± 30	AD 245 – AD 402
		219	Left Femur	GrA-69537	0.04	14.2	5.4	3.1	x	x
		263	Left Femur	GrA-69589	1.39	37.4	13.5	3.2	1815 ± 30	AD 130 – AD 330
		269	Left Femur	GrA-69590	4.45	42.3	15.4	3.2	1840 ± 30	AD 124 – AD 311
		342	Right Humerus	GrA-69592	6.66	46.4	16.9	3.2	1895 ± 30	AD 69 – AD 226
		456	Left Tibia	x	x	x	x	x	x	x
RML 778	1st c. BC – 4th c. AD	114	Left Femur	x	x	x	x	x	x	x

3.3. Establishing environmental isotope baselines

3.3.1. Local geology and climate

The geology of Lebanon consists primarily of limestone formations and limestone marine deposits that show very little variation in type (Fig. 4). The massive limestone formations date to the early Jurassic period (200–150 MA), with subsequent limestone deposits occurring from the Cretaceous (150–100 MA) to the Miocene (23–5.3 MA) periods. In certain parts of the country, sandstone layers (lower Cretaceous) are found to rest above the limestone formations and below subsequent marine limestone deposits. Large basaltic deposits (Cenozoic period; 66 MA–present) are found in the extreme north and in the extreme southeast of the country, and older basaltic features that date to the Jurassic and Cretaceous periods are located on the main mountain ranges. The geology of Beirut consists primarily of marine limestone deposits. However, due to its close proximity to the sea, as well as the Beirut River, the area is overlain with swathes of red sand dunes as well as littoral and alluvial deposits (Dubertret 1955; Walley 1998a, 1998b).

Most of Lebanon is characterized by a Mediterranean climate which consists of moderately cold and rainy winters, hot and humid summers, and mild spring and autumn seasons. Beirut is situated on the coast where temperatures range between 7 °C in the wintertime and 32 °C in the summertime. The city experiences frequent rainfall mainly between October and March and local humidity levels are quite elevated, remaining fairly constant at 70% (Faour et al. 2004) (Fig. 5).

3.3.2. Strontium geological baselines

A wide-ranging analysis to establish the strontium isotope composition of the underlying geology of Lebanon as a whole has not yet been undertaken, and no published data pertaining to the more localized environment of Beirut is yet available. The geological baselines utilized in this paper are therefore values from areas outside the city, and primarily from the Mount Lebanon range that has an underlying geology similar to, but not the same as, Beirut (Abdel-Rahman 2002; Abdel-Rahman and Nassar 2004; Rich et al. 2015) (Fig. 4). While the marine deposit values may be the same in both locales, the interaction of this recent deposit with the older limestone formations found in Mount Lebanon may result in signatures different from what characterizes the coast. Similarly, Beirut is covered by red sand dunes and alluvial deposits that contribute to its local isotope range, which are absent from the Lebanese mountains.

Despite this limitation, the values presented in Table 3 offer general isotopic ranges that serve as provisional reference values for the context of Beirut. Signatures from alkali basaltic rock, found both in Mount Lebanon and in the northern regions of the country are also listed in order to have a scope of geological values local to Lebanon. The tentative geological baseline for Beirut, however, will consist of the maximum and minimum limestone values, ranging between **0.7070** and

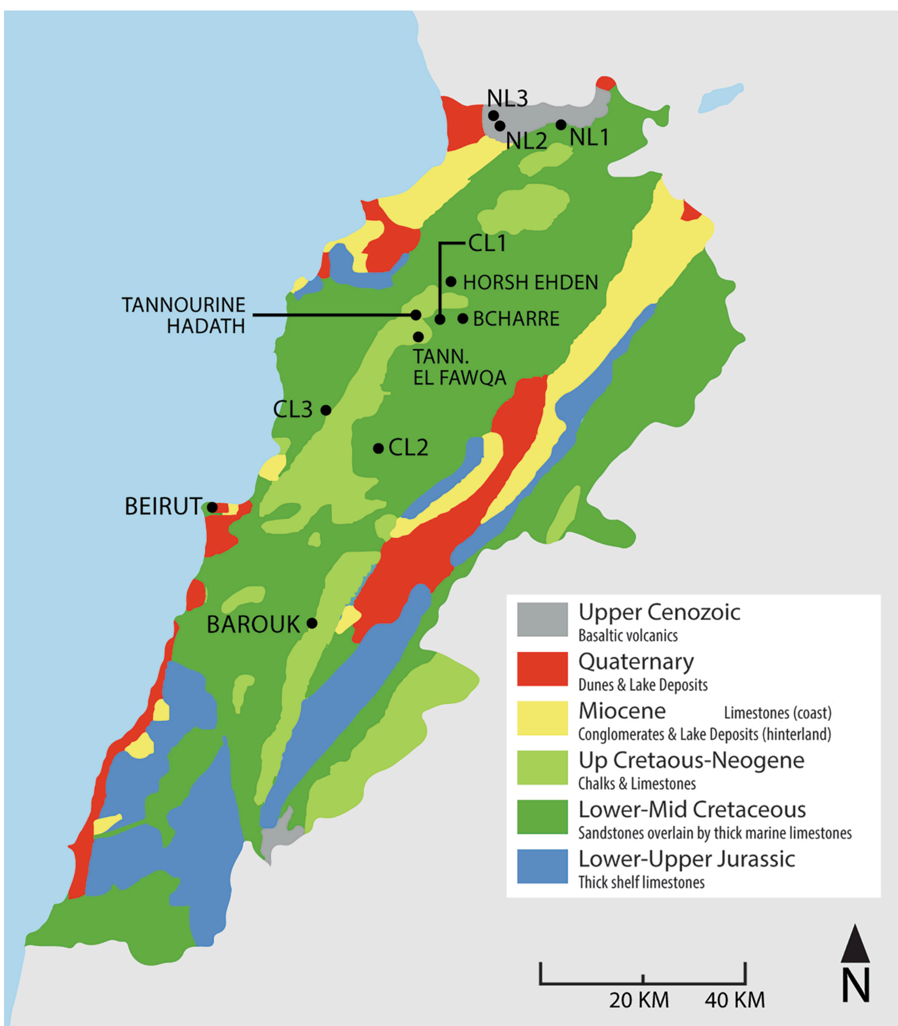

Fig. 4. Geological map of Lebanon (adapted from Walley 1998a). Also indicated are the different regions from which bedrock and/or flora have been analyzed for Sr isotope composition (see Tables 3 and 5).

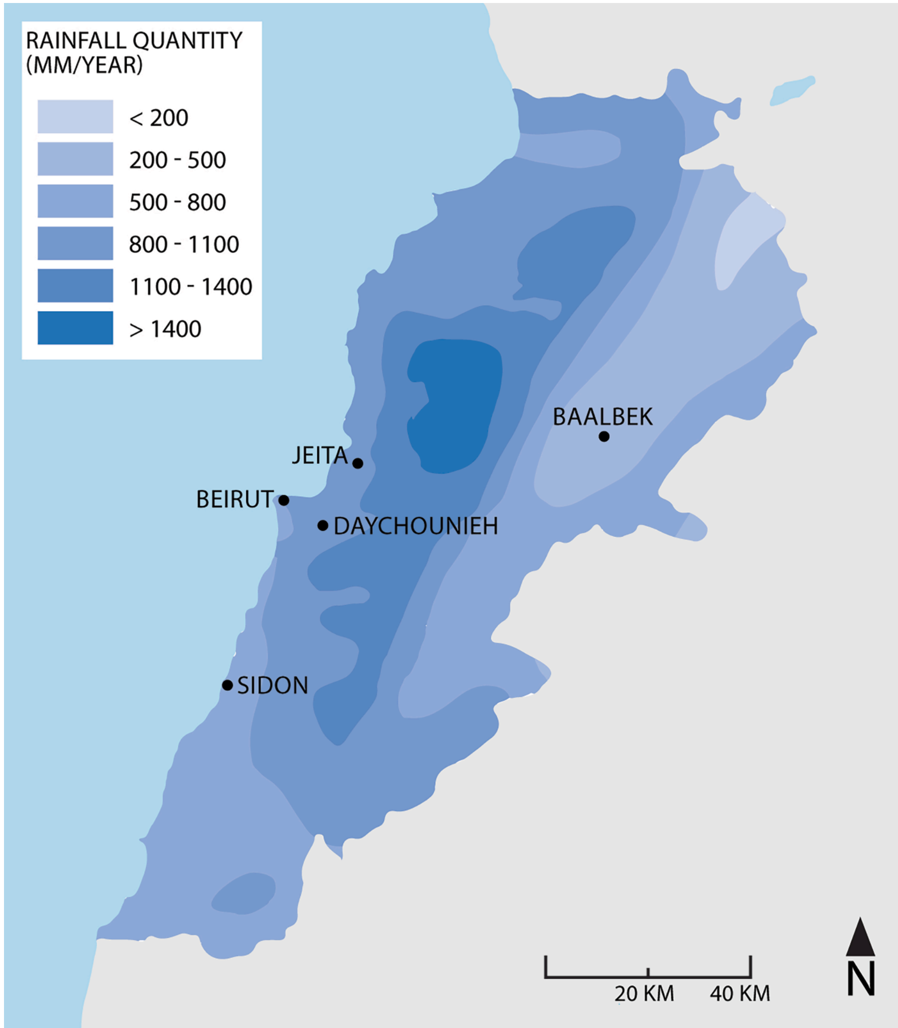

Fig. 5. Precipitation map of Lebanon (adapted from Plassard 1971).

Table 3
Isotope composition of underlying bedrock in Mount Lebanon (after Abdel-Rahman 2002; Abdel-Rahman & Nassar 2004; Rich et al. 2015). The values most relevant to the geology of Beirut are those of the Barouk, Horsh Ehden, and Tannourine El-Fawqa limestones (indicated in bold characters).

Sample Location	Type	$^{87}Sr/^{86}Sr$ value (2σ)
Barouk	**Limestone**	**0.70696 (0.00009)**
Horsh Ehden	**Limestone**	**0.70792 (0.00005)**
Tannourine El-Fawqa	**Limestone**	**0.70698 (0.00009)**
Tannourine Hadath – 1	Sandstone	0.70736 (0.00013)
Tannourine Hadath – 2	Sandstone	0.70739 (0.00012)
Central Lebanon (CL) – 1	Alkali Basalt	0.703669
Central Lebanon (CL) – 2	Alkali Basalt	0.703528
Central Lebanon (CL) – 3	Alkali Basalt	0.702971
North Lebanon (NL) – 1	Alkali Basalt	0.703579
North Lebanon (NL) – 2	Alkali Basalt	0.703349
North Lebanon (NL) – 3	Alkali Basalt	0.703317

0.7079. The coastal location of Beirut, however, also increases the contribution of marine sea-splash and sea-spray (0.7092) on local Sr values. This occurs through the aerial deposition of seawater into the local environment, as well as the consumption of salt-based foodstuffs (such as brines or salted fish) and crops grown on the coast (Montgomery 2010).

