Mobility patterning during the Neolithic and the Bronze Age in north-central Myanmar

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Abstract

This study examines patterns of human mobility between two archaeological sites in north-central Myanmar during the Late Neolithic and Early Bronze Age (late 2nd to early 1st millennium BC). By analysing strontium isotope ratios in an interindividual as well as an intraindividual approach, we reveal that individual mobility was more pronounced during the Neolithic period (larger range of strontium isotope ratios), likely linked to the exploitation of a broader subsistence area. In contrast, the Bronze Age shows a shift towards smaller mobility, with the majority of individuals exhibiting local strontium isotopic compositions. Notably, a small number of individuals with distinct strontium isotopic signatures were associated with unique funerary practices. We discuss the implications of these findings in relation to subsistence strategies and cultural transformations between the Late Neolithic and Early Bronze Age. This research offers valuable insights into mobility, subsistence, and social dynamics in late prehistoric Myanmar, contributing to broader discussions within the contexts of Mainland Southeast Asia and southern China.

1. Introduction

Investigations of past mobility patterns, via cultural, bioarchaeological, genetic, linguistic material or other media, are fundamentals to the archaeological endeavour. While data distribution and density are critical for regional-scale interpretations, regions vary in size and complexity, which can impact the comparability of datasets. Mainland Southeast Asia (hereafter MSEA) is a modern geopolitical term referring to Cambodia, Laos, Myanmar, Peninsular Malaysia, Thailand and Vietnam (Figure 1). MSEA covers more than two million square kilometres, has land borders with Bangladesh, India and China totalling nearly 5800 km, as well as a combined coastline of over 10,000 km. The region's climate ranges from polar/tundra (ET, Köppen-Geiger) in the Himalayan north to tropical rainforest (Af) in the equatorial south, with small zones of hot arid steppe (BSh) and vast expanses of tropical monsoon (Am) and savannah (Aw) environments (Beck et al., 2018). Unsurprisingly, such ecological diversity has led to a wide variety of adaptations by some present-day, and almost all recent-historical and ethnographically-attested populations, whose descendants now number over 280 million persons. Unfortunately, due to discontinuous economic and political development during the 20th century, the late prehistory of MSEA has for decades been largely written, if not from the perspective of Thailand, then with predominantly (central and northeast) Thai data (Higham, 2014, 2002, e.g. 1989; Higham and Thosarat, 1998).

This data disparity also exists for strontium isotope-based mobility research, which was first applied on skeletal (human and/or animal) assemblages at Neolithic Khok Phanom Di on the Bangkok Embayment (Bentley, 2004; Bentley et al., 2007), followed by the Neolithic-to-Iron Age Ban Chiang in upper northeast Thailand (Bentley et al., 2005), before setting up in the Upper Mun River Valley in lower northeast Thailand at: Bronze Age Ban Lum Khao (Bentley et al., 2009), Iron Age Noen U-Loke (Cox et al., 2011), Neolithic-to-Iron Age Ban Non Wat (King et al., 2015, 2014, 2013) and finally at Iron Age Non Ban Jak, which included a local 'Sr-isoscape' study (Schalburg-Clayton, 2023). A single site strontium-isotope dataset on skeletal assemblages exists for Cambodia, at the southeastern Iron Age cemetery of Vat Komnou (Ikehara-Quebral et al., 2017), which also included consideration of strontium bioavailability (Shewan et al., 2020). Vietnam has two strontium isotope studies from the northern cemeteries of 7th millennium BC hunter-gatherer Con Co Ngua and Neolithic Man Bac, however these lack an environmental baseline (Huffer, 2012; Huffer et al., 2022; Oxenham et al., 2018). Laos currently lacks any archaeological strontium isotope data on skeletal assemblages, as does Peninsular Malaysia, while southwestern China has a dozen such studies – though curiously none exist from southeastern China (Tang and Wang, 2023). India has very few strontium isotope data on skeletal seemblages (Dey et al., 2024; Sehrawat et al., 2024), and none from northeast Indian states bordering MSEA, nor from Bangladesh. The patchy chronospatial distribution of MSEA strontium isotope datasets on skeletal assemblages extends to the western frontier, Myanmar, where only one pilot study has been published of eighteen individuals from two neighbouring cemeteries in the northerly Sagaing Region, thirteen from Late Neolithic Oakaie 1 and five from Bronze Age Nyaung'gan (Bentley et al., 2018).

Within a MSEA context, we employ the terms Neolithic, Bronze Age and Iron Age *stricto sensu*, to indicate the presence of cultigens, and copper-base and ferrous metallurgy, respectively, irrespective of social complexity (Pryce et al., 2018a, 2018b; Pryce et al., 2024). Nevertheless, and of relevance for examining ancient mobility, the regional hunter-gatherer to Neolithic transition is likely associated with a demographically significant movement of farming communities from the southerly Chinese provinces, Yunnan and Guangxi, into northern MSEA from the early-mid 3rd millennium BC, who then settled and interbred with pre-existing populations – according to the Two-Layer Model (e.g. d'Alpoim Guedes et al., 2020; Higham, 2021; Matsumura et al., 2017; Oxenham et al., 2011; Piper et al., 2022, 2017). Conversely, the MSEA Neolithic to Bronze Age transition seems to have occurred with remarkable consistency across lowland river basins (Chindwin/Irrawaddy, Chao Phraya, Mekong and Red) during the 12th-10th centuries BC (Frelat and Souday, 2015; Higham et al., 2015, 2020; Pryce et al., 2018c; Pryce et al., 2024; Yao et al., 2020). Attributed to exchange relations rather than major population movements, the Bronze Age transition does appear to coincide with a shift in subsistence economy from a mixed economy to greater dependence on agricultural production (Dal

Martello, 2022; Gao et al., 2020; King et al., 2014; Ma et al., 2024). The début of the MSEA Iron Age is coeval with rapidly intensifying trans-Eurasian connectivity, particularly with South Asia, from the mid-1st millennium BC (e.g. Bellina et al., 2022; Dussubieux et al., 2024; Hoppál et al., 2023; Pryce et al., 2024), as well as a generally drying climate and associated evolutions in agricultural regimes, animal husbandry, settlement patterning and hydraulic constructions (Castillo et al., 2018; Wohlfarth et al., 2016).

Within Myanmar, Halin and Ywa Gon Gyi have very early (probable) Neolithic phases (Pautreau et al., 2010;. Pryce et al., 2024), but no site has yet convincingly captured the hunter-gatherer to Neolithic transition (Aung et al., 2015; cf. Aung Thaw, 1971; Schaarschmidt et al., 2019). However, twenty years of bilateral research between the French National Centre for Scientific Research and the Department of Archaeology of the Myanmar Ministry for Religious Affairs and Culture in the north-central part of the country have provided considerable insight into the Neolithic, Bronze and Iron Age prehistoric phases and the Pyu and Bagan historical periods. Under the co-directorship of Prof. Jean-Pierre Pautreau, from 2001–2011 the *Mission Archéologique Française au Myanmar* (hereafter MAFM) focused on Iron Age cemeteries in the Samon River Valley, south of Mandalay (e.g. Pautreau, 2007; Pautreau et al., 2010). These excavations exposed many burials and features, but the remains were left *in situ* or reburied, and the sampling of material culture and skeletal material was not permitted due to the national policy at that time. In 2013 the MAFM investigated an Iron Age cemetery, Kan Gyi Gon (Pryce et al., 2013), in Magway Region, then from 2014–2016 the site complex Oakaie/Nyaung'gan (Pryce et al., 2018b), and finally from 2017–2020 the UNESCO-listed Halin complex (Pryce et al., 2024), both in the Sagaing Region (Figure 1). Due to a policy change, since in 2015 the MAFM was able to lift skeletal and other remains and conduct in-depth post-excavation and laboratory-based studies. These new data are beginning to shed light on the critical four millennia that saw parts of northern Myanmar transition from universally hunter-gather communities to partial full-state (Pyu) and imperial (Bagan) socio-political complexity, as well as how these cultural evolutions relate to the historical trajectory of MSEA and beyond.

This fundamental research has first focused on the construction of radiometric chronologies (Pryce et al., 2018c; Pryce et al., 2024), the production of techno-stylistically defined ceramic (Favereau et al., 2018) and hard-stone bead (Georjon et al., 2021) typologies, and the identification of long-distance exchange systems, both riverine (North-South) and terrestrial (East-West), for non-ferrous base metals (Pryce et al., 2018a) and glass (Dussubieux and Pryce, 2016). The focus on cemeteries has also laid the groundwork for pivotal advances in genetic (Lipson et al., 2018), bioarchaeological and funerary archaeology research (Pradier, 2022; Pradier et al., 2019). Strontium isotope analyses on skeletal assemblages have revealed notable site-based differences, sex-based variation at Oakaie 1—with females exhibiting wider ranges in their strontium isotopic composition than males—and limited long-distance migration (Bentley et al., 2018). Meanwhile, analysis of stable carbon and oxygen isotopes has suggested similar subsistence practices between north-central Myanmar and Yunnan, a region just 300 km to the east (Willis et al., 2023).

With this paper, we aim to build upon the decadal multinational efforts on strontium isotope mobility research in Cambodia, Vietnam and especially Thailand, by contributing towards redressing the data balance to the west, with 55 late prehistoric individuals (108 datapoints) from the Sagaing Region of north-central Myanmar. Our study adopts a distinct methodology that investigates intra-individual variation through multi-tooth sampling and represents the first comprehensive attempt to construct local strontium isotope proxies for the region. By integrating these methods and approaches, our research provides a more nuanced understanding of mobility, subsistence, and cultural interactions, contributing to a broader framework for interpreting the region's prehistoric social dynamics.

We aim to offer one of the rare regional datasets that is not only inter and intra-site, from the two cemeteries at, Oakaie, and Halin (HL29), 80 km east, but also diachronic, covering the Neolithic and Bronze Age phases. While ongoing political instability since 2021 has limited our ability to conduct a robust evaluation of strontium bioavailability, we present anthropologically and historically significant data patterns that offer intriguing contrasts to existing case studies from eastern Mainland Southeast Asia (MSEA). Unlike previous prehistoric mobility studies focused primarily on migration (Cox et al., 2011; Ikehara-Quebral et al., 2017; King et al., 2015, 2013) or kinship (Bentley et al., 2021, 2018, 2009, 2007, 2005; Huffer et al., 2022), our study examines mobility at both the intra-individual and inter-individual levels, providing a novel perspective on the complex social dynamics of the region.

1.1 **Geology**

Strontium isotope ratios ($^{87}Sr/^{86}Sr$) that might be acquired by humans or animals through diet vary significantly based on the underlying geology of a region (Bentley, 2006). Precise geological maps are still lacking for Myanmar, and those available are restricted to specific areas of geological interest such as volcanoes and fault systems. However, our goal is to explore the range of $^{87}Sr/^{86}Sr$ in human teeth, which will allow us to understand how widely people roamed. Therefore, while a complete strontium 'iso-scape' is out of the scope of this study, it is critical that we know the range in $^{87}Sr/^{86}Sr$ in the local and regional geology that will allow us to understand how changes in the range in the measured skeletal remains reflect migration.

The two areas under study are located in the same geological unit, the Shwebo Basin and comprise sedimentary rock from the Palaeogene, Neogene and Quaternary (Bender, 1983; Myint Thein and Maung Maung, 2017). These rocks were deposited in the ocean and the strontium isotopic composition of the ocean ranged from 0.7077 in the Paleogene to 0.70916 in the Quaternary.

The Oakaie/Nyaung'gan area lies in the Wuntho-Popa magmatic arc, which is dated from the early upper Cretaceous to the late Cretaceous and mid-Miocene (Mitchell et al., 2012) and has $^{87}Sr/^{86}Sr$ values close to mantle values at 0.7043 to 0.7047. The Oakaie region comprises two volcanoes, one c. 3 km to the southwest of the Oakaie cemetery, Twintaung, and one c. 2 km to the northeast where the Nyaung'gan cemetery is located. These volcanoes have had periods of activity extending from the Middle Miocene to the Quaternary (Lee et al., 2016; Licht et al., 2020, 2018; Maury et al., 2004; Zhang et al., 2020). The Twintaung volcano has a K-Ar age of 0.44 ± 0.12 Ma (Maury et al., 2004). The Oakaie prehistoric activity area is situated on the plateau between the two volcanoes on upper Miocene-Pleistocene strata, on the Irrawaddy formation and Quaternary alluvium (Myint Thein and Maung Maung, 2017). As is clear from this, the $^{87}Sr/^{86}Sr$ that the teeth could have been exposed to is between 0.7043 and 0.7092, which offers a large range for exploring mobility.

Halin is situated c. 14 km west of the Shan scarps and the Sagaing Fault that divide the country north to south between the Burma Plate and the Shan Plateau (Mitchell et al., 2012). The Shan plateau is very old with age estimates from the Proterozoic (2.5 to 0.5 Billion years ago) to the Triassic (250 to 200 Million years ago), whereas the Burma plate is mostly constituted of sediment dated to the late Tertiary and Quaternary (Bender, 1983), which is similar to the Oakaie area.

1.2 **Archaeology**

Our study encompassed two regions: the Oakaie/Nyaung'gan region located some 20 km north of Monywa city, along the eastern side of the Chindwin River, and the Halin region located 80 km east of the former, on the western side of the Irrawaddy River.

1.2.1 Oakaie/Nyaung'gan

Located on the northwestern lip of an extinct volcano crater (95.0600°E, 22.4110°N), itself fewer than nine kilometres from the Chindwin River (Figure 2), Nyaung'gan was the first site in Myanmar attributed to a potential Bronze Age (Pauk, 1999). The cemetery was discovered accidentally by farming activity in the mid-1990s, followed by rescue excavations by the Mandalay Department of Archaeology in 1998-99 (Moore and Pauk, 2001; Pauk, 1999), which led to the construction of the present site museum. Prior to Nyaung'gan, Myanmar specialists were not even certain that a Bronze Age existed nationally (Stargardt, 1990), but unfortunately no radiometric dating was forthcoming from the original excavation due to a lack of suitable bone or charcoal samples. Providing an absolute chronological framework was one of the MAFM's main objectives from the outset, and thus in 2014 the mission relocated to Oakaie village, about 1 km southwest of the Nyaung'gan cemetery. Instead of returning to the original excavation, the MAFM decided to investigate heavy concentrations of funerary and domestic surface scatters, starting about 1.5 km south of Oakaie village, and 3.5 km northeast of the Twintaung volcano crater (Figure 2). Of the four locations excavated between 2014 and 2016, only 'Oakaie 1' ('OAI1', 95.0492°E, 22.3901°N), transpired to be a formal cemetery (Pradier et al., 2019), as opposed to residential infant burials at domestic/industrial Oakaie 2, and purely domestic/industrial Oakaie 3 and 4 (Georjon et al., 2021; Pryce et al., 2018c).

The OAI1 cemetery underwent partial exposure during two consecutive excavations of $80m^2$ (2014), and $105m^2$ (2015). These revealed a total of forty single and six plural burials, encompassing adults of both sexes, as well as subadults and a dog. The graves were dug into the sterile volcanic tuff at various depths and orientations, with funerary offerings including bivalve shells, pottery, stone beads and bracelets, bone bracelets, shell beads, spindle whorls and a cowrie shell. Notably, a single bronze axe was discovered in burial S15, located at an upper, and by definition, Bronze Age level (Pryce et al., 2018a). The analysis of burial intercuttings, superimpositions, orientations and offerings revealed at least three burial phases but, due to the lack of viable carbon (charcoal, collagen, dentine, apatite) for dating within the cemetery, we err on the side of caution by distinguishing only Neolithic and Bronze Age levels (Pradier et al., 2019). However, based on radiocarbon dating and interpolated techno-stylistic pottery analyses from nearby settlements and industrial sites, these levels can be reconstructed as dating to a late 2nd millennium BC Neolithic and terminal 2nd – early 1st millennium BC Early Bronze Age phases (Favereau et al., 2018; Pryce et al., 2018c).

1.2.2 Halin

Situated about 80 km to the east of the Oakaie/Nyaung'gan complex and between the courses of the Mu and Irrawaddy Rivers, Halin is one of the three major Pyu (2nd – 9th c. AD) cities inscribed on the UNESCO World Heritage list in 2014 and a salt production site (Figure 3). The Pyu city-states are among the oldest literate urban polities in MSEA and, in addition to historic remains, Halin hosts numerous prehistoric settlement and funerary deposits over a 25 km^2 area (Figure 3). These span a regionally-precocious early-3rd millennium BC Neolithic, a 12th-11th c. BC Bronze Age transition comparable to Yunnan and Thailand, and an Iron Age transition potentially from the 6th c. BC, which is among the earliest in MSEA (Pryce et al., 2024). The MAFM excavations carried out in four seasons from 2017 to 2019, focused on funerary (HL17), settlement and salt production sites (HL19 & HLTP1) and mixed usage (HL29 & HL30) sites.

HL29 was excavated by a Myanma team in 2009, revealing 51 individuals of presumed Bronze Age date, now preserved in a site museum (Swe, 2010). To refine the stratigraphy and provide radiometric dating, in 2017 the MAFM excavated an 8 × 4 m trench, HL29-1, 10 m north of the site museum (95.8066°E, 22.4576°N). This trench exposed four layers, three of which contained burials. HL29-1 was extended to the north with another 8 x 4 m in 2018, HL29-2, which revealed similar layers in lower densities. MAFM excavations uncovered a total of 52 inhumations and nine cremations, with various grave goods such as pottery, stone beads, bivalve shells, polished stone bangles, animal remains, ivory bangles, copper-base artefacts, and spindle whorls. Funerary activities on the site took place in two main stages, one represented by cremation and dated to the early 2nd millennium AD Bagan period, and the other characterised by inhumations and dated to the late 2nd/early 1st millennium BC Bronze Age (Pryce et al., 2024). The Bronze Age burial practices are, with the exception of one context with additional treatment (B42), single supine primary burials. The study of the Bronze Age burial practices allowed us to distinguish two main burial groups. Burial groups were distinguished by orientation, grave goods, and intercutting rather than their depth (Pradier, 2022, 2021).

Located about 300 m south of HL29, HL30 was also excavated by Myanma colleagues in 2009, exposing 34 individuals attributed to the Neolithic and Iron Age phases, some of which are now displayed in a site museum (Swe, 2010). In 2019, the MAFM opened an 8 x 8 m trench just north of the site museum (95.8055°E, 22.4551°N). This revealed 18 individuals in mid-late 1st millennium BC Iron Age and mid-late 2nd millennium BC Neolithic levels, as well as a dense early 1st millennium BC Bronze Age settlement layer comprising infant burials in ceramic pots, fireplaces, animal bones and stone tools (Pryce et al., 2024).

1.3 **Material**

Among the 57 individuals discovered in the Oakaie 1 cemetery, 30 were sampled for strontium isotope analysis, including seven individuals from the Bentley et al. (2018) pilot-study. Six other individuals from Bentley study were resampled from another tooth. Among them twenty-four are adults and six were subadults, among the adults nine were females, six were males and nine were unsexed.

The analysis was carried out on deciduous (n=7) and permanent (n=44) teeth. For 18 individuals, samples were taken from more than one tooth, depending on sample availability and preservation. Samples were taken from the M1 and M3 for seven individuals, from the M1 and M2 for five individuals, from the M2 and M3 for one individual, from the dm1 and M1 for one individual, from the dm1 and dm2 for three individuals and from the M1, M2 and M3 for one individual. Only one tooth was sampled from the 13 remaining individuals.

Among the 92 individuals excavated in HL29, 22 were sampled: 19 adults and three subadults. Two of the adults were female, five were male and 12 were unsexed. The analysis was conducted on 39 teeth, among them two deciduous teeth (dm1) and 37 permanent teeth. Samples were taken from two teeth for 17 individuals : the dm1 and M1 for two individuals, the M1 and M3 for 12 individuals, and the M1 and M2 for two individuals. Only one tooth was sampled from the remaining six less well-preserved individuals.

Additionally, cortical bones from the mid-shaft region of the femur of eight individuals (seven from HL29 and one from HL30), dental roots from eight individuals (two from

Oakaie 1, three from HL29 and three from HL30) and enamel from four animal teeth from HL30 Bronze Age layer were sampled.

2. Methodology

2.1 **Excavation, ageing and sexing**

Burials were recorded following the ‘anthropologie de terrain’ methodology (Duday, 2009). The human bones were subsequently cleaned, restored and studied in the Halin Museum facility in Myanmar where the sampling took place.

Age estimation for subadults was based on tooth formation and eruption (AlQahtani et al., 2010), bone maturation and long bone length (Scheuer and Black, 2000). Adults were divided into three age groups, young, middle and old based on late fusion of the epiphyses and morphological assessment of the auricular surface of the os coxae (Schmitt, 2005). Sex estimation for adults was based on pelvic morphology using a metric method (DSP2, Bruzek et al., 2017) and a morphological approach (Bruzek, 2002). Additionally, for individuals without or with poorly preserved os coxae, a linear discriminant analysis based on pelvic-sexed individuals and using post-cranial measurements was applied, following the methodology of Murail et al. (1999).

2.2 **Baseline**

2.2.1 Geology

As discussed above, the geological diversity observed in Myanmar suggests a large range of $^{87}Sr/^{86}Sr$ that the past humans could have been exposed to. However it would be good to verify the range of $^{87}Sr/^{86}Sr$ for the specific regions where our fossils were excavated.

Regarding the Oakaie 1 region, strontium isotope ratios from the Chindwin River at Monywa are available (0.70824-0.70951, Table 2, Chapman et al., 2015). Given the absence of tributaries that could modify these isotope ratios with new water of different $^{87}Sr/^{86}Sr$, this dataset should serve as a reliable regional baseline. The river flowing approximately 8 km west of Oakaie-Nyaung’gan likely served as a primary water source for both humans and livestock, as well as a source of aquatic food, for humans in the past.

For the Halin area, a strontium isotope ratio was obtained from a water sample collected by Yoshiyuki Izuka from a stream near the Halin archaeological museum, providing a localized and preliminary geological signature (0.70813). Additional $^{87}Sr/^{86}Sr$ are available for the Irrawaddy River, sampled 350 km upstream at Myitkyina (0.71277-0.71764), and are consistent with samples taken by Izuka approximately 100 km upstream (0.71226-0.71354) (Chapman et al., 2015). Importantly, no close water stream is likely to modify this ratio between the sampling sites and the Halin area. The Irrawaddy River, flowing 16 km east of the Halin site, is the nearest permanent river and may have served as a significant source of food in the past.

2.2.2 Human bones and animal teeth as local proxies

We supplemented these geological data with new data gained from human and animal materials that reflect the current local environment to more reliably contextualise the $^{87}Sr/^{86}Sr$ values from the two studied groups. We used strontium isotope ratios in dentine from two dental root samples (from individuals S44 and S51 from Oakaie 1) as a secondary proxy of the Oakaie 1 site-specific geological composition (**Table 1**). For the Halin area, we sampled six roots and eight bones from individuals of the HL29 and HL30 cemeteries and four enamel samples from mammals, *Bos*, *Sus*, *Canis* and *cervidae* from the HL30 Bronze Age habitation layer (**Table 2**).

2.3 **Residential mobility assessment**

Deciduous teeth from infants are particularly valuable because they are less likely to reflect changes in habitat compared to older individuals (Knipper et al., 2018). Therefore, the variation observed in the strontium isotope ratios of deciduous teeth likely reflects local environmental differences and can serve as a reliable indication for identifying local versus non-local origins. In this study, we employed a 3σ threshold to assess the mean offset between paired deciduous teeth or between deciduous and first molar (M1) values. This approach is more conservative than the 2σ threshold proposed by Knipper et al. (2018) considering the lack of a local isoscape. A consistent strontium isotope ratio between these teeth suggests that food resources were derived from the same geological area, indicating continuous habitation. In contrast, significant differences in isotope ratios point to food sources originating from different territories, suggesting a potential change in habitat during childhood.

2.3.1 Sampling on human teeth

Where possible, the sampling focused on several teeth from the same individual, to give a mobility age gradient between an early forming tooth, typically the M1 (sampled part forming between 1.5 and 3.5 years old) and a late forming tooth, the M3 (sampled part forming between 10.5 and 14.5 years old) (AlQahtani et al., 2010; Hrnčíř and Laffoon, 2019). In the absence of M1 or M3, the M2 (forming between 4.5 and 8.5 years old) was sampled. In the case of immature individuals, we sampled the first deciduous molar (dm1, forming between birth and 1.5 years old) as well as the first permanent molar or, in its absence, the dm2 (forming between 1.5 months and 1.5 years old).

2.3.2 Bulk enamel, dentine and bone sample preparation and measurement:

One enamel chip was taken for each tooth either from the mesial, lingual, buccal or distal side of the superior third of the tooth crown. The dentine was taken from a dental root, and bone powder was extracted from the cortical part of the femoral diaphysis.

Preparation of the samples was undertaken at the School of Ocean and Earth Science, University of Southampton. To remove any surface contamination, all teeth and bone samples were placed in ultra-pure water in an ultrasonic bath for 30min. Every ten minutes the bath was rinsed, and the water changed. Samples were dried overnight at

60°C. Bulk enamel samples of around (40mg) were extracted using a scalpel, and any adhering dentine was removed using a Dremel-type tool.

The same amount of bone or root powder was extracted from the inner part of the cortical bone and tooth root. All samples were placed in an ultrasonic bath for a further 20min and rinsed using ultra-pure water. To remove diagenetic strontium overprints, samples were leached in 2ml of 5% acetic acid overnight for the enamel and 2% for the bones and dentine samples. Samples were subsequently rinsed four times and dried in an oven at 60°C overnight.

Strontium elemental analysis was conducted in the Department of Earth Sciences at the University of Cambridge. Samples were diluted in 6M HNO_3 and the concentration was checked using an ICP-OES Agilent to identify any post-depositional contamination and to calculate the dilution required for column chemistry (~300 ng Sr).

An aliquot containing 300ng Sr was dried down and subsequently dissolved in 200 µl of 3M HNO_3. Samples were loaded onto a separation column with 130 µL of Sr spec resin. The strontium fraction was collected with 600µl of DI water and subsequently dried down on a hot plate. Isolated strontium was then loaded onto outgassed 99.98% Re filaments, in 1 µl 2M HNO_3, along with 0.5 lL TaF_5 activator. The filament was slowly heated to dry it down. The $^{87}Sr/^{86}Sr$ measurements were carried out using a Thermo-Finnigan Triton Thermal Ionisation Mass Spectrometer (TIMS) in the Laboratory of Marine Biogeochemistry in the Department of Earth Sciences, University of Cambridge (Standard NBS 987 average 0.71027 2sd = 0.000013, n=32).

2.4 **Statistics**

Ouliers were identified using a Generalized ESD (Extreme Studentized Deviate) test. Non-parametric Mann–Whitney U test was used for comparisons of two independent groups. Difference in isotopic variance was evaluated with a Brown–Forsythe test. All analyses were conducted in JASP (Version 0.19.0) using a significance threshold of $\alpha = 0.05$.

3. Results

A total of 108 data points are presented here, 52 from Oakaie 1, including 13 from Bentley et al (2018) and 56 from the Halin area, including 48 from HL29 and eight from HL30 (**Table 3**).

3.1 **Baseline**

For the Oakaie/Nyaung'gan area, two dentine samples provide a glimpse of the local strontium concentration and isotope ratio baseline. These two samples show a very high strontium concentrations compared to the enamel-based samples, contrary to the similar concentration expected (Budd et al., 2000), suggesting they very likely represent the strontium isotopic composition of the cemetery's surrounding soil. These two data points have a $^{87}Sr/^{86}Sr$ of 0.70650 and 0.70693, which is notably low compared to the enamel results (**Table 1 and Figure 4**). To adopt the most conservative approach in defining the local range for Oakaie/Nyaung'gan, we also include the Chindwin River $^{87}Sr/^{86}Sr$ as representative (Chapman et al., 2015). Consequently, the local range for this area is defined as spanning a range from 0.70650 to 0.70951 (**Table 1**).

More data are available for the Halin area (**Table 2**). The dentine samples from dental roots (n=6), the human bones (n=8), the animal tooth enamel from HL30 Bronze Age layer (n=4) and the water sample (n=1, Iizuka pers. com.) give us a local radiogenic strontium isotope ratio ($^{87}Sr/^{86}Sr$) of 0.70813 to 0.71007.

3.2 **Oakaie 1**

The $^{87}Sr/^{86}Sr$ obtained for the Oakaie 1 individuals ranges from 0.70650 to 0.70927, with a mean of 0.70760 ± 0.00063 (1σ, n=50) (**Figure 4**). Duplicate samples (n=2) from the pilot study (Bentley et al 2018) showed no significant difference between the two studies. 3.2.1 Subadults versus adults

The variability of $^{87}Sr/^{86}Sr$ is greatest for the first molars (**Figure 5**), mean 0.707772 ± 0.000699 (1σ, n=15) and the lowest variability is seen for deciduous teeth, including dm1 with a mean of 0.70671 ± 0.00018 (1σ, n=4) and dm2 with a mean of 0.70684 ± 0.00008 (1σ, n=3) (**Table 3 and Figure 5**). This brings them closer to the values obtained from the roots, which have particularly low $^{87}Sr/^{86}Sr$. The lower mean $^{87}Sr/^{86}Sr$ calculated from deciduous teeth may reflect diagenetic alteration of the strontium isotope ratio of these teeth, which are more sensitive to diagenesis, but this is not corroborated by elemental analysis (**supplementary material 1**).

3.2.2 Sex difference

A sex-based difference is observed; female (n=9) have a strontium isotope ratio between 0.70723 and 0.70880, with a mean of 0.70795 ± 0.00047 (1σ, n= 11. Male (n= 6) have $^{87}Sr/^{86}Sr$ ranging from 0.70673 and 0.70786, with a mean of 0.70730 ± 0.00035 (1σ, n=10), with values approaching those of deciduous teeth. This difference is statistically significant (Mann-Whitney U = 94.00, p = 0.005) (**Figure 4**). Females tend to have a more radiogenic strontium isotope composition than males (higher $^{87}Sr/^{86}Sr$), as well as more variability, although the latter was not statistically significant (Brown-Forsythe test F(1, 19) = 0.527, p = 0.477) (**Figure 4**). Analysis of these values by sex and tooth class shows that the $^{87}Sr/^{86}Sr$ for females are always higher than for males. Unsexed adults have the most disparate $^{87}Sr/^{86}Sr$ ratios ranging from 0.70727 to 0.70928 with a mean ratio of 0.70789 ± 0.00058 (1σ, n=17) which is statistically significant compared to the male individuals (Mann-Whitney U = 30.00, p = 0.005) and not to the females (Mann-Whitney U = 107.00, p = 0.547)

3.2.3 Intra individual difference

Strontium isotope ratios obtained from the same individual (n=17) show some differences between teeth, with the four subadults and the two females showing on average smaller offsets than the three males and the seven adults of undetermined sex. The difference in

$^{87}Sr/^{86}Sr$ between deciduous teeth (dm1-dm2) and between deciduous and permanent teeth (dm1-M1) in subadults shows very little variability compared to adults. For four of the thirteen adults with more than one tooth sampled (30.8%), there was a difference higher than our 3σ threshold indicative of a relocation during childhood. The individuals were a male (S31), an adolescent (S27) and two unsexed adult individuals (S4 and S22).

3.3 **HL29**

The $^{87}Sr/^{86}Sr$ ratios of the individuals from HL29 (n=22) ranged from 0.70844 to 0.72207, with a mean of 0.70982 ±0.00288 (1σ, n=38). Most individuals (81.6%) have highly consistent $^{87}Sr/^{86}Sr$ between 0.70844 and 0.70959 with a mean of 0.70881±0,00027 (1σ, n=31). Individuals B2, B37 and B42 yielded $^{87}Sr/^{86}Sr$ well outside our calculated local range (Figure 6).

