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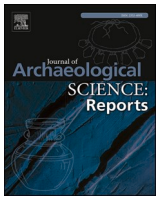

They came from near and far – Strontium isotope analysis of people buried at the early Christian site of Varnhem, southwestern Sweden

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ABSTRACT

The Christianization of Sweden (8th–11th centuries) was a period of political, social, and religious change, and it implies a period of movement and mobility. Recent excavations at the Varnhem estate church grounds (Kata Gård), originally built around CE 1000 in Västergötland, Sweden, have yielded information about this period. This study uses strontium isotope analysis to investigate the lives of these early Christians buried at Kata Gård and identify the non-locals. Our results indicate that a large part of the adult population was non-local and had spent their childhoods in other geological areas, whereas the children had mostly local strontium isotope signatures.

1. Introduction

Scandinavia during the 8th–11th centuries saw dynamic change, as this period is marked by high mobility, political, religious, and cultural exchanges (Skre, 1998; Kjellström et al., 2005; Brink and Price, 2008; Lund, 2013; Roesdahl, 2016; Lindkvist, 2020). Although the Christianization of Sweden was slow and life continued normally, members of the social elite began to build farm churches, sometimes near the old religious sites (Brink and Price, 2008; Roesdahl, 2016; Lindkvist, 2020; Vretemark, 2020). This is evident in Varnhem (Fig. 1) in the province of Västergötland, the location of one of the first established Christian settlements in Sweden (Vretemark and Axelsson, 2008; Axelsson and Vretemark, 2013; Vretemark, 2020). Around the 1150s, a Cistercian abbey was built here, however, the site's history before the building of the abbey was less well known, which prompted a research project named 'Varnhem – before the monks came' (Vretemark and Axelsson, 2008). Excavations and radiocarbon dates revealed a continuously site that was inhabited from the Roman Iron Age to the Early Medieval Period. This included hundreds of Viking Age graves, the foundation and ruins of a private estate church, and other buildings, all evidence of a thriving community prior to the arrival of the monks.

The wooden church, which was later rebuilt in to stone, was originally built around CE 1000 and is situated at the Kata Gård estate, named after one of its female residents (Vretemark and Axelsson, 2008). Excavations of the church and its surroundings have revealed a large, socially stratified cemetery with approximately 3000 burials. Of those, 300 have been excavated, revealing well-preserved skeletal remains dating from the late 9th century to the late 12th century (Vretemark, 2014). Social stratification is evidenced by the manner of burial, with the finer masonry stone coffins found near the church. Kata, after whom the estate has been named, was buried in a limestone coffin with a runic stone lid. The runic inscription reads, 'Kättil erected this stone in memory of his wife, Kata, Torgil's sister.' All three were part of the local aristocracy around CE 1050 (Västergötlands, xxxx; Vretemark and Axelsson, 2008).

Several individuals from Kata Gård have undergone various analyses (DNA, osteological, and isotopic), thus providing insights into their individual life histories (e.g., Vretemark and Axelsson, 2008; Vretemark, 2014, Vretemark, 2020; Margaryan et al., 2020; Bertilsson et al., 2023; Rodríguez-Varela et al., 2023; Wathen et al., xxxx). The DNA results (n = 31 individuals, three individuals are included in the present study: ind. 17, 27, and 276) revealed that the population was genetically similar to other Viking Age populations in Southern Scandinavia (Margaryan, et al., 2020). Furthermore, and quite surprisingly, the genetic diversity in Varnhem was even higher than in the Late Viking-Age town of Sigtuna, the early Christian urban center in East Central

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Fig. 1. Map showing the location of Varnhem in relation to other cities in Scandinavia. Created using QGIS (QGIS Development Team, 2025) with data from OpenStreetMap. Basemap: © OpenStreetMap contributors, © CARTO.

Sweden, where the genetic affinities were characterized as very heterogeneous, reflecting distant connections and high mobility (Krzewińska et al., 2018; Margaryan et al., 2020: EDF6).

The burial practices at the site indicate the remnants of pre-Christian burial customs, as evidenced by grave goods such as axes and coins. These goods, the coins particularly, suggest contact and interaction with other areas, including England (Vretemark, 2020). Radiocarbon analysis of the individuals from Kata Gård produced dates as early as the first decades of the AD 900s, when most of the Scandinavian population was pagan (Vretemark et al., 2020). This suggests that Christianity was practiced in Sweden nearly a century earlier than previously believed (Vretemark and Axelsson, 2008). Additionally, