NO-FEE OPEN ACCESS JOURNAL indexed in Scopus

Bulletin of the International Association for Paleodontology

Volume 19, Issue 1, 2025

Established: 2007

CONTENT

Reviewers of this issue:

Aspalilah Alias, David Bulbeck, Aman Chowdhry, Andrea Cucina, Jannick Detobel, Lorenzo Franceschetti, Laura Gonzalez-Garrido, Rakesh Gorea, Tamas Hajdu, HebaIbrahim Lashin, Matthew James Lee, Senad Muhasilović, Masniari Novita, Oskar Nowak, Amir Abdul Rahim, Rabi'ah Al-Adawiyah binti Rahmat, Kasia Sarna Bos, Ricardo H.A. Silva, Ana Maria Silva, Parul Sinha, Nurtami Soedarsono, Marlin Tolla, Leticia Vilela Santos, Selma Zukic.

We thank all the reviewers for their effort and time invested to improve the papers published in this journal.

Strontium isotope analysis of human dental enamel from a mass burial at Udhruh fortress, Southern Jordan: a paleomobility study*

• Abdulla Al-Shorman (1), Mansour Shqairat (2), Fawzi Abudanah (2), Ali Khwaileh (1) •

1 - Department of Anthropology, Yarmouk University, Irbid, Jordan
2 - Department of Archaeology, Al-Hussein Bin Talal University, Ma'an, Jordan

Address for correspondence:

Abdulla Al-Shorman
Department of Anthropology, Yarmouk University, Irbid, Jordan
E-mail: alshorman@yu.edu.jo

Bull Int Assoc Paleodont. 2025;19(1):16-24.

Abstract

Udhruh Fortress in southern Jordan was constructed in AD 303–304 by the Roman Legionis VI Ferratae as part of the Limes Arabicus to serve as a stronghold against desert nomads. Recent excavations within the fortress have unearthed several unstratified skeletal remains, raising questions about their identity and origin. To address this, we conducted $^{87}Sr/^{86}Sr$ analysis on dental enamel from 10 individuals to determine their potential mobility, which mirrors the origin of ingested food during childhood and thus the geological region where individuals spent their early years. To establish a bioavailable strontium ratio for Udhruh fortress, we considered the published $^{87}Sr/^{86}Sr$ ratios from three sites near Udhruh, specifically Basta, Khirbet Nawafleh, and Dajaniah. All the reported strontium data were corrected against the NIST SRM987 standard by Wang and colleagues. The results of the study indicated no evidence of migration into the study area but revealed a high likelihood of mobility between fortresses and/or sites within the region. In other words, the sampled individuals were predominantly local Roman legionnaires, reinforcing the notion that 'Roman' identity was primarily associated with the power and authority of the Roman state, rather than rooted in shared cultural traits.

Keywords: Udhruh; Jordan; strontium; isotope; mobility

** Bulletin of the International Association for Paleodontology is a journal powered by enthusiasm of individuals. We do not charge readers, we do not charge authors for publications, and there are no fees of any kind. We support the idea of free science for everyone. Support the journal by submitting your papers. Authors are responsible for language correctness and content.*

Introduction

The Udhruh Fortress, located 15 km east of Petra in southern Jordan, was one of the Roman fortresses built to protect the eastern frontier in Arabia (modern Jordan) against roaming desert nomads (1). The fortress was supported by a temporary military camp at Tell Abara, two kilometers to the southeast (2, 3), as was the case for many other fortresses on the eastern frontier (4). Udhruh Fortress exhibits a trapezoidal form, with its longest stretches along the north and south, measuring 246 m and 248 m, respectively. Conversely, the west and east sides span 177 m and 207 m, respectively (Figure 1). The walls are uniformly six meters tall, and three meters thick, punctuated by 20 projecting towers. Near the western perimeter, remnants of a structure suggest its potential role as the principia, or headquarters, adding intrigue to its historical significance (5).