3.3.1 Subadults versus adults

The three subadults have highly consistent values, ranging between 0.70866 and 0.70876 with a mean of 0.70869±0.00004 (1σ, n=5). The obtained ratios are consistent with the ratios obtained for most of the adults. There is no difference between the deciduous teeth (dm1, n=2) and the permanent molars (M1, n=3).

3.3.2 Sex difference

Two teeth were sampled from each of two female individuals (B2 and B23), yielding strontium isotope ratios ranging from 0.70852 to 0.71188, with a mean of 0.71029 ± 0.00170 (1σ, n=4). For five male individuals, where two teeth were sampled, the ratios ranged from 0.70844 to 0.71006, with a mean of 0.70895 ± 0.00051 (1σ, n=10). The difference between sexes was not statistically significant (Mann-Whitney U = 11.00, p = 0.240). Adult individuals which the sex could not be assessed yielded strontium isotope ratios ranging from 0.70853 to 0.71048 with a mean of ± 0.00389 (1σ, n=19). The difference between unsexed adult and male individuals was not significant (Mann-Whitney U = 75.00, p = 0.377), nor was it significant when compared to females (Mann-Whitney U = 46.00, p = 0.557).

3.3.3 Intra individual difference

Seven of the 16 individuals with samples from two teeth (i.e. 43.8%) yielded an offset between their teeth larger than our 3σ calculated threshold suggesting childhood relocation. The individuals were three males (B45, B46 and B47), two females (B2 and B23) and two unsexed adults (B37 and B42).

4. Discussion

4.1 **The nonlocals:**

As already mentioned, the absence of a detailed local strontium isoscape for the Oakaie/Nyaung'gan region complicates the identification of non-local individuals. The $^{87}Sr/^{86}Sr$ data from the nearby Nyaung'gan cemetery (~2 km away; Bentley et al., 2018) provide a comparative baseline. At Oakaie 1, while our strontium isotope ratios are less radiogenic (lower $^{87}Sr/^{86}Sr$) than those from Nyaung'gan, they still fall within the range obtained from the two dentine samples and the Chindwin River (Chapman et al., 2015). Individual S36 is among the highest values within the Oakaie 1 dataset but aligns well with the Nyaung'gan strontium isotope range, suggesting its value may correspond to the local variability instead of having a non-local origin. Individual B3A from Nyaung'gan is therefore the only assessed non-local individual based on his $^{87}Sr/^{86}Sr$ (Bentley et al., 2018).

At Halin, the largely homogeneous strontium isotope ratios within the HL29 cemetery suggest a predominantly local population. Exceptions include three individuals—B2, B37, and B42—whose distinct $^{87}Sr/^{86}Sr$ values point to non-local origins. B2, may have moved to the Halin area after the formation of her M3 (approximately 14.5 years of age, AlQathani 2010). B42 exhibits highly $^{87}Sr/^{86}Sr$ (up to 0.72207), consistent with a signature from the Mogok region east of the Sagaing fault (Mitchell et al., 2012). B37 on the other hand exhibits $^{87}Sr/^{86}Sr$ between our local and the Irrawaddy values.

Our findings at Oakaie 1 and Halin (HL29) are consistent with MSEA patterns. Studies in Northeast Thailand and northern Vietnam show that, while long-distance migration occurred, only minor fractions of populations can be demonstrated to have moved during the Neolithic and the Bronze Age (Bentley et al., 2005; Huffer et al., 2022; King et al., 2015). Notable exceptions are the influx of female immigrants at Neolithic Khok Phanom Di during the mortuary period 3B (mid-Neolithic 1750–1700 cal-BC, (Bentley et al., 2007)). The relatively low number of newcomers likely reflect social or economic factors, such as trade or specialised crafts, that may have facilitated the movement of selected individuals (Higham, 2011; Pryce et al., 2023).

4.2 **Sex differences and childhood change of habitats**

Strontium isotope variation between tooth types among Oakaie 1 individuals does not reveal significant age-related patterns. Although M3 ratios are slightly less radiogenic (lower $^{87}Sr/^{86}Sr$) than those of the earlier-forming M1 and M2 teeth, the difference is not statistically significant ($F(2, 40) = 1.22$, $p = 0.305$). However, significant childhood changes in strontium isotope ratios were observed in four individuals, two adults of indeterminate sex (S4 and S22), one adolescent (S27) and a male (S31); suggesting shifts between the age of 3.5 and 14.5 years. These shifts likely reflect relocations during childhood and adolescence.

Despite the small sample size at Oakaie 1, available male individuals present larger differences in $^{87}Sr/^{86}Sr$ between sampled teeth than females, suggesting greater mobility during teeth formative years. This aligns with findings from Ban Chiang, where strontium isotope data indicate higher male mobility (Bentley et al., 2005). Hypotheses for this pattern include a division of labour, where boys travelled for subsistence activities such as hunting, and a matrilocal system, where men joined their wives' communities after marriage. Male strontium isotope ratios closely match those of subadults, suggesting local origins, while the broader range of female ratios points to possible differences in geographical origins or subsistence, hinting at a patrilocal system.

Male mobility may also be linked to herding practices. Excavations at OAI2 and OAI3 revealed substantial quantities of cattle bones, some with distinct $\delta^{13}C$ and $\delta^{18}O$ isotopic values (Willis et al., 2023). For these isotopic differences to be evident, individuals would need to have consumed a significant amount of food sourced from these distant areas or from animals that grazed in those regions. Additional explanations, such as fosterage or apprenticeship, may also account for these mobility patterns (Hrnčíř and Laffoon, 2019), but we have no evidence for this in the Myanmar Bronze Age.

At HL29, eight individuals (50% of the observed adults) exhibited significant changes in strontium isotope ratios during childhood. These changes, occurring between the formation of M1 and M3, indicate residential relocations or local dietary shifts. Notably, three individuals—B2, B37, and B42—moved to Halin after their M3s formed, while others (e.g., B23, B45) experienced shifts within the local range, likely reflecting relocations to geologically similar areas or dietary adjustments. The pattern observed between sexes and unsexed adults indicates a lack of significant differences, suggesting a homogeneous group comprising males and females of local origins. Only individual B2, a female identified as an outlier, may have been relocated to Halin after the formation of her M3.

4.3 **Land use strategy**

A key difference between Oakaie 1 and HL29 is the variation in their strontium isotope ratios. The Brown-Forsythe test revealed significantly less variation at HL29 compared to Oakaie 1 ($F(1, 80) = 10.933$, $p = 0.001$, Figure 7; HL29 individuals B2, B37 and B42 removed to kept consistency between datasets). This difference in $^{87}Sr/^{86}Sr$ variation suggests an inter-site difference in subsistence economies related to local Sr-isotope variability in the landscape. HL29 individuals may have relied predominantly on locally sourced food or moved within a strontium-homogeneous region during their youth. Conversely, Oakaie 1 individuals likely accessed food from diverse territories or moved across strontium-heterogeneous areas. Although subsistence data for Myanmar are limited, isotopic evidence suggests a mixed diet of C3 (e.g., rice) and C4 resources, with temporal shifts in animal husbandry from the Neolithic to the Bronze Age in contrast with the rest of MSEA with a diet predominantly focused on C3 resources (Willis et al., 2023). Reduced strontium isotope variation at HL29 aligns with findings from Ban Non Wat and Ban Lum Khao, where early Bronze Age populations relied heavily on local rice agriculture (King et al., 2015, 2013). Similar patterns are observed at Xingyi in Yunnan, where millet and rice cultivation dominated during the Bronze Age (Ma et al., 2024).

In Myanmar, however, it remains unclear whether local production fully met dietary demands. Preliminary data from HL30, a Bronze Age habitation layer, reveal numerous

Cervidae bones, suggesting the role of hunting in a broader subsistence strategy. Despite this diversity, the homogeneity of HL29 strontium isotope ratios highlights a primarily localized diet, contrasting with the more varied strontium composition at Oakaie 1.

4.4 **Funerary Practices**

One of the most interesting cases from the Oakaie 1 cemetery is that of S27, an adolescent who seems to have experienced mobility during childhood. This individual was buried in an unusually large grave with its arms crossed over its abdomen —a distinctive position not observed in other graves at the site (Pradier et al., 2019). The connection between potential mobility and unique funerary treatment is further illustrated by B3A from the nearby Nyaung'gan site (Bentley et al., 2018). Represented solely by a cranium and mandible, this male individual exhibits highly radiogenic $^{87}Sr/^{86}Sr$ ratios, matching the signature of the Pondaung or Yaw formations, some 40 km west of Nyaung'gan (Licht et al., 2013). Interestingly, B3A's remains were incorporated into the burial of B3B, a subadult who was interred with numerous grave goods, including pots, beads, a dog, and a tortoise (Pradier, 2022).

At Halin, the HL29 cemetery reveals similarly distinctive funerary features of potentially nonlocal individuals. Both B37 and B42 are found in the northeast corner of the excavation area potentially at the edge of the cemetery. B42 was part of a highly disturbed context, with disarticulated remains potentially representing a looted burial or dumping pit. B37, by contrast, was buried in a supine position consistent with local customs apart from a flat stone placed over the pelvis. Three other individuals—B45, B46, and B47—who may have experienced mobility during childhood were buried side-by-side in the same row in the northern part of the excavated area. This spatial clustering may indicate shared experiences or social connections among these individuals.

Interestingly, some of the bones of both B3A (Nyaung'gan) and B42 (Halin) were manipulated. Burial with such additional treatment has been observed during the Neolithic at Baiyangcun in Yunnan (Dal Martello et al., 2018) and during the Bronze Age at Ban Lum Khao (Higham et al., 2004), Non Nok Tha (Bayard and Solheim II, 2010) and Ban Non Wat in northeast Thailand. At the latter, this practice has been hypothesized to mark higher-status individuals (Higham, 2024). In our case, this additional treatment appears to reflect their non-local origins. Such differential practices for migrants are not confined to the Bronze Age. Two non-local individuals from the Neolithic phase of Ban Non Wat were also subject to distinct funerary practices compared to the rest of the individuals (King et al., 2013).

Grave goods at Oakaie 1 reveal further complexities. Some individuals were buried with both closed and open ceramics (Favereau et al., 2018), a pattern unique to certain females whose $^{87}Sr/^{86}Sr$ ratios were highly homogeneous and significantly different from other individuals (Mann-Whitney $U = 24.00$, $p = 0.014$). This suggests that shared geographic origins, potentially tied to differential mobility patterns among females, may have influenced their funerary treatment. However, this interpretation is tempered by the limited sample size and the broader range of isotopic variation observed among other individuals.

Grave goods deposits at HL29 exhibit some distinct features as well, with individuals accompanied by polished stone bracelets or over 100 beads (n=19) exhibiting significantly different isotopic variation compared to others (Mann-Whitney U = 275.00, p = 0.005), Figure 8). This suggests a potential link between isotopic compositions and perceived social status in death. Individuals with local strontium isotopic composition were associated with more adornment and bronze items, indicative of higher social status, potentially associated with a predominantly local diet. In contrast, those with diverse isotopic compositions may reflect greater mobility or access to a broader range of food sources. Additionally, the presence of wild animal remains at HL30 suggests that game meat might have been a key dietary resource for individuals of lower socioeconomic status, while livestock could have been reserved for higher-status individuals.

5. Conclusion

Understanding the intricate patterns of mobility between the Neolithic and Bronze Age is essential for shedding light on the social and cultural transformations that occurred during these two pivotal periods. In our examination, we have identified that mobility was notably higher during the Neolithic period. This increased movement could be attributed to various factors such as long-range migrations, herding practices, fostering arrangements, and apprenticeship systems but we lack data to be sure. Interestingly, our findings reveal pronounced gender disparities in mobility patterns; women in late prehistoric north-central Myanmar seem to have lower mobility than men during childhood. This trend suggests that women may have integrated into communities at a later stage, often coinciding with marital age, which may reflect broader societal norms and practices regarding gender roles during this time. Conversely, archaeological evidence from Bronze Age sites, specifically HL29 and Nyaung'gan, indicates a marked decrease in mobility. However, this decline in movement was not uniform; it varied significantly among individuals based on their burial practices. Our research indicates that individuals of higher status, or those who were well-furnished, tended to be locals. These individuals likely participated in complex exchange systems that enabled them to acquire valuable items such as hard stone ornaments and copper-base weapons made from exotic materials, thereby underscoring the emergence of some degree of social stratification during the Bronze Age. The phenomenon of tentative and localised hierarchies is rare in MSEA but not confined to Myanmar; similar patterns have been observed in northeastern Thailand. However, a noteworthy distinction exists between these two regions. In Myanmar, the emerging elite appears to be closely associated with bronze weaponry. The interplay between mobility, social stratification, and conflict during the regional Bronze Age offers a rich arena for further exploration. Understanding how these dynamics functioned in both Myanmar and northeastern Thailand can provide valuable context for the broader regional interactions, including those with southwestern China, particularly in terms of trade networks, cultural exchanges, and the impact of external influences on local power structures.

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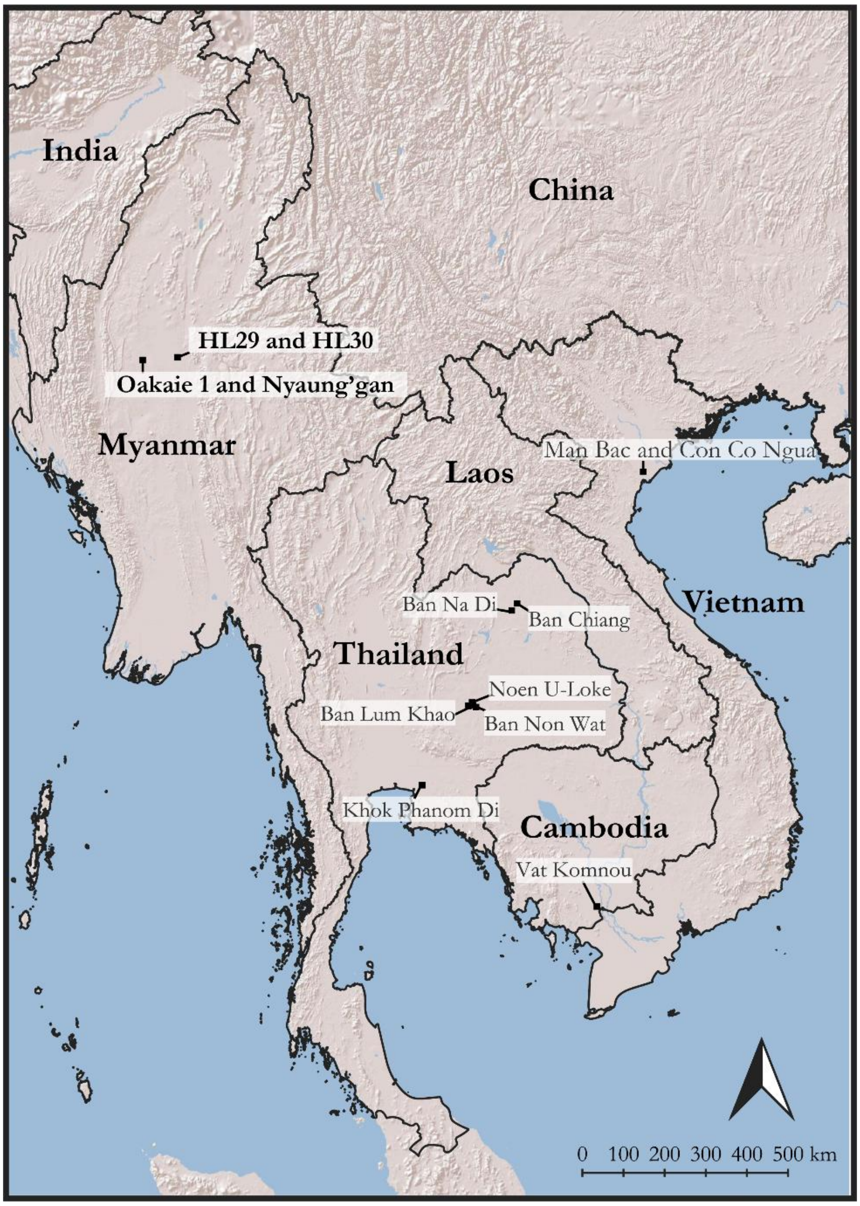

Figure 1: Geographical location of the sites studied

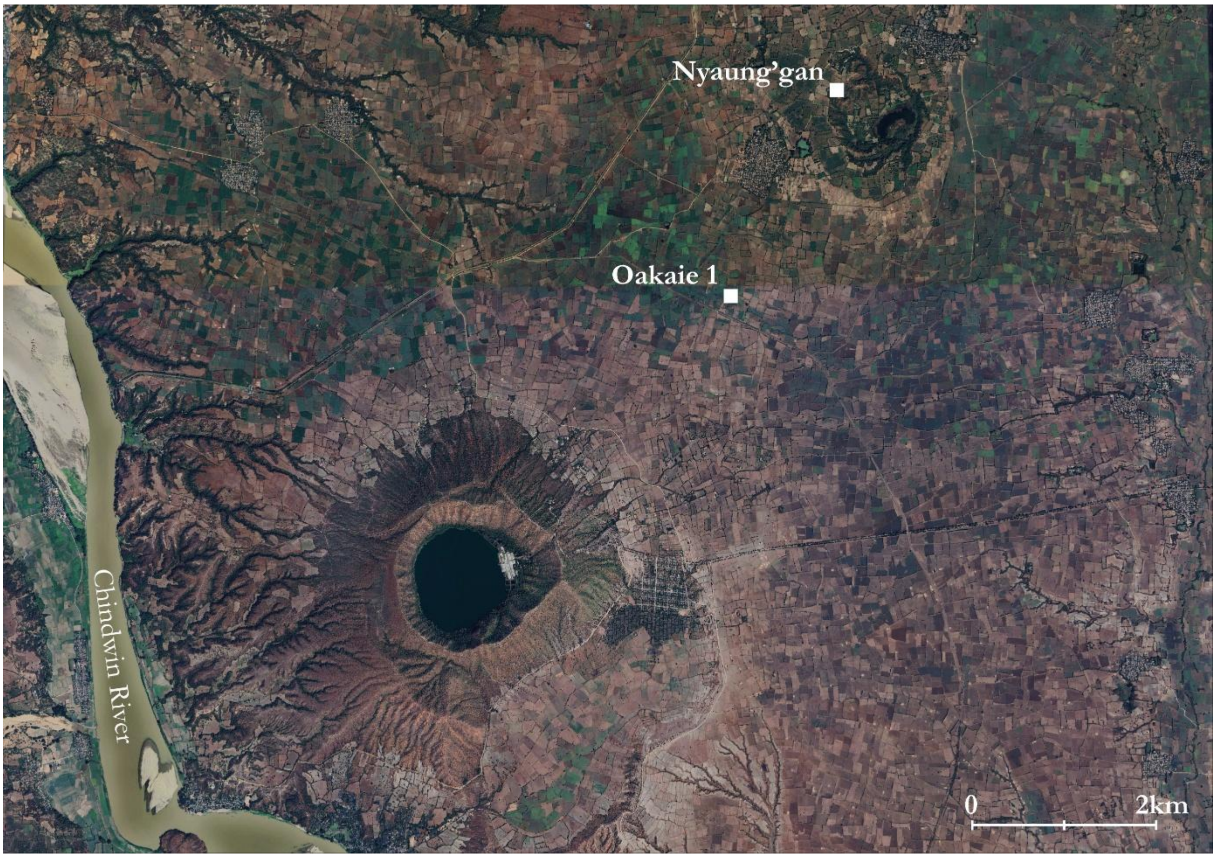

Figure 2: Localisation of Oakaie 1 and Nyaung’gan sites (satellite images ©Google Earth)

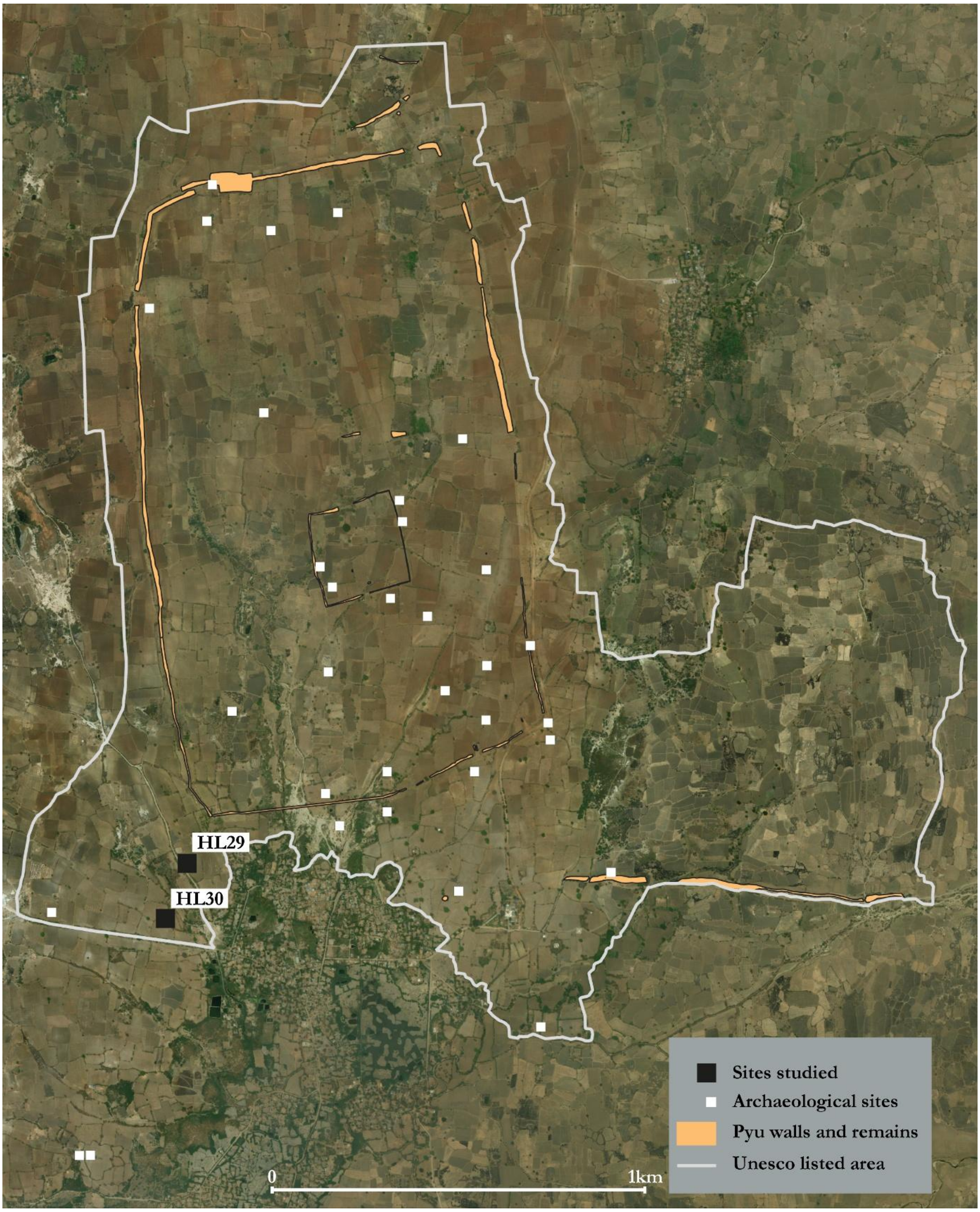

Figure 3: Halin area map with the localisation of the studied sites, HL29 and HL30

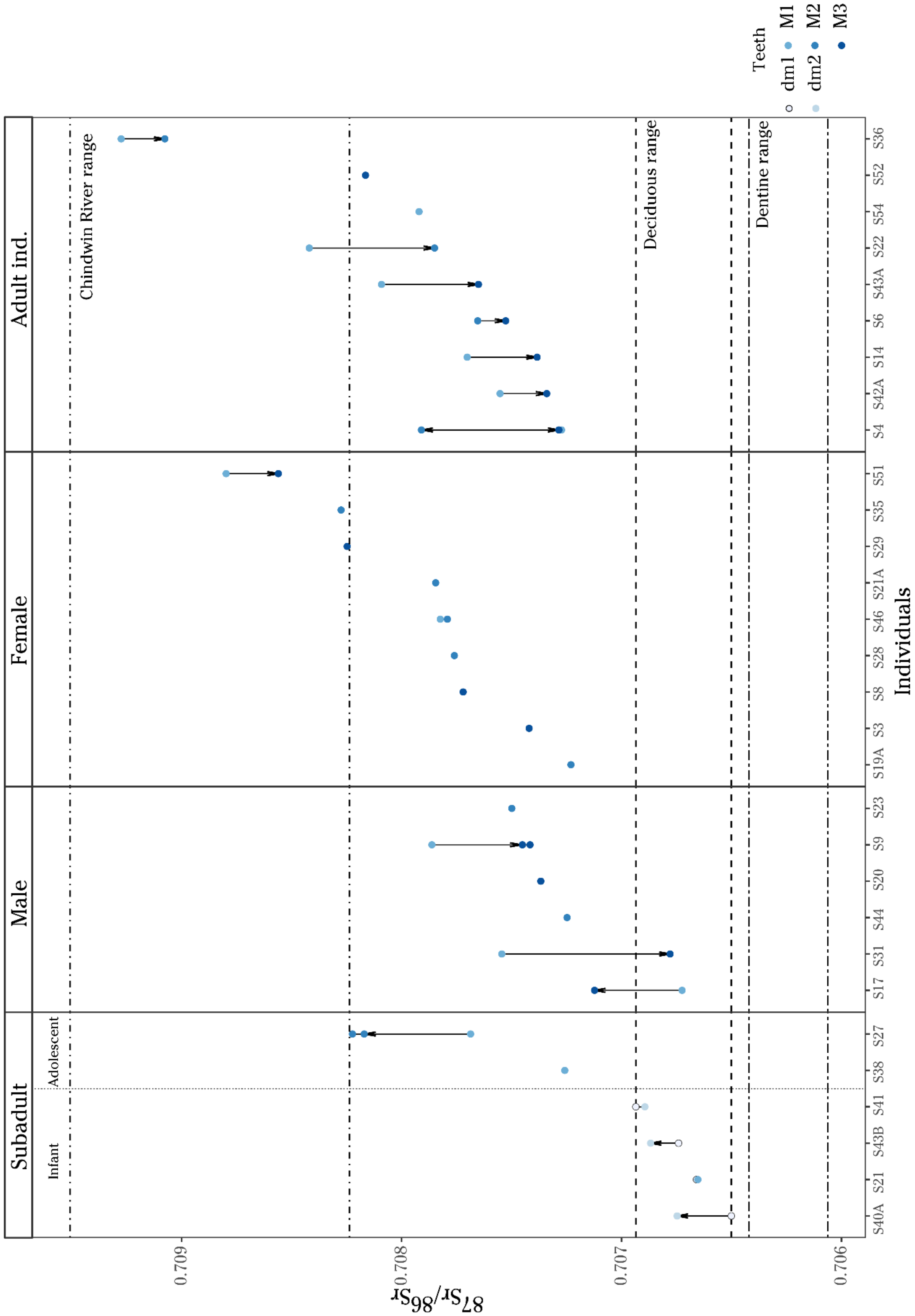

Figure 4: $^{87}Sr/^{86}Sr$ data by individual, age, sex and tooth type for the Oakaie 1 site

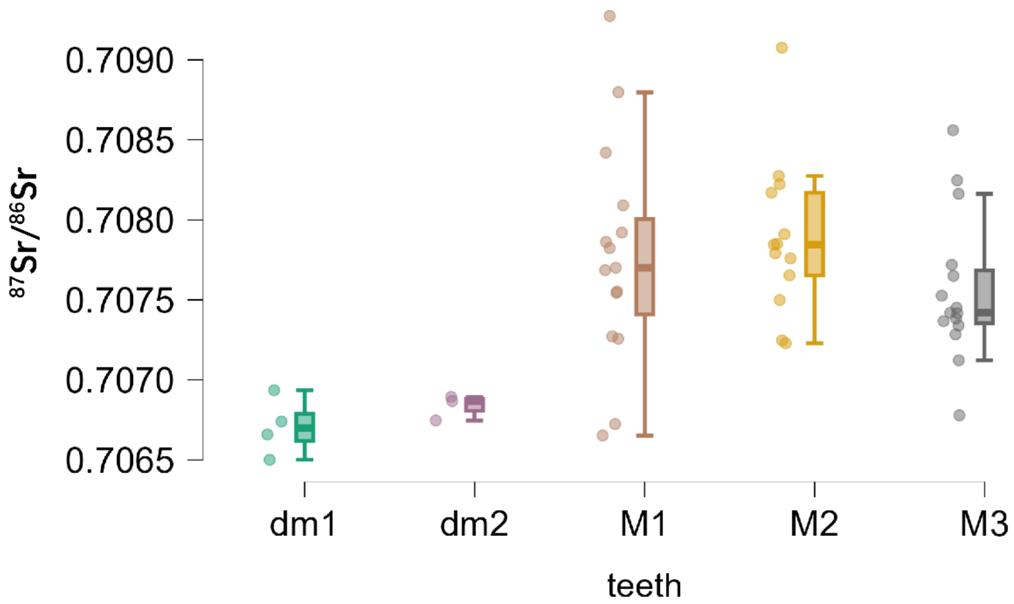

Figure 5: $^{87}Sr/^{86}Sr$ variation by tooth types for the Oakaie 1 site

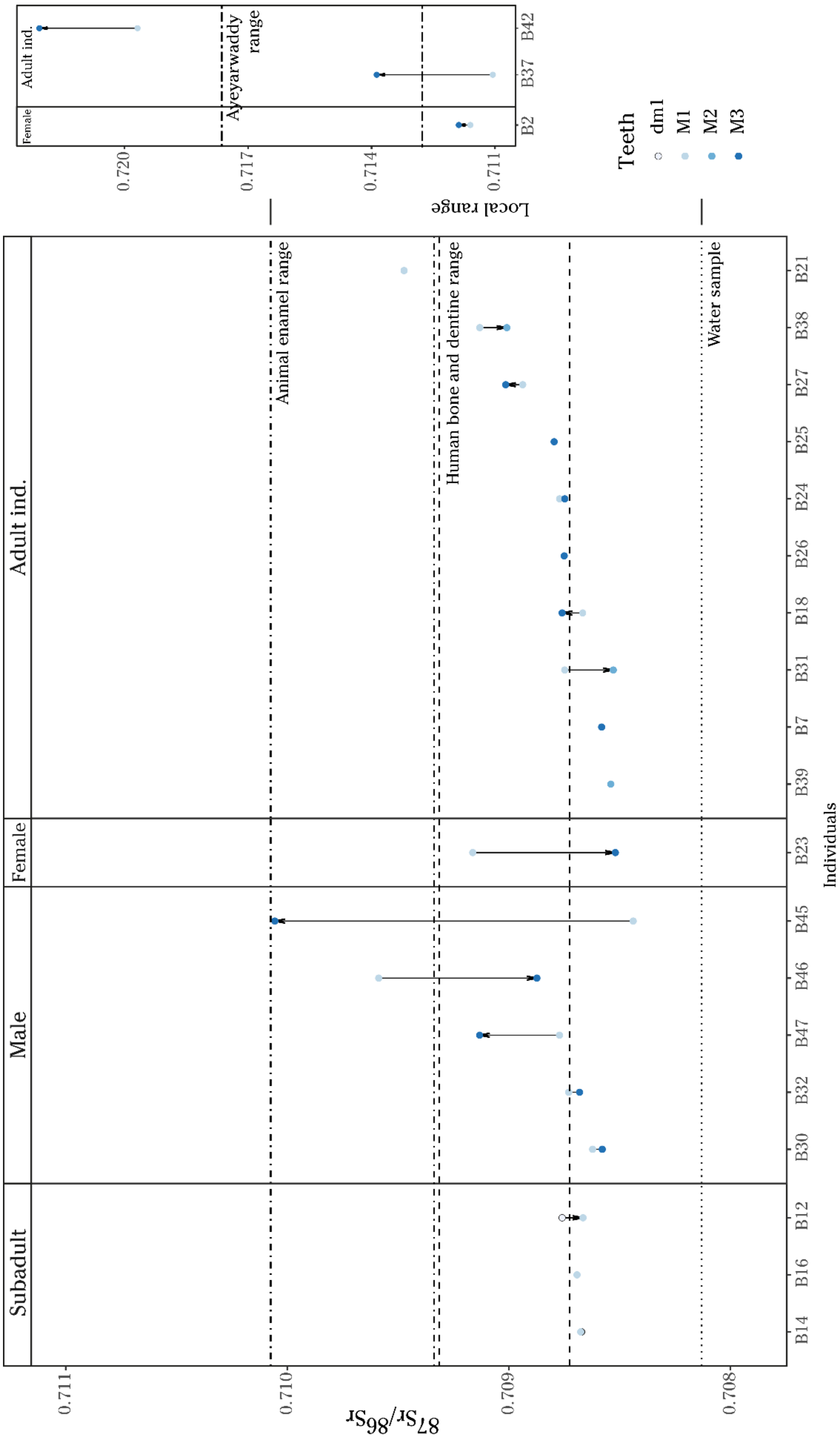

Figure 6: $^{87}Sr/^{86}Sr$ data by individual, age, sex and tooth type for the HL29 site

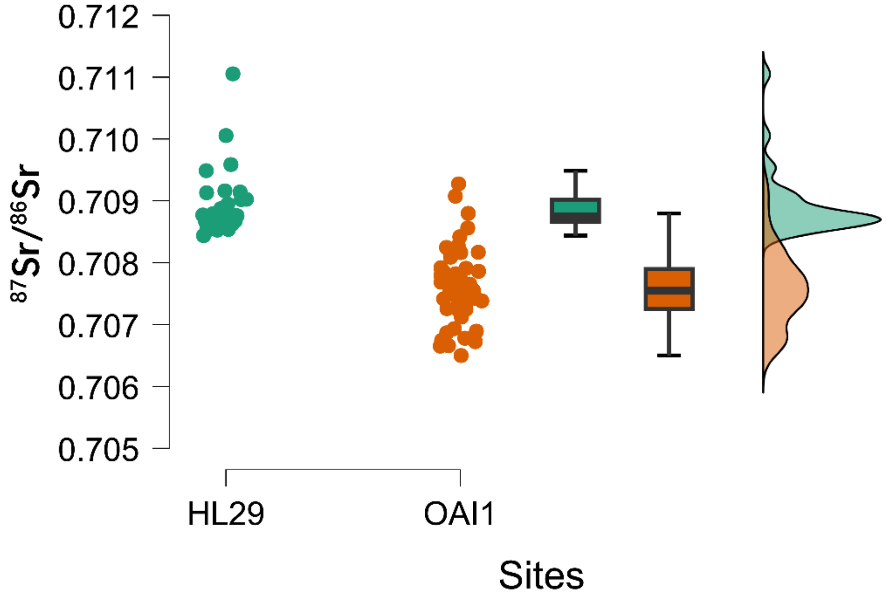

Figure 7: $^{87}Sr/^{86}Sr$ variationbetween HL29 and Oakaie 1, B2, B37 and B42 outliers from HL29 are not shown

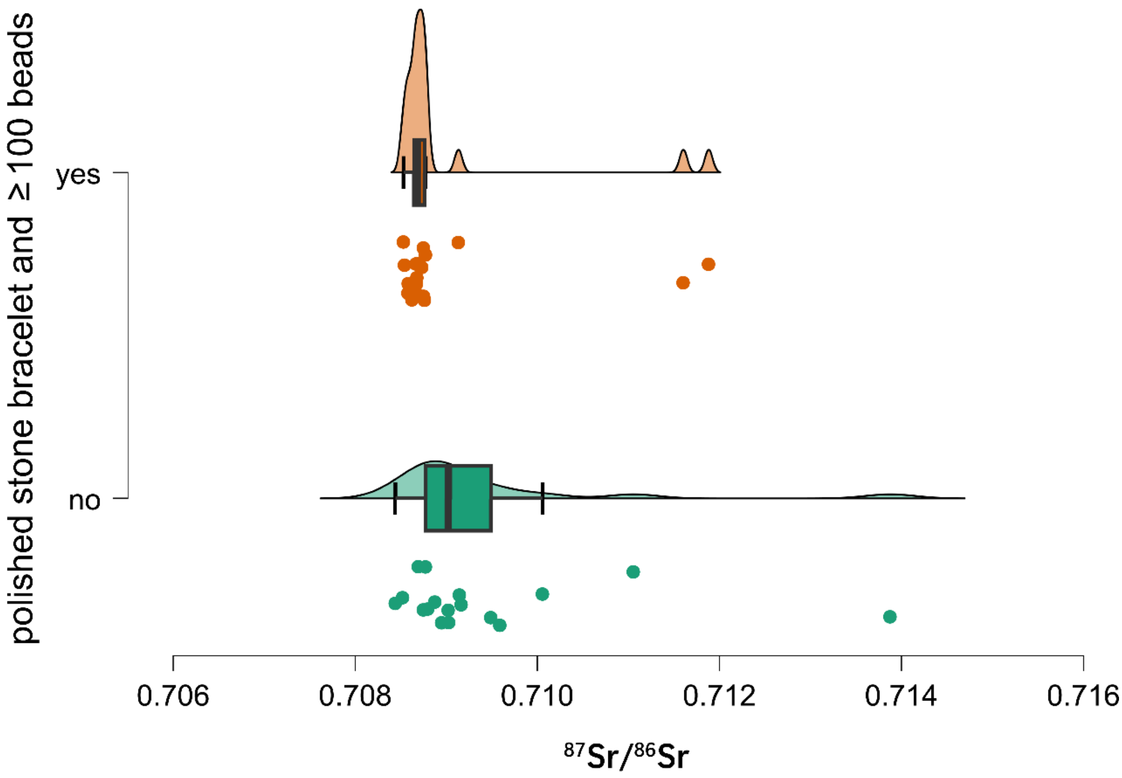

Figure 8: $^{87}Sr/^{86}Sr$ variation in HL29 between individuals with stone bangles and/or more than a hundred beads and individuals with less adornment, B42 is not shown

Table 1: Data studied in this research

Site	Burial code	Reference	material	specie	tooth	tooth type	87Sr/86Sr	error	Age	Sex	number of beads	polished stone bangle	open and closed ceramics
OAI 1	S19A	Bentley et al 2018	enamel	homo	-	M2	0,70723		adult	female	16	-	-
OAI 1	S20	Bentley et al 2018	enamel	homo	-	M3	0,707367		adult	male	-	-	-
OAI 1	S21A	Bentley et al 2018	enamel	homo	-	M2	0,707845		adult	female	2	1	1
OAI 1	S22	Bentley et al 2018	enamel	homo	-	M2	0,70785		adult	unsexed	-	-	-
OAI 1	S27	Bentley et al 2018	enamel	homo	-	M2	0,70817		subadult	-	-	-	-
OAI 1	S28	Bentley et al 2018	enamel	homo	-	M2	0,70776		adult	female	-	-	1
OAI 1	S35	Bentley et al 2018	enamel	homo	-	M2	0,708275		adult	female	-	-	-
OAI 1	S38	Bentley et al 2018	enamel	homo	-	M1	0,707258		subadult	-	-	-	-
OAI 1	S4	Bentley et al 2018	enamel	homo	-	M2	0,70791		subadult	-	2	-	-
OAI 1	S42A	Bentley et al 2018	enamel	homo	-	M3	0,70734		adult	unsexed	-	-	-
OAI 1	S52	Bentley et al 2018	enamel	homo	-	M3	0,708164		adult	unsexed	-	-	-
OAI 1	S8	Bentley et al 2018	enamel	homo	-	M3	0,70772		adulte	female	1	-	1
OAI 1	S9	Bentley et al 2018	enamel	homo	-	M3	0,707416		adult	male	-	-	-
OAI 1	S14	this study	enamel	homo	loLM3	M3	0,70738371	4,06E-06	adult	unsexed	6	-	-

OAI1	S14	this study	enamel	homo	loRM1	M1	0,70770156	4,00E-06	adult	unsexed		6	-	-	
OAI1	S17	this study	enamel	homo	upLM1	M1	0,70672456	4,40E-06	adult	male	-		-	-	
OAI1	S17	this study	enamel	homo	upLM3	M3	0,70712249	4,09E-06	adult	male	-		-	-	
OAI1	S21B	this study	enamel	homo	loLm1	dm1	0,70665918	4,15E-06	subadult	-		14	-	-	
OAI1	S21B	this study	enamel	homo	upLM1	M1	0,70665276	5,44E-06	subadult	-		14	-	-	
OAI1	S22	this study	enamel	homo	loRM1	M1	0,70841966	4,21E-06	adult	unsexed	-		-	-	
OAI1	S23	this study	enamel	homo	loRM2	M2	0,70749870	3,82E-06	adult	male	-		-	-	
OAI1	S27	this study	enamel	homo	loLM1	M1	0,70768620	4,08E-06	subadult	-	-		-	-	
OAI1	S27	this study	enamel	homo	loLM2	M2	0,70822344	4,67E-06	subadult	-	-		-	-	
OAI1	S29	this study	enamel	homo	loLM3	M3	0,70824764	4,01E-06	adult	female	-		-	-	
OAI1	S3	this study	enamel	homo	loLM3	M3	0,70742008	4,78E-06	adult	female		6	-		1
OAI1	S31	this study	enamel	homo	upLM1	M1	0,70754407	6,69E-06	adult	male	-		-	-	
OAI1	S31	this study	enamel	homo	loRM3	M3	0,70677925	4,29E-06	adult	male	-		-	-	
OAI1	S36	this study	enamel	homo	loRM1	M1	0,70927496	5,06E-06	adult	unsexed	-		-	-	
OAI1	S36	this study	enamel	homo	loLM2	M2	0,70907634	4,21E-06	adult	unsexed	-		-	-	
OAI1	S38	this study	enamel	homo	loLM2	M2	-	-	subadult	-		5	-	-	