3.3.3. Oxygen baselines

The oxygen isotope composition of rainwater from Beirut ranges between **−6.1‰ – −3.3‰** (Table 4), with a mean value of **−5.0 ‰ (±1.9, 2σ)** (Saad et al. 2005).

Rainwater, however, was not the only source of drinking water in the city. Residents in Roman Beirut had access to water through wells dug in the ground. Although water in these aquifers is recharged primarily from local coastal precipitation, it could have up to 30% contribution from underground sources from higher elevations (Saad et al. 2004). In addition to the wells, an aqueduct was built in the mid-1st c. AD that channelled water to the city from springs located at higher altitudes in the Mount Lebanon range. The exact source from which the aqueduct was fed is still unknown. A possible source is hypothesized at Daychounieh, which is approximately 12.2 km from Beirut at an altitude of 250 m asl, although springs from higher up in Mount Lebanon, at an altitude of 500 m, are also a possibility (Davie et al. 1997) (Fig. 6). All this illustrates the mixing of water sources in the city and consequently, the less straightforward nature of estimating the oxygen isotope signature of drinking water in Beirut.

Data from the aquifer and spring sources providing water to Roman Beirut were not available. Instead, values are considered from a spring source in Mount Lebanon that is comparable to the one thought to have fed the ancient aqueduct. The Jeita catchment area is located 15 km north of Beirut, at a distance of 5 km from the coastline (Fig. 6). It covers a surface area of 406 km^2 and extends over altitudes ranging between

Table 4
δ ^{18}O values of the Beirut precipitation and Jeita catchment area in Mount Lebanon (after Saad et al. 2005; Königer and Margane 2014; Königer et al. 2017).

Location	Water Source	Number of Samples	Mean Value/Range δ $^{18}O_{dw}$ (‰ VSMOW)
Beirut	Precipitation	Samples collected twice daily on a monthly basis between November & March over a three-year period (2003–2005)	−6.10 – −3.30
Mount Lebanon	Precipitation	88	−6.48 – −4.51
	Snow	17	−7.79
		21	−7.92
	Cave Drip Water	111	−5.24
	Spring Water	796	−8.02 – −6.82

Fig. 6. Map of Lebanon and the main locations mentioned in this study. The zone delimited in red consists of the Jeita catchment area.

60 m asl and 2626 m asl. Research undertaken in Jeita involved a comprehensive study that measured the isotope composition of different water sources in the specified area, including rainfall, snow, cave drip water, and water from six natural springs discharging from two different aquifers (Königer and Margane 2014; Königer et al. 2017). The combined isotope range of the different sources was between −8.0 and −4.5 ‰ (Table 4).

The rainwater values from Beirut will be used as the primary baseline for drinking water in this study. However, in order to account for the contribution of water from the Mount Lebanon range by way of the aqueduct, the most depleted water values from the Jeita spring (-8.0‰) will be used as a secondary and possible minimum cut-off value for the oxygen isotope range of Beirut, with the understanding that the mixing of the different sources will have resulted in a hybrid local isotope signature.

3.4. Establishing biologically available Sr values

3.4.1. Fauna and flora

In the study by Rich et al. (2015), cedar tree twigs and increment cores (heartwood) of 5 mm diameter were analyzed to characterize the strontium isotope ratios of the living forests. Wood samples from five forest sites in the Mount Lebanon range were analysed (see Fig. 4). The isotope ratios are listed in Table 5 and appear to vary from the signatures of the underlying bedrock (see Table 3). Due to the same underlying Jurassic limestone formation, cedar trees in Tannourine El-Fawqa, Bcharre, and the Barouk forests presented similar isotope ratios despite the distance separating them. The Horsh-Ehden cedars had a different signature, likely due to the more recent marine limestone deposits that the forest rests upon. Likewise, the Tannourine-Hadath values were also divergent due to the underlying sandstone bedrock. Based on the premise of an overall similar underlying geology, and despite their significant distance from Beirut, the minimum (0.7077) and maximum (0.7085) values of the cedar trees growing on limestone bedrock (Barouk, Bcharre, Tannourine El-Fawqa, and Horsh Ehden forests) will be used in this study as broad baselines for the BASr in local vegetation. Strontium results from a plant sample from Beirut by Henderson et al. (2009) produced a signature of 0.7079 which also falls within this range.

Additionally, the three faunal samples from Beirut that were analyzed in this study yielded Sr isotope ratios ranging between 0.7082 and 0.7084 (Table 5), which suggests that they were locally raised. The BASr values from vegetation and fauna represent the Sr which the human population would have incorporated through their diet. As such, a conservative BASr range between **0.7077** and **0.7085** is defined for Beirut and its surroundings, with an average of **0.7082 (±0.0005, 2SD)**.

Table 5
$^{87}Sr/^{86}Sr$ isotope ratios of cedar wood from Mount Lebanon (after Rich et al. 2015), one plant sample from Beirut (after Henderson et al. 2009), and fauna from Beirut. The first four forest sites (indicated in bold) include the Mount Lebanon flora growing on limestone bedrock whose values are used to establish local BASr baselines in this study.

Sample Type	Location	Sample	$^{87}Sr/^{86}Sr$ value (2σ)
Vegetation	**Barouk**	**Twigs**	**0.70827 (0.00020)**
	Bcharre – 1	**Cedar increment core**	**0.70833 (0.00066)**
	Bcharre – 2	**Cedar increment core**	**0.70827 (0.00246)**
	Tannourine El-Fawqa – 1	**Cedar increment core**	**0.70824 (0.00024)**
	Tannourine El-Fawqa – 2	**Cedar increment core**	**0.70848 (0.00015)**
	Tannourine El-Fawqa – 3	**Cedar increment core**	**0.70836 (0.00076)**
	Horsh-Ehden – 1	**Cedar increment core**	**0.70798 (0.00038)**
	Horsh-Ehden – 2	**Cedar increment core**	**0.70795 (0.00040)**
	Horsh-Ehden – 3	**Cedar increment core**	**0.70769 (0.00259)**
	Horsh-Ehden – 4	**Cedar increment core**	**0.70850 (0.00014)**
	Tannourine-Hadath – 1	Cedar increment core	0.70866 (0.00036)
	Tannourine-Hadath – 2	Cedar increment core	0.70897 (0.00063)
	Tannourine-Hadath – 3	Cedar increment core	0.70850 (0.00064)
	Tannourine-Hadath – 4	Cedar increment core	0.70911 (0.00024)
	Beirut	Plant	0.707928
Fauna	BEY 198 – 368	Cattle tooth – Right mandibular M1	0.708189 (0.000010)
	SFI 1056 – 806	Equid tooth – mandibular P4	0.708185 (0.000008)
	SFI 1056 – 820	Caprine tooth – Right maxillary M3	0.708420 (0.000009)

3.4.2. Comparative human population from Lebanon: Bronze age Sidon

Human strontium and oxygen isotope ratios from Sidon involved respective mean values of 0.7083 (±0.0009, 2SD) and −6.1‰ (±3.4, 2SD) (Stantis et al. 2022). Sidon's surface geology consists primarily of quaternary sand dunes and lake deposits and is therefore somewhat different from the geology of Beirut, which is predominantly influenced by the underlying marine limestone in addition to the surface sand dunes and alluvial deposits (Dubertret 1955; Walley 1998a). As a coastal city, Sidon's climate is not very different to that of Beirut, although it does receive on average less rainfall than the latter (Fig. 5). Other sources of potable water in Sidon would similarly have included both local springs and those originating further south on the Mount Lebanon range.

While isotope ratios from Sidon may not serve as direct proxies for local signatures in Beirut due to differences in local geologies and drinking water sources, they offer comparative values from Lebanon that are important for studies of close distance mobility.

3.5. Human Skeleton results

3.5.1. Strontium isotopes

The strontium isotope data for the 19 human samples (17 enamel and 2 calcined petrous portions) are presented in Fig. 7 and Table 6. Also shown in Fig. 7 are the maximum and minimum value points of the Mount Lebanon limestone geology and the local BASr, as well as the 2SD range of the mean BASr (0.7082 ± 0.0005, 2SD). The latter two include values from the limestone cedar wood, the Beirut plant sample, and the faunal dentition.

The human enamel samples fall between 0.7080 and 0.7100, with a mean of 0.7086 ± 0.0008, 2SD. The majority of samples ($n = 17$; 89.47%) cluster closely together and fall within 2SD of the biologically available strontium values. With the exception of two skeletons (10.53%), most of the analyzed individuals present strontium isotope ratios consistent with childhoods spent in Beirut, or on similar geology.

On the other hand, Skeleton 2469 ($^{87}Sr/^{86}Sr$ ratio: 0.7092) and Skeleton 1420 ($^{87}Sr/^{86}Sr$ ratio: 0.7100) have childhood strontium isotope compositions that are significantly higher than those of the remaining individuals and well above the baseline values for Beirut and its neighbouring mountains. These values also do not correspond to the geological signals of other types of bedrock from Lebanon (Table 3). Instead, the higher ratios indicate origins on more radiogenic terrains and/or contributions from proximity to seawater that has a value of 0.7092 (Hess et al. 1986).

3.5.2. Oxygen isotopes

The oxygen isotope data for 17 human enamel samples are presented in Fig. 8 and Table 6. The maximum and minimum values for Beirut rainwater are indicated in Fig. 8, in addition to the mean rainwater value from the city (-5.0‰ ± 1.9, 2σ). The lowest value of the spring water from the Jeita catchment area is also shown (-8.0‰), which corresponds to the signal of water coming from the elevated Mount Lebanon springs.

The $\delta^{18}O_{dw}$ of the human samples fall between −6.1‰ – −2.5‰ ($\delta^{18}O_{phos}$ = 17.9‰ – 20.3‰), with a mean of −4.4‰ (±2.1, 2SD) (mean $\delta^{18}O_{phos}$ = 19.0‰ ±1.4, 2SD). Fifteen of the samples (88.24%) fall within the range of Beirut rainwater. Those individuals may therefore be said to have spent their childhood in Beirut or a region with a similar climate. Two skeletons (11.76%), Skeleton 1902 (-2.5‰) and Skeleton 2284 (-3.0‰), however, present oxygen values higher than the local rainwater range. This indicates drinking water that is more enriched in ^{18}O than that of Beirut, which suggests water sourced from a warmer climate than Beirut.

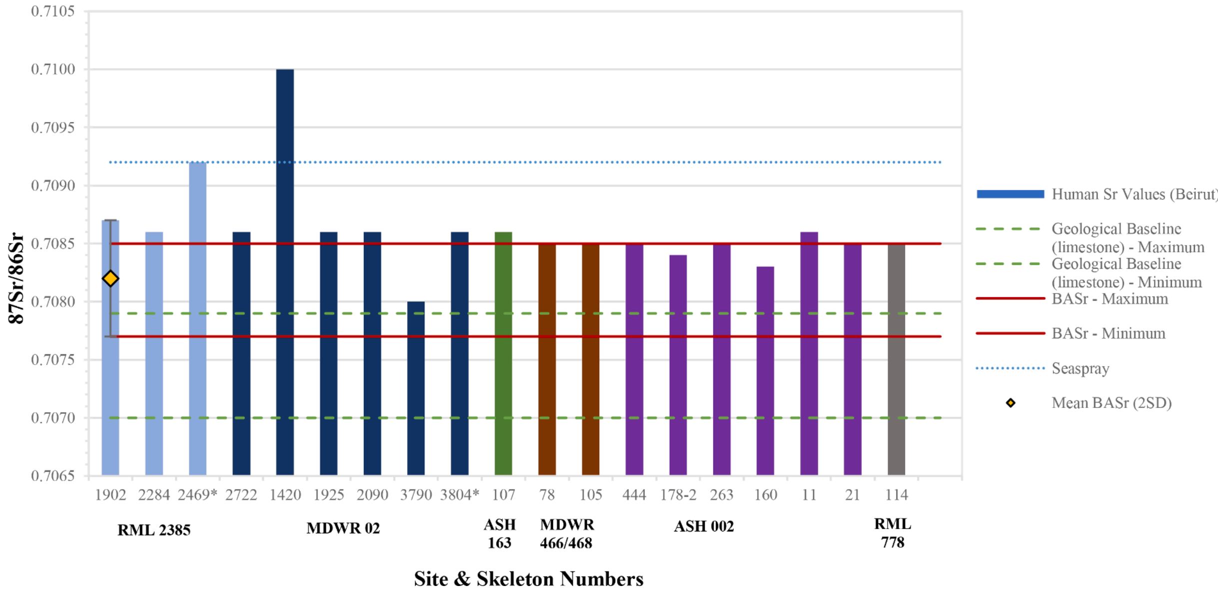

Fig. 7. Strontium isotope data from Beirut (*corresponds to cremated individuals).

Table 6
Sr and O isotope results of the human skeletons from Beirut. The carbonate oxygen results ($\delta^{18}O_{carb.}$) were converted to phosphate values ($\delta^{18}O_{phos.}$) using the equation of Chenery et al. 2012 ($\delta^{18}O_{phos.} = 1.0322*\delta^{18}O_{carb.} - 9.6849$), and the measured $\delta^{18}O_{phos.}$ was converted into $\delta^{18}O_{dw}$ using Daux et al.'s (2008) Equation 6: $\delta^{18}O_{dw} = 1.54(\pm0.09) \times \delta^{18}O_{phos.} - 33.72(\pm1.51)$ (*consists of a cremated individual).

Site-Skeleton Number	$^{87}Sr/^{86}Sr$ ($\pm2\sigma$)	$\delta^{18}O_{carb.}$ (‰ SMOW)	$\delta^{18}O_{phos.}$ (‰ SMOW)	$\delta^{18}O_{dw}$ (‰ SMOW)
RML 2385 – 1902	0.708715 (0.000012)	29.02	20.27	−2.50
RML 2385 – 2284	0.708562 (0.000010)	28.72	19.96	−2.98
RML 2385 – 2469*	0.709202 (0.000008)	–	–	–
MDWR 02 – 2722	0.708615 (0.000012)	26.73	17.91	−6.14
MDWR 02 – 1420	0.709992 (0.000011)	28.49	19.73	−3.34
MDWR 02 – 1925	0.708563 (0.000010)	27.01	18.20	−5.69
MDWR 02 – 2090	0.708587 (0.000009)	27.88	19.09	−4.32
MDWR 02 – 3790	0.707970 (0.000008)	27.06	18.25	−5.62
MDWR 02 – 3804*	0.708555 (0.000011)	–	–	–
ASH 163 – 107	0.708602 (0.000010)	28.47	19.70	−3.38
MDWR 466/468 – 78	0.708504 (0.000010)	28.19	19.41	−3.83
MDWR 466/468 – 105	0.708541 (0.000009)	27.98	19.20	−4.15
ASH 002 – 444	0.708545 (0.000009)	27.48	18.68	−4.95
ASH 002 – 178–2	0.708443 (0.000010)	27.69	18.89	−4.63
ASH 002 – 263	0.708549 (0.000008)	27.52	18.72	−4.89
ASH 002 – 160	0.708325 (0.000010)	28.32	19.55	−3.61
ASH 002 – 11	0.708573 (0.000011)	27.62	18.83	−4.72
ASH 002 – 21	0.708518 (0.000010)	27.66	18.86	−4.68
RML 778 – 114	0.708507 (0.000011)	26.99	18.17	−5.74

3.5.3. Strontium and oxygen isotopes

The strontium and oxygen isotopes are presented together in Fig. 9. An oxygen value of −7.0‰ is given to the two cremated samples for their illustration on the scatter plot. The dotted box represents the estimated strontium biosphere and $\delta^{18}O_{dw}$ ratios of Beirut. While most skeletons fall within this range, four individuals plot outside of it.