According to Parker (6), Udhruh Fortress was built during the Late Roman Period (AD 135–324). Its architecture bears a resemblance to that of other fortresses along the Limes Arabicus during this period, such as Humayma (7, 8) and el-Lejjun (9). Kennedy and Falahat (10) substantiated this date by uncovering a Latin inscription on a stone slab near the fort's west gate, which asserted that the Roman Legionis VI Ferratae constructed the fortress in AD 303–304, under Emperor Diocletian's rule. In addition, another inscription from Humayma Fort stated that a unit of the Legionis VI Ferratae was briefly stationed there in the early second century AD (11), after which they most likely moved to Udhruh and replicated Humayma's architectural style. The Roman occupation of the fortress lasted for circa 20 years, until the beginning of the Byzantine period in AD 324 (10). The shorter Roman occupation of the fortress did not alter the cultural or demographic characteristics of the locals; instead, the Romans relocated locals beyond the designated fortress area (12). Keeping the local population in the vicinity provided economic benefits for the fortress by ensuring a steady supply of daily necessities (13), as archaeological findings indicate intense agricultural activity in Wadi Udhruh, east of the fort (14).

The Udhruh Fortress's strategic location and role in regional defense make it a focal point for understanding the military and social dynamics of the time. Despite the fortress's historical significance, much about the legionnaires that were stationed in it remains unknown, particularly regarding their origins and mobility. The 2008 and 2009 excavations uncovered commingled human skeletal remains in unstratified layers near the eastern wall, likely caused by looting in both recent and ancient times (15, 16). The fluorine content analysis proves that the skeletal remains were deposited over two interment periods and that the spacing between the interments is relatively short (17). Although the skeletal remains were found alongside Roman coins and pottery, the mixed stratigraphy made it difficult to determine their origin and/or interment intervals assuming that they did not die during the same period. It remains unclear whether these skeletons belonged to foreign Roman legionaries, recruited local legionnaires, or local inhabitants who lived at the site after the fall of the Limes Arabicus. Radiocarbon dating was not conducted at this time because the spacing in interment periods of the three suggested groups would have been short, preventing sufficient chronological resolution to differentiate them. However, there is evidence that Legionis VI Ferratae recruited legionaries from distant regions in Jordan such as Capitolias in the north (2) or even adjacent settlements such as Petra and Humayma (11). According to the Notitia Dignitatum Zodocatha (modern Sadaqa, southwest of Udhruh) was garrisoned by the Equites promoti indigenae, which was a cavalry formed by local nomads (18). According to Mayerson (19), local nomads recruited by the Roman army did not serve in Arabia. Instead, they were stationed in distant regions such as Egypt and Phoenicia, away from their fellow tribesmen and thus adding more debates about the origins of the legionnaires at Udhruh Fortress.

The identity of a Roman soldier was deeply rooted in his military service, which not only provided a sense of pride and achievement but also defined his place within the military community (20). However, Roman soldiers' identities were shaped by both their military roles and social connections. They weren't just defined by military life but also by interactions with civilians and family ties, reflecting a dynamic social fabric, especially in the late Roman period (21). In the Near East, the identity of Roman soldiers, while culturally weak and often blending into the local landscape, was a powerful symbol of Roman political might, integrating diverse groups into both the military and local power structures, and reflecting the dynamic, flexible nature of Roman identity as long as the army stood (22).

The main goal of this study is to analyze the strontium isotopes in the dental enamel of the recovered skeletal remains to determine their origins, as enamel forms during childhood and remains unchanged throughout an individual's life (23). Consequently, the geological characteristics of the regions where these individuals spent their early years can be inferred. The second objective is to examine the mobility pattern among sites historically connected with Udhruh along the Limes Arabicus, including Basta, Khirbet Nawafleh, Dajaniah, Petra, and Humayma.

$^{87}Sr/^{86}Sr$ concept and literature from southern Jordan

The naturally occurring alkaline earth element, strontium, manifests in geological formations with three isotopes (^{86}Sr, ^{87}Sr, and ^{88}Sr), with the $^{87}Sr/^{86}Sr$ ratio serving as an indicator of geological formation age (24). Through rock weathering, radiogenic ^{87}Sr is released into soil, subsequently incorporated into plant and animal tissues, including those of humans (25). Consequently, the $^{87}Sr/^{86}Sr$ values observed in human bones and teeth reflect both childhood diet and the geological region of early life (26). Dental enamel provides precise estimates of bioavailable strontium, given the stability of ^{87}Sr and ^{86}Sr values within enamel crystals over an individual's lifetime (27, 28, 29). Conversely, bone strontium may indicate local concentration during an individual's final years (26). Analyzing faunal, floral, and water samples determines local $^{87}Sr/^{86}Sr$ values, with an emphasis on multiple sample types for accurate strontium range determination (23). Identification of statistical outliers within enamel strontium isotope distributions assists in differentiating local origins from those elsewhere (30).

Unfortunately, there is a paucity of studies utilizing strontium isotope analysis to investigate ancient mobility in southern Jordan. However, Perry and colleagues (23) analyzed dental enamel from Nabatean Khirbet edh-Dharih, detecting one non-local individual. Alt and colleagues (31) analyzed dental enamel from 22 individuals at Basta, identifying three non-locals and correlating the high incidence of inherited maxillary lateral incisor absences with an exclusive mating system, substantiated by strontium data. Beherec and colleagues (32) sampled Wadi Faynan Iron Age tooth enamels, finding all locals except one likely from the Golan Heights. Perry and colleagues (33) analyzed the dental enamel of 31 individuals excavated from the Byzantine Faynan cemetery and found that most individuals were local to the site. Perry and colleagues (34) reported non-local immigration to Aila from Turkey, Iraq, Egypt, or the Persian Gulf during the mid-fourth to fifth centuries AD. Leppard and colleagues (35) noted that the late Neolithic and Chalcolithic migrations in Jordan declined due to cultural and behavioral changes in the Mediterranean. Although the researcher cited here found that most of the examined individuals were local to the place they were recovered from, spanning various archaeological periods, this conclusion may be limited, likely due to the insufficient availability of high-resolution bioavailable strontium isotope data. Without such data, it is challenging to precisely establish the size of mobility and interaction among ancient populations in southern Jordan. Further studies using more spatially distributed bioavailable strontium data could help us better understand population movements and interactions over time in this region.

Materials and methods

The study comprises 10 right lower molars, representing 10 individuals excavated from square six in the field seasons of 2008 and 2009, located close to the eastern wall of the fortress (Figure 1). The nature of the recovered remains (commingled and broken) precluded the estimation of age and sex at this time. However, we found the epiphyses of the long bones (head of the femur) and clavicles fused, with the former typically fully fused at an age above 17 years and the latter above 29 years (36). No pathologies could be inferred due to the nature of the skeletal materials as mentioned above. To ensure that the sampled teeth belong to 10 different individuals, we only sampled teeth that are well-preserved, loose (not in occlusion), and permanent right second lower molars. To ensure precise analysis, each tooth sample underwent meticulous preparation. Initially, the tooth was cleansed with acetone swabs to eliminate surface dirt. Subsequently, using a low-speed drill, an inverted cone engraving bit delicately removed the outer enamel layer from each tooth, with the bit precisely cleaned with acetone after drilling each tooth. Approximately 20 mg of inner enamel was then abraded into a fine powder using the same low-speed drill, with the bit again cleaned with acetone between samplings. The resulting powder from each sample was carefully preserved in sealed plastic vials.

Following collection, the samples were transported to the Isotope Geochemistry Laboratory within the Department of Geological

Sciences at the University of North Carolina at Chapel Hill (UNCCH) for chemical processing and analysis. The powdered tooth enamel underwent dissolution in 500 mL of distilled 7N HNO3, followed by evaporation and subsequent redissolution in 250 mL of 3.5N HNO3. Strontium extraction from the samples was achieved using EiChrom Sr-Spec resin. Further preparation involved drying the sample, followed by redissolving it with 2 mL of 0.1 M H2PO4 and 2 mL of TaCl5. The resulting solution was then loaded onto rhenium filaments for analysis. Isotopic ratios were measured using a VG Micromass Sector 54 TIMS in quintuple-collector dynamic mode, with the internal ratio $^{86}Sr/^{88}Sr$ = 0.1194 utilized for correcting mass fractionation effects. Data were measured relative to NBS-987 UNCCH $^{87}Sr/^{86}Sr$ = 0.710250 ± 0.000020 (2σ) and corrected against NIST SRM987 0.710255 after Wang and colleagues (37). The $^{87}Sr/^{86}Sr$ ratios of dental enamel, Basta, Khirbet Nawafleh, and Dajaniah were corrected by multiplying these ratios by 1.00000292, 0.99882532, 0.99999121, and 0.99999121, respectively.

Figure 1. An aerial photograph of Udhruh fortress showing the location of Square 6.

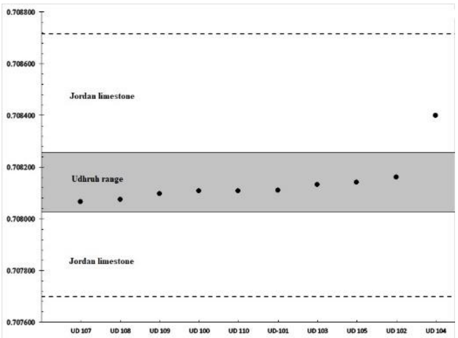

Figure 2. The $^{87}Sr/^{86}Sr$ values of the dental enamel from Udhruh bounded by 2σ.

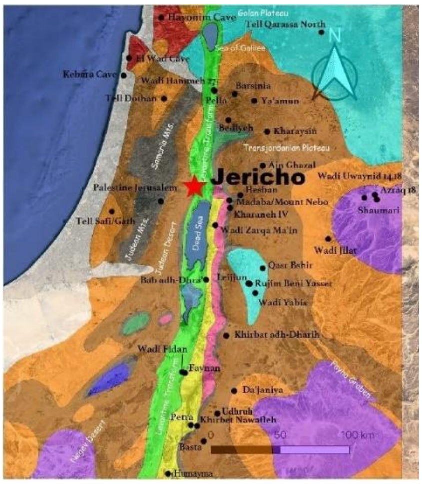

Figure 3. Bioavailable $^{87}Sr/^{86}Sr$ in Jordan. © Wang and colleagues (37). Creative Commons Attribution 4.0 International License.

Results

Udhruh is located on a limestone geological bed that stretches across Jordan's north-south direction, with an $^{87}Sr/^{86}Sr$ range of 0.707699 to 0.708716 (Figure 2). However, the archaeological sites in proximity to Udhruh reported more specific values. For example, the bioavailable $^{87}Sr/^{86}Sr$ in Basta (no. of samples = 10), 20 km to the southwest, is 0.708137-0.708258 2σ (31); Khirbet Nawafleh (no. of samples = 2), 14 km to the west, is 0.708082-0.708095 2σ (23); and 0.708028 for Dajaniah (no. of samples = 1), which is 14 km to the northeast (23). These sites enclose Udhruh fortress and are in the same geological formation (limestone), indicating that Udhruh bioavailable strontium would range from 0.708028 to 0.708258 (see Tables 1 and 2).

The $^{87}Sr/^{86}Sr$ ratios in tooth enamel from Udhruh fortress were relatively uniform indicating that the sampled individuals probably consumed similar foods during their childhood (mean = 0.708140 ± 0.000096 1σ) (Table 2). Dental enamel $^{87}Sr/^{86}Sr$ ratios are within the bioavailable strontium established above for Udhruh fortress except for sample UD 104 ($^{87}Sr/^{86}Sr$ = 0.708399), which lies above +2 σ of bioavailable strontium but remained within the region encompassing the geological limestone formation of Jordan in north-south direction (Figure 3). The geological formation east of Udhruh fortress is chalk, marl, clay, and flint formation with a bioavailable $^{87}Sr/^{86}Sr$ that ranges between 0.708014-0.708932 and intersects with the bioavailable strontium from Dajaniah (0.708028) published by Perry (23). The geological formation west of Udhruh fortress is sandstone (city of Petra and Humayma fort) having a bioavailable strontium range from 0.707710-708320 and intersects with the bioavailable strontium of Udhruh (Figure 3).

Discussion

The population migration during the Roman period into Udhruh fortress was pivotal in determining the origin of the skeletal remains discovered within its confines. Unlike formal burials conforming to Roman typology, as outlined by Al-Shorman (17), these remains were haphazardly mixed and deposited across various archaeological strata. In cases of Roman soldiers' deaths, this suggests a swift and informal burial practice, as observed by Hope (38) and Turner (39). In Roman fortifications and military campaigns, deceased soldiers were either cremated or interred in trenches (40). However, the construction of pyres for cremation purposes required substantial quantities of timber and fuel, which weren't always readily available, making burials preferable (41). Such a practice was also reported from the Late Roman fort at ʻ Ayn Gharandal Fort, where several skeletal remains were unearthed from cist burials (trenches) along the west, north, and east curtain walls, often devoid of significant grave goods. These burials were not part of a structured cemetery plan but rather seem to have been ad hoc, individual interments (42). Given the abandonment of ʻAyn Gharandal Fort before AD 363 (43) and Udhruh in AD 324, it is possible that a political event led to the hurried nature of these burials at both fortresses, the fall of Limes Arabicus, or was coerced by the ritual that considered the deceased as pollutants (44).

The $^{87}Sr/^{86}$ Sr values of human dental enamel from Udhruh fortress presented here do not provide evidence of immigration from outside of the region delineated by the sites of Basta, Khirbet Nawafleh, and Dajaniah; however, there is evidence of one individual who had an origin outside these sites but of $^{87}Sr/^{86}Sr$ value within the range of north-south limestone formation or the chalk marl clay east of Udhruh, most likely Dajaniah fort (37). Yet, reconstructing migration patterns in the north-south direction is difficult because of the limited geological diversity found in limestone formations in this direction (23, 37), which stretches approximately 500 km from the north of Jordan to Aqaba city in the south.

It is substantial that none of the sampled individuals consumed European food during childhood negating the possibility of a European origin because the bioavailable strontium levels in European landscapes are far higher than the area of study; > 0.708 (45). Put simply, if the sampled individuals were soldiers, they were likely recruited from the local inhabitants who consumed childhood diets that had strontium values within the bioavailable values of the study area, which was not uncommon during this period (46, 47, 48, 49, 50). There is evidence to believe that the Roman Legionis VI Ferratae, who constructed Udhruh fort, took part in the expedition to annex Petra and then served as the legionary garrison—or part of it—during the next generation; however, it is possible that locals from the Petra region had probably joined the legion (2). The Nabatean army, as an independent military force, was largely disbanded after Roman annexation in AD 106.

Table 1. The original and corrected $^{87}Sr/^{86}Sr$ ratios of human dental enamel from Udhruh.

Sample	$^{87}Sr/^{86}Sr$	Sr-standard	Corrected $^{87}Sr/^{86}Sr$ against NIST SRM987 0.710255 (37)
UD 107	0.708066	0.710250 ± 0.000020 (2σ)	0.708071
UD 108	0.708074	0.710250 ± 0.000020 (2σ)	0.708079
UD 109	0.708095	0.710250 ± 0.000020 (2σ)	0.708100
UD 100	0.708106	0.710250 ± 0.000020 (2σ)	0.708111
UD 110	0.708106	0.710250 ± 0.000020 (2σ)	0.708111
UD-101	0.708109	0.710250 ± 0.000020 (2σ)	0.708114
UD 103	0.708132	0.710250 ± 0.000020 (2σ)	0.708137
UD 105	0.708141	0.710250 ± 0.000020 (2σ)	0.708146
UD 102	0.708160	0.710250 ± 0.000020 (2σ)	0.708165
UD 104	0.708399	0.710250 ± 0.000020 (2σ)	0.708404

Table 2: The original and corrected $^{87}Sr/^{86}Sr$ ratios of faunal and soil samples from Basta, Khirbet Nawafleh, and Dajaniah.

Site	Sample	$^{87}Sr/^{86}Sr$	Sr-standard	Corrected $^{87}Sr/^{86}Sr$ against NIST SRM987 0.710255 (37)
Basta	*Bos taurus*	0.708249	0.710264 ± 0.000015 (2σ)	0.708245
Basta	*Bos* indeterminate	0.708141	0.710264 ± 0.000015 (2σ)	0.708137
Basta	*Bos primigenius*	0.708241	0.710264 ± 0.000015 (2σ)	0.708237
Basta	*Bos primigenius*	0.708186	0.710264 ± 0.000015 (2σ)	0.708186
Basta	*Bos* indeterminate	0.708182	0.710264 ± 0.000015 (2σ)	0.708178
Basta	*Sus* indeterminate	0.708215	0.710264 ± 0.000015 (2σ)	0.708211
Basta	Soil sample	0.708229	0.710264 ± 0.000015 (2σ)	0.708225
Basta	*Bos* indeterminate	0.708187	0.710264 ± 0.000015 (2σ)	0.708183
Basta	*Bos taurus*	0.708176	0.710264 ± 0.000015 (2σ)	0.708172
Basta	*Bos taurus*	0.708262	0.710264 ± 0.000015 (2σ)	0.708258
Khirbet Nawafleh	Rodent enamel	0.708089	0.710270 ± 0.000014 (2σ)	0.708082
Khirbet Nawafleh	Rodent enamel	0.708102	0.710270 ± 0.000014 (2σ)	0.708095
Dajaniah	Rodent enamel	0.708035	0.710270 ± 0.000014 (2σ)	0.708028

Some soldiers may have been integrated into the Roman military structure, particularly into auxiliary units to provide support to the Roman legions (51). The bioavailable strontium of Petra (0.707710–0.708320) intersects at its upper end with Udhruh dental enamel ratios (0.708099–0.708160) as well as Humayma for which also located on the same sandstone bed as Petra, and that the Legionis VI Ferratae stayed at Humayma for a while (11).

After the Roman Legionis VI Ferrata left Udhruh fortress, smaller-scale habitation continued into the Byzantine period and nearly two centuries later became denser, with a church likely built in the sixth century AD (52). A cemetery was probably established close to the church, where many tombstones with Greek inscriptions were recovered (3), reducing the likelihood of the dead being buried inside the fortress. The archaeological and strontium isotope data strongly suggest that the recovered skeletal materials likely belong to local Roman legionnaires, thus resolving the established debates about the origin of the legionnaires of Udhruh fortress.

Besides bedrock geology, other factors may impact the bioavailable $^{87}Sr/^{86}Sr$ at any given archaeological site. These factors include imported foods, food preparation techniques, reliance on foods with different levels of strontium and/or calcium with variable uptake by the body, the use of dung in agricultural fields from animals with different patterns of transhumance, exposure to aeolian dust, and the transfer of sediment and soil due to fluvial erosion (53). Consequently, settlements within the same geological formation can have slightly different local $^{87}Sr/^{86}Sr$ ranges (54, 55, 23, 34). Considering these factors, sample UD 104 likely accessed food sources not far from the area of study.

Conclusions

Contextualizing strontium isotope analysis in human dental enamel with archaeological and historical data has proven highly effective in tracing ancient migration patterns across an important part of the Limes Arabicus, where Roman fortresses are located. The study's analysis of the $^{87}Sr/^{86}Sr$ ratios provides new evidence suggesting the possibility of population mobility between Roman forts and/or sites in southern Jordan, namely Basta, Khirbet Nawafleh, Dajaniah, Udhruh, Petra, and Humayma. In addition, the $^{87}Sr/^{86}Sr$ ratios suggest that there were no migrations far outside of the region of study or even those in proximity. The strontium data supports the notion that the identity of being "Roman" was primarily linked, by both Romans and outsiders, not so much to cultural characteristics but rather to the formidable might and authority of the Roman state, whether manifested centrally or in its outlying regions.

Declaration of Interest

None

Author Contributions

AA: Supervision, Methodology, Writing – Review & Editing, Conceptualization; MS: Excavation, Sample preparation, Writing – Original Draft; FA: Excavation: Literature, Writing – Review & Editing; AK: Analysis, Writing – Original Draft

Statement on the use of artificial intelligence in manuscript preparation

Artificial intelligence was not used in the preparation of this manuscript.

References

1. Graf D. The "Via Militaris" in Arabia. Dumbarton Oaks Pap. 1997;51:271–81.
2. Kennedy D. The Roman Army in Jordan. 2nd ed. London: Council for British Research in the Levant; 2004.
3. Abudanah F. Settlement Patterns and Military Organisation in the Region of Udhruh (southern Jordan) in the Roman and Byzantine Periods [PhD thesis]. Newcastle upon Tyne: Newcastle University; 2006.
4. Fradley M, Wilson A, Finlayson B, Bewley R. A lost campaign? New evidence of Roman temporary camps in northern Arabia. Antiquity. 2023;97(393):1–6.
5. Killick A. Udruh—the frontier of an Empire: 1980 and 1981 seasons, A preliminary report. Levant. 1983;15:110–31.
6. Parker S. The Typology of Roman and Byzantine Forts and Fortresses in Jordan. Stud Hist Archaeol Jordan. 1995;5:251–60.
7. Oleson J, Amr K, Foote R, Schick R. Preliminary Report of the Ḥumayma Excavation Project, 1993. Annu Dep Antiq Jordan. 1995;39:317–54.
8. Oleson J, Amr K, Foote R, Logan J, Reeves M, Schick R. Preliminary Report of the Al-Ḥumayma Excavation Project, 1995, 1996, 1998. Annu Dep Antiq Jordan. 1999;43:411–50.
9. Parker S. The Roman frontier in Central Jordan: final report on the Limes Arabicus Project 1980–1989. Vol. XL. Washington DC: Dumbarton Oaks Studies; 2006.
10. Kennedy D, Falahat H. Castra Legionis VI Ferratae: a building inscription for the legionary fortress at Udruh near Petra. J Roman Archaeol. 2008;21:150–69.
11. Oleson J, Reeves M, Fisher B. New Dedicatory Inscriptions from Humayma (Ancient Hawara), Jordan. Z Papyrol Epigr. 2002;140:103–21.
12. Killick A. Udhruh: The Caravan City and Desert Oasis. A Guide to Udhruh and its Surroundings. Hants: Romsey; 1987.

13. Breeze D, Abudanah F, Braund D, Driessen M, James S, Konrad M, et al. Frontiers of the Roman Empire: The Eastern Frontiers. Summertown: Archaeopress Publishing Ltd; 2022.
14. Abudanah F, Shqairat M, Alfalahat H. Udhruh: History and archaeology in light of field studies. Jordan J Hist Archaeol. 2010;4(3):99–126.
15. Abudanah F, Shqairat M, Falahat H. The 2008 excavations at Udhruh: Introduction and preliminary report. Annu Dep Antiq Jordan. 2010;54:35–44.
16. Abudanah F, Shqairat M, Falahat H. The second season of excavation at Udhruh: Preliminary Report. Annu Dep Antiq Jordan. 2010;54:45–9.
17. Al-Shorman A. The Necropolis of Abila of the Decapolis 2019–2020. Oxford: Archaeopress Publishing Ltd; 2022.
18. Seeck O. Notitia Dignitatum. Frankfurt: Minerva; 1962.
19. Mayerson P. Saracens and Romans: Micro-macro relationships. Bull Am Sch Orient Res. 1989;274:71–9.
20. Coulston J. Military identity and personal self-identity in the Roman army. In: Ligt L, Hemerlrijk, Singor H, editors. Roman Rule and Civic Life: Local and Regional Perspectives. Amsterdam: Brill; 2004. p. 133–52.
21. Gardner A. Identities in the Late Roman army: Material and textual perspectives. In: TRAC 2000: Proceedings of the Tenth Annual Theoretical Roman Archaeology Conference. Oxford: Oxbow Books; 2000. p. 35–47.
22. Brennan P. The last of the Romans: Roman identity and the Roman army in the late Roman Near East. In: Proceedings of a Conference held at the Humanities Research Centre in Canberra. Canberra: Meditach; 1998. p. 191–203.
23. Perry M, Coleman D, Delhopital N. Mobility and exile at 2nd century A.D. Khirbet edh-Dharih: Strontium isotope analysis of human migration in western Jordan. Geogr Int J. 2008;23(4):528–49.
24. Kenoyer J, Price T, Burton H. A new approach to tracking connections between the Indus Valley and Mesopotamia: initial results of strontium isotope analyses from Harappa and Ur. J Archaeol Sci. 2013;40:22:86-97.
25. Sehrawat J, Agrawal S, Kenney A, Grimes V, Rai N. Use of strontium isotope ratios in potential geolocation of Ajnala skeletal remains: a forensic archaeological study. Int J Legal Med. 2023;1–12. doi:10.1007/s00414-023-03109-8.
26. Price T, Grupe G, Schröter P. Reconstruction of migration patterns in the Bell Beaker period by stable strontium isotope analysis. Appl Geochem. 1994;9:413–17.
27. Plomp E, Holstein I, Kootker L, Verdegaal-Warmerdam S, Verdegaal-Warmerdam T, Davies G. Strontium, oxygen, and carbon isotope variation in modern human dental enamel. Am J Phys Anthropol. 2020;172(4):586–604.
28. Kootker L, Laffoon J. Assessing the preservation of biogenic strontium isotope ratios ($^{87}Sr/^{86}Sr$) in the pars petrosa ossis temporalis of unburnt human skeletal remains: A case study from Saba. Rapid Commun Mass Spectrom. 2022;36:1–8.
29. Kusaka S, Satto T, Ishimaro E, Yamada Y. Strontium isotope analysis on human skeletal remains from the Hobi and Ikawazu shell-mounds in Aichi Prefecture, Japan. Anthropol Sci. 2022;130(1):25–32.
30. Wright L. Identifying immigrants to Tikal, Guatemala: defining local variability in strontium isotope ratios of human tooth enamel. J Archaeol Sci. 2005;32:555–66.
31. Alt K, Benz M, Muller W, Berne M, Schultz M, Schmidt-Schultz T, et al. Earliest evidence for social endogamy in the 9,000-year-old population of Basta, Jordan. PLoS One. 2013;8(6)\:e65649.
32. Beherec M, Levy T, Tirosh O, Najjar M. Iron Age Nomads and their relation to copper smelting in Faynan (Jordan): Trace metal and Pb and Sr isotopic measurements from the Wadi Fidan 40 cemetery. J Archaeol Sci. 2016;60:70–83.
33. Perry M, Coleman D, Dettman D, Grattan J, al-Shiyab A. Condemned to metallum: The origin and role of 4th–6th century A.D. Phaeno mining camp residents using multiple chemical techniques. J Archaeol Sci. 2011;38:558–69.
34. Perry M, Jennings C, Coleman D. Strontium isotope evidence for long-distance immigration into the Byzantine port city of Aila, modern Aqaba, Jordan. Archaeol Anthropol Sci. 2017;9:943–64.
35. Leppard T, Esposito C, Esposito M. The bioarchaeology of migration in the ancient Mediterranean: meta-analysis. J Mediterr Archaeol. 2020;33(2):211–41.
36. Buikstra J, Ubelaker H. Standards for data collection from human skeletal remains. Research series no. 44. Fayetteville: Arkansas Archeological Survey; 1994.
37. Wang X, Zhang B, Ingman T, Eisenmann S, Lucas M. Isotopic and proteomic evidence for communal stability at Pre Pottery Neolithic Jericho in the Southern Levant. Sci Rep. 2023;13:16360.
38. Hope V. Remembering Rome: memory, funerary monuments and the Roman soldier. In: Williams H, editor. Archaeologies of Remembrance. Death and Memory in Past Societies. New York: Springer; 2003. p. 113–40.

39. Turner D. Military Defeats, Casualties of War and the Success of Rome \[PhD thesis]. Chapel Hill: University of North Carolina; 2010.
40. Toynbee J. Death and Burial in the Roman World. Baltimore: Johns Hopkins University Press; 1971.
41. Noy D. Building a Roman funerary pyre. Antichthon. 2000;30:30–45.
42. Darby R, Darby E. The 'Ain Gharandal archaeological project: A preliminary report on the 2010 and 2011 seasons. Annu Dep Antiq Jordan. 2012;56:405–22.
43. Darby R, Darby D. The Late Roman fort at ̔Ayn Gharandal, Jordan: interim report on the 2009–2014 field seasons. J Roman Archaeol. 2015;28:261–70.
44. Retief F. Burial customs and the pollution of death in ancient Rome: procedures and paradoxes. Acta Theol. 2010;26(2):128–46.
45. Hoogewerff J, Reimann C, Ueckermann H, Frei R, Frei K, Aswegen T, et al. Bioavailable $^{87}Sr/^{86}Sr$ in European soils: A baseline for provenancing studies. Sci Total Environ. 2019;672:1033–45.
46. Peters F. Romans and Bedouin in Southern Syria. J Near East Stud. 1978;37(4):315–26.
47. Wesch-Klein G. Soziale Aspekte des römischen Heerwesens in der Kaiserzeit. Stuttgart: Steiner; 1998.
48. Herz P. Die Mobilität Römischer Soldaten in Friedenszeiten. In: Lo Cascio E, Tacoma L, editors. The Impact of Mobility and Migration in the Roman Empire. Leiden: Brill; 2015. p. 80–99.
49. Speidel M. Roman soldiers' gravestones in Greater Syria: Thoughts on designs, imports, and impact. In: Blomer M, Raja R, editors. Funerary Portraiture in Greater Roman Syria. Turnhout: Brepols; 2019. p. 53–66.
50. Mazzilli F. Roman soldiers in the religious, social, and spatial network of the Hauran. Mythos. 2022;16:1–33.
51. Graf D. The Nabataean army and the cohortes Ulpiae Petraeorum. In: Dabrowa E, editor. The Roman and Byzantine Army in the East. Krakow: Archeobooks; 1994. p. 265–311.
52. Vannini G, Nucciotti M. From Petra to Shawbak. Archaeology of a frontier. Milan: Giunti; 2009.
53. Åberg G, Fosse G, Stray H. Man, nutrition and mobility: A comparison of teeth and bone from the Medieval era and the present from Pb and Sr isotopes. Sci Total Environ. 1998;224:109–19.
54. Bentley R. Strontium isotopes from the earth to the skeleton: a review. J Archaeol Method Theory. 2006;13:135-87.
55. Montgomery J, Evans J, Cooper R. Resolving archaeological populations with Sr isotope mixing models. Appl Geochem. 2007;22:1502–15.