OAI 1	S4	this study	enamel	homo	loLM1	M1	0,70727290	5,34E-06	adult	unsexed		2	-	-	
OAI 1	S4	this study	enamel	homo	loLM3	M3	0,70728496	5,81E-06	adult	unsexed		2	-	-	
OAI 1	S40A	this study	enamel	homo	upLm1	dm1	0,70650070	4,30E-06	subadult	-	-		-	-	
OAI 1	S40A	this study	enamel	homo	upLm2	dm2	0,70674712	4,80E-06	subadult	-	-		-	-	
OAI 1	S41	this study	enamel	homo	loRm1	dm1	0,70693489	6,34E-06	subadult	-	-		-	-	
OAI 1	S41	this study	enamel	homo	loRm2	dm2	0,70689367	4,48E-06	subadult	-	-		-	-	
OAI 1	S42A	this study	enamel	homo	upLM1	M1	0,70755234	5,29E-06	adult	unsexed	-		-	-	
OAI 1	S43A	this study	enamel	homo	loRM1	M1	0,70809104	4,26E-06	adult	unsexed	-		-	-	
OAI 1	S43A	this study	enamel	homo	loRM3	M3	0,70765028	5,05E-06	adult	unsexed	-		-	-	
OAI 1	S43B	this study	enamel	homo	loLm1	dm1	0,70674072	4,51E-06	subadult	-		5	-	-	
OAI 1	S43B	this study	enamel	homo	upLm2	dm2	0,70686784	3,97E-06	subadult	-		5	-	-	
OAI 1	S44	this study	enamel	homo	loRM2	M2	0,70724754	1,20E-05	adult	male	-		-	-	
OAI 1	S46	this study	enamel	homo	upLM1	M1	0,70782397	4,31E-06	adult	female	-		-	-	
OAI 1	S46	this study	enamel	homo	upLM2	M2	0,70779203	3,97E-06	adult	female	-		-	-	
OAI 1	S51	this study	enamel	homo	upRM1	M1	0,70879778	4,31E-06	adult	female		2	-		1
OAI 1	S51	this study	enamel	homo	loM3	M3	0,70856035	4,70E-06	adult	female		2	-		1

OAI1	S54	this study	enamel	homo	loLM1	M1	0,70792046	2,76E-05	adult	unsexed	-	-		-
OAI1	S6	this study	enamel	homo	upRM2	M2	0,70765393	4,26E-06	adult	unsexed		14	1	-
OAI1	S6	this study	enamel	homo	upRM3	M3	0,70752656	4,36E-06	adult	unsexed		14	1	-
OAI1	S9	this study	enamel	homo	upLM1	M1	0,70786215	5,34E-06	adult	male	-	-		-
OAI1	S9	this study	enamel	homo	upLM3	M3	0,70745065	6,97E-06	adult	male	-	-		-
OAI1	S44	this study	root	homo	loRM2	M2	0,70606178	4,35E-06	adult	male	-	-		-
OAI1	S51	this study	root	homo	upRM1	M1	0,70642041	3,85E-06	adult	female	-	-		-
HL29	B18	this study	bone	homo	Rfemur	-	0,70889045	4,35E-06	subadult	-	-	-		-
HL29	B2	this study	bone	homo	Lfemur	-	0,70889457	4,41E-06	adult	female	-	-		-
HL29	B30	this study	bone	homo	Rfemur	-	0,70889884	4,29E-06	adult	male	-	-		-
HL29	B31	this study	bone	homo	Rfemur	-	0,70894287	4,37E-06	adult	unsexed	-	-		-
HL29	B32	this study	bone	homo	Rfemur	-	0,70902484	4,68E-06	adult	male	-	-		-
HL29	B45	this study	bone	homo	Rfemur	-	0,70888491	4,65E-06	adult	male	-	-		-
HL29	B46	this study	bone	homo	Rfemur	-	0,70884779	4,24E-06	adult	male	-	-		-
HL29	B12	this study	enamel	homo	upRm1	dm1	0,70875918	4,05E-06	subadult	-		7	1	-
HL29	B12	this study	enamel	homo	upRM1	M1	0,70866490	4,32E-06	subadult	-		7	1	-

HL29	B14	this study	enamel	homo	loLM1	M1	0,70867542	4,16E-06	subadult	-	313	1	-
HL29	B14	this study	enamel	homo	loLm1	dm1	0,70867151	4,65E-06	subadult	-	313	1	-
HL29	B16	this study	enamel	homo	upLM1	M1	0,70869204	4,17E-06	subadult	-	-	-	-
HL29	B18	this study	enamel	homo	loRM1	M1	0,70866631	4,30E-06	adult	unsexed	148	-	-
HL29	B18	this study	enamel	homo	loLM3	M3	0,70875940	5,28E-06	adult	unsexed	148	-	-
HL29	B2	this study	enamel	homo	loLM3	M3	0,71188029	4,52E-06	adult	female	119	-	-
HL29	B2	this study	enamel	homo	upRM1	M1	0,71160134	4,23E-06	adult	female	119	-	-
HL29	B21	this study	enamel	homo	upRM1	M1	0.70948835	7,49E-06	adult	unsexed	-	-	-
HL29	B21	this study	enamel	homo	upRM2	M2	-	-	adult	unsexed	-	-	-
HL29	B23	this study	enamel	homo	upLM1	M1	0,70916278	6,68E-06	adult	female	72	-	-
HL29	B23	this study	enamel	homo	upRM3	M3	0,70851894	4,56E-06	adult	female	72	-	-
HL29	B24	this study	enamel	homo	loLM1	M1	0,70877056	4,37E-06	adult	unsexed	-	-	-
HL29	B24	this study	enamel	homo	loLM3	M3	0,70874733	3,95E-06	adult	unsexed	-	-	-
HL29	B25	this study	enamel	homo	upLM3	M3	0,70879531	4,93E-06	adult	unsexed	23	-	-
HL29	B26	this study	enamel	homo	upLM3	M3	0,70874981	4,36E-06	adult	unsexed	171	1	-
HL29	B27	this study	enamel	homo	upLM1	M1	0,70894788	4,81E-06	adult	unsexed	-	-	-

HL29	B27	this study	enamel	homo	upLM3	M3	0,70902533	5,63E-06	adult	unsexed	-	-	-
HL29	B30	this study	enamel	homo	upRM3	M3	0,70857818	4,15E-06	adult	male	346	1	-
HL29	B30	this study	enamel	homo	upRM1	M1	0,70862166	4,23E-06	adult	male	346	1	-
HL29	B31	this study	enamel	homo	loRM1	M1	0,70874765	4,32E-06	adult	unsexed	636	1	-
HL29	B31	this study	enamel	homo	loRM2	M2	0,70852838	4,51E-06	adult	unsexed	636	1	-
HL29	B32	this study	enamel	homo	upRM1	M1	0,70872949	4,78E-06	adult	male	546	1	-
HL29	B32	this study	enamel	homo	upRM3	M3	0,70868058	4,29E-06	adult	male	546	1	-
HL29	B37	this study	enamel	homo	loLM1	M1	0,71105376	4,19E-06	adult	unsexed	2	-	-
HL29	B37	this study	enamel	homo	loLM3	M3	0,71387465	4,06E-06	adult	unsexed	2	-	-
HL29	B38	this study	enamel	homo	loRM1	M1	0,70914337	4,22E-06	adult	unsexed	35	-	-
HL29	B38	this study	enamel	homo	loRM2	M2	0,70902026	4,13E-06	adult	unsexed	35	-	-
HL29	B39	this study	enamel	homo	upLM2	M2	0,70853952	4,51E-06	adult	unsexed	141	-	-
HL29	B42	this study	enamel	homo	loLM1	M1	0,71968341	5,25E-06	adult	unsexed	-	-	-
HL29	B42	this study	enamel	homo	loLM3	M3	0,72206740	4,45E-06	adult	unsexed	-	-	-
HL29	B45	this study	enamel	homo	loLM1	M1	0,70843853	4,09E-06	adult	male	2	-	-
HL29	B45	this study	enamel	homo	loLM3	M3	0,71005606	4,07E-06	adult	male	2	-	-

HL29	B46	this study	enamel	homo	upLM1	M1	0,70958712	4,23E-06	adult	male		17	-		-
HL29	B46	this study	enamel	homo	upLM3	M3	0,70887321	4,54E-06	adult	male		17	-		-
HL29	B47	this study	enamel	homo	loLM1	M1	0,70877118	4,58E-06	adult	male		199	-		-
HL29	B47	this study	enamel	homo	loLM3	M3	0,70913157	3,72E-06	adult	male		199	-		-
HL29	B7	this study	enamel	homo	loLM3	M3	0,70858099	4,83E-06	adult	unsexed		112		1	-
HL29	B16	this study	root	homo	upLm1	dm1	0,70881091	4,34E-06	subadult	-	-		-		-
HL29	B30	this study	root	homo	upRM3	M3	0,70883339	4,56E-06	adult	unsexed	-		-		-
HL29	B45	this study	root	homo	loLM1	M1	0,70872646	3,76E-06	adult	unsexed	-		-		-
HL30	B21	this study	bone	homo	Rfemur	-	0,70931997	4,60E-06	adult	unsexed	-		-		-
HL30	B11	this study	root	homo	upLM2	M2	0,70912382	4,09E-06	adult	unsexed	-		-		-
HL30	B21	this study	root	homo	loLM2	M2	0,70924573	4,47E-06	adult	female	-		-		-
HL30	B7	this study	root	homo	loLM3	M3	0,70885881	4,05E-06	adult	unsexed	-		-		-
HL30	bos	this study	enamel	animalia	-	-	0,70933057	4,04E-06	-	-	-		-		-
HL30	canis	this study	enamel	animalia	-	-	0,71007460	4,10E-06	-	-	-		-		-
HL30	cervinae	this study	enamel	animalia	-	-	0,70926657	4,13E-06	-	-	-		-		-
HL30	sus	this study	enamel	animalia	-	-	0,70950172	4,34E-06	-	-	-		-		-

Table 2: Local range data for the Oakaie area

Samples types	number of samples	Site	$^{87}Sr/^{86}Sr$ range	Reference
Dentine	2	OAI1	0.70650-0.70951	this study
Water	22	Monywa	0.70824-0.70951	Chapman et al 2015
Local range	**24**		**0.70650-0.70951**	

Table 3: Local range data for the Halin area

Sample types	Number of samples	Site		$^{87}Sr/^{86}Sr$ range
		HL29	HL30	
Dentine	6	3	3	0.70873-0.709246
Bone	8	7	1	0.70885-0.70932
Animal enamel	4		4	0.70933-0.71007
Water	1			0.70813
Local range	19	10	8	**0.70813-0.71007**