Skeleton 2284 presents strontium values consistent with signals from Beirut, but the drinking water ratio is higher than the local range. It is possible that this individual had an upbringing in an area that is geologically similar to Beirut, but of a slightly warmer climate. Nevertheless, considering the limited availability and resolution of data on drinking water from the city, in addition to the challenges inherent to the applicability of baselines for $\delta^{18}O_{dw}$ for humans, this individual cannot yet be confidently categorized as a non-local. The individual is instead listed as a possible migrant. Skeleton 1902 similarly presented a drinking water ratio above the local range. This skeleton also displayed strontium values slightly above the Beirut ratio, which increases the likelihood of a foreign origin. Nonetheless, and due to the current conservative Sr baselines, this individual, too, is for the time being categorized only as a possible migrant.

On the other hand, two other individuals (2469 and 1420) plot well outside the estimated Beirut range. Both skeletons present higher strontium isotope ratios, indicating an upbringing in an area that is geologically different from Beirut and likely of older rock formation. The values, however, do not plot close together which in turn signal migration to Beirut from different regions. Only the strontium value is measurable for the cremated individual (Skeleton 2469), but Skeleton 1420 presents a $\delta^{18}O_{dw}$ ratio just outside the estimated drinking water range of Beirut. This indicates that although the area in which Skeleton 1420 was raised was geologically different to Beirut, it likely had a similar moderate climate.

4. Discussion

4.1. Isotopic signatures and burial practices

The isotopic analysis of human skeletons from Beirut has shed light on the make-up of the buried population following Roman annexation. Ten of the individuals selected for isotope analysis belonged to the early Roman period (mid-1st c. BC – 1st c. AD) and nine to the mid- to late Roman period (late 1st c. AD – 4th c. AD). Most skeletons, including those from the early period, produced isotope signatures consistent with

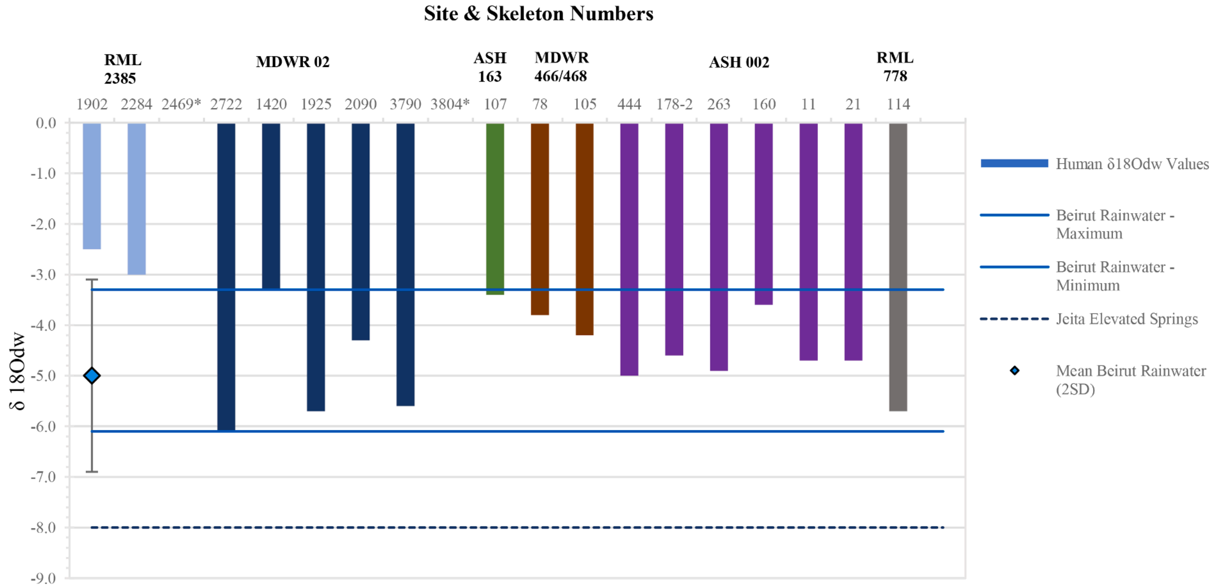

Fig. 8. Oxygen isotope data from Beirut (*corresponds to cremated individuals).

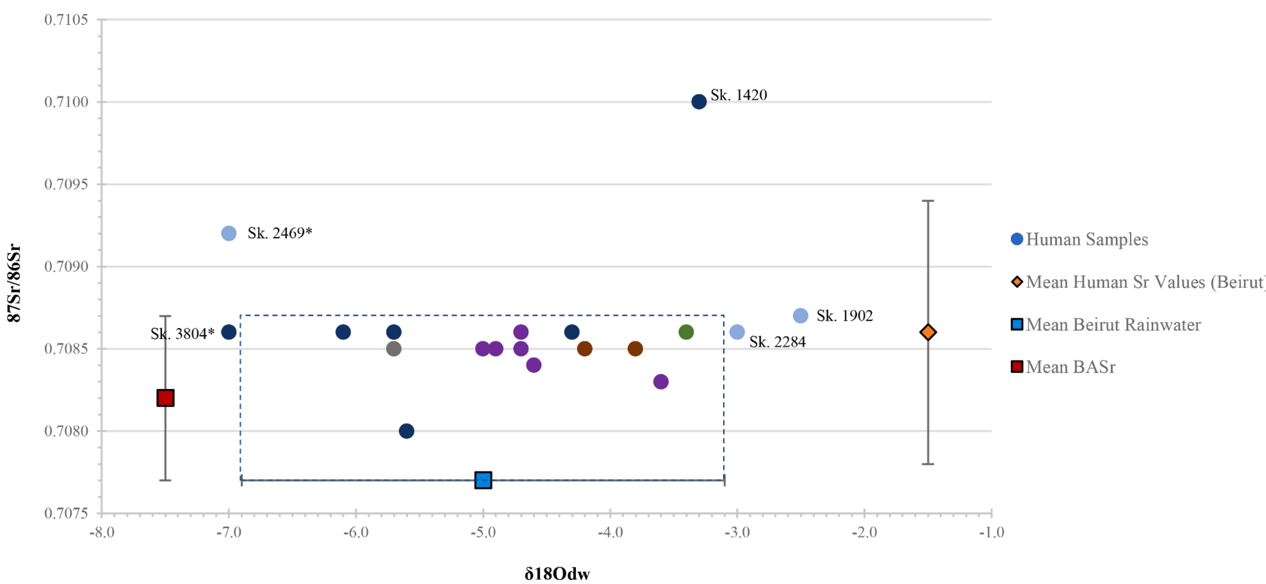

Fig. 9. Strontium and oxygen isotope data from Beirut. The blue box encloses the range of local BASr and drinking water oxygen values from Beirut.

local values. Although isotope analysis can only exclude rather than confirm local origins (Eckardt et al. 2015), a majority of local signatures combined with typically local manners of burial indicate that at least some of the individuals within this subset were part of the indigenous population of Beirut. This confirms that the local population remained in the city following the settlement of the Roman colonists.

Only two individuals were isotopically identified as non-locals (Skeletons 1420 and 2469) and two others as possible migrants (Skeletons 1902 and 2284). This seems unusual for the context of a Roman colony, let alone the first in the Near East. The geology of Beirut, however, is similar to that of many other areas in the Mediterranean and it is possible that the strontium and oxygen isotope systems are not discriminant enough between its different regions. Some of the skeletons presenting "local" values may as such be "hidden migrants". Furthermore, it is important to remember that only a small percentage of the total skeletons were analysed. Although the isotopic examination of additional skeletons may yield a different picture of the buried cohort, this outcome could also suggest that the majority of migrants and/or colonists were buried elsewhere in the city.

The foreign and possible non-local individuals that were identified belonged to the early Roman period and each presented different isotopic ratios. This indicates a varied pool of incomers with geographic origins from different parts of the Roman world. These migrants included both males and females. Most were buried in a manner that was typical of or similar to local practice (Skeletons 1420, 1902, 2284), while one displayed starkly atypical burial rites (Skeleton 2469).

Skeleton 1420, a male individual, was buried in a cist grave with glass unguentaria, a glass vessel, and a terracotta figurine. Similarly, Skeleton 1902, whose sex could not be determined, was buried in a simple pit grave with glass unguentaria and gold leaves placed on the facial cranium. Skeleton 2284, a possible female, was also buried in a simple pit grave with glass unguentaria. Compared to the majority of burials in the city, none of the three graves stands out as particularly unusual. The grave forms remain outwardly inconspicuous in the funerary landscape and blend with the adjacent tombs, and unguentaria were the most common grave good in Berytus. Nonetheless, the cist grave, terracotta figurine, and the gold leaves associated with Individuals 1420 and 1902, respectively, were relatively infrequent features in the early Roman period, which would categorize both burials as slightly more elaborate.

In contrast, all elements of the burial of Skeleton 2469 indicate a foreign practice. This individual was cremated, and the remains were inurned in a lead vessel – a rare burial receptacle in the early Roman Levant – which in turn was placed within a stone container and buried in the ground. In this latter case, both the archaeological and the isotopic evidence signal a migrant identity.

4.2. Communicating Non-local Identities: Migrants and colonists

Many factors influence why and how individuals decide for or against highlighting their migrant identities. Identity is a highly complex concept. It involves multiple facets of an individual's persona and tends to shift and evolve over time as a consequence of personal experiences and broader social influences (Eckardt 2015). As such, a non-local origin may not always be emphasized by some individuals who might instead deem it more important to communicate other facets of their identity, such as gender or status. Likewise, in other cases, a migrant identity may be prioritized over the expression of other aspects of a person's social and cultural persona. Adherence to foreign or imported traditions may reflect a personal choice linked to deeply held beliefs and customs, or could be a strategy for deliberate self-differentiation from the wider population in order to communicate rank, authority, and social distinction.

The differences in burial practice between the identified migrants in Beirut are likely linked to their differing places of origin, which is confirmed by their respective isotope signatures that indicate childhood residences in different geological regions. It is possible that migrants buried in a local fashion originated from regions that practised customs similar to those of Beirut, or that they (and/or their social group) adopted local tradition following their relocation to the city, perhaps through newfound kinship with local groups.

Considering the historical premise of early imperial army recruits originating from the Italian peninsula, isotope analysis can be used to help distinguish between potential colonists and other migrants unaffiliated with the veteran contingent. Since the non-local Sr signatures from Beirut fall within the range of BASr values of the Italian peninsula (Salesse et al. 2018; Nikita et al. 2022), an Italian provenance may not be excluded for Skeletons 1420 and 2469. The $\delta^{18}O_{dw}$ of Skeleton 1420 also corresponds to large areas of coastal Italy and does not add any discriminative information. The $\delta^{18}O_{dw}$ of the two potential migrants whose Sr signatures matched local Beirut values, as well as values from regions within Italy, do not exclude an Italian or a Mediterranean origin either (Salesse et al. 2018; https://wateriso.utah.edu/waterisotopes/pages/data_access/figures.html).

Despite these results, isotope analysis would only help eliminate, rather than prove, a colonial identity. To confirm a veteran affiliation, additional and specific indicators must be identified in the mortuary evidence. Evidence of a colonist identity may usually be found explicitly stated in epitaphs, or may otherwise be inferred through the identification of burial practices characteristic of the colonist group.

Since funerary epitaphs were absent from the burials included in this study, indications of such an identity are sought through characteristic mortuary customs. One such custom is the practice of burning the dead body. Cremation was highly uncommon in the Near East upon its annexation into the Roman Empire. It was, however, the dominant manner of treating the body in the western provinces (Morris 1992). In the Near East, the rare examples of cremation burials have primarily been linked to active Roman soldiers stationed in the region (de Jong 2017). The early occurrence of cremation burials in the first colony in the Near East is therefore highly suggestive of the cremating group being associated with the colonial contingent that imported and maintained this distinctive tradition. The non-local possible female individual who was cremated in Beirut may as such have been a member of a veteran's household. Interestingly, in addition to being consistent with values from Italy, the Sr isotope signature of Individual 2469 also matches values from France where one of the colonizing legions of Berytus, *legio VIII Augusta*, was previously stationed. Based on this information, as well as what is known of relationships formed between soldiers and local women (see Section 1.2), it may be possible that this individual had familial ties with a veteran during the latter's active duty and subsequently relocated with him to Berytus following his retirement.

Archaeological evidence suggestive of a colonial identity was absent from the remaining three burials. While a colonial association cannot be entirely ruled out (especially for Skeleton 1420 whose Sr signature matches areas in the Western Provinces, including France and Spain), these cases may also indicate independent migration to Berytus in the early Roman period which would represent an uninterrupted continued mobility to the city from the pre-Roman era (Jidejian 1997). Since their burial practices correspond to local burial rites, regional migration is considered by comparing the Sr and $\delta^{18}O_{dw}$ of the three skeletons to datasets from the Roman East. A possible place of origin for Individual 1420 is Western Anatolia. Individuals 1902 and 2284 may both have come from areas in the Southern Levant and Western Anatolia, with the added possibility of Crete for Individual 2284.

5. Conclusion

Evidence for mobility and its impact on Roman Beirut had so far relied primarily on ancient literary sources, epigraphy, and numismatic evidence. Despite their important contribution, these sources are associated with certain limitations. Origins, for one, are not always recorded in ancient inscriptions. And the epigraphic habit, in any case, was not very common in Roman Beirut. In fact, none of the burials included in this paper were associated with epitaphs. Literary sources, on the other hand, tend to be biased towards elite groups and male individuals, which leads to a skewed representation of ancient mobility. Likewise, the numismatic evidence from Beirut elucidates only the mobility of colonists to the city. While this is of great value to understanding the early colonization of the city, it provides little information on the movement of individual colonists and their families, as well as that of other migrants unaffiliated with the veteran contingent. Similarly, the archaeological evidence does not always reveal much information about the geographic origin of the individual through the artefacts included in the grave, or the associated burial rites. In fact, archaeological findings may in certain cases even mask a non-local origin, as observed with some of the (possible) migrants identified in Beirut.

Since this geographic identity is not always retained, reflected or communicated in the social and cultural identity of an individual, biomolecular approaches are very useful in identifying the archaeologically invisible migrants. The biologically determined isotope data is furthermore unaffected by the biases of ancient epigraphic or literary practices that excluded large sections of society. Granted that the human bone and dental samples are well preserved, isotope analysis enables the exploration of origins for individuals belonging to various social groups, as well as of different ages, sexes, and social status.

This research was the first to implement a biomolecular approach to the study of ancient mobility in Roman Lebanon. The main goals were, first, to establish isotopic values characteristic of the local human population of Berytus and, second, to identify potential non-local individuals in the burial assemblage. The analysis of nineteen human skeletons from Roman Beirut generated the first set of local human values and identified migrants to the city. While the latter are quite few in number, it is possible that additional foreigners are present among the skeletons that were not sampled for isotope analysis from these same archaeological sites. Moreover, the number of burials associated with Roman Beirut far exceeds those contained within the sites included in this study. While some migrants were found to be buried alongside the local population in this assemblage, spatial differentiation may have played a role in the burial location of others, particularly that of the elite colonists. This stands to be explored through the study of additional burials from the city.

The research findings also highlight female mobility in the Roman period. At least half of the foreigners and possible non-locals consisted of possible female individuals who were associated with the veteran contingent, as well as non-colonial migrants. Not only does this provide an avenue to examine women's associations with the Roman army, but it also permits exploring the general movement of a social group that has often been under-represented in ancient sources.

As one of the first studies on human mobility in ancient Lebanon using isotopes, this research has helped generate primary baselines which future projects will build on and further develop. Ongoing and planned isotopic studies on the local context strive to create a robust isoscape of the country that includes additional isotope systems and aim to further develop local baseline ranges through broader environmental, botanical, and skeletal analyses that will better serve diverse archaeological questions. Moreover, the application of other isotope analyses on human remains will aid in identifying the most effective isotope system (s) to detect mobility in the context of Beirut. This will enable the development of more refined and targeted research methodologies that are better equipped to provide the necessary answers and insights to local research.

CRediT authorship contribution statement

Vana Kalenderian: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Christophe Snoeck:** Formal analysis, Resources, Writing – review & editing. **Sanne W.L. Palstra:** Formal analysis, Resources, Writing – review & editing. **Geoff M. Nowell:** Formal analysis, Resources, Writing – review & editing. **Assaad Seif:** Resources, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All relevant data are contained in the manuscript.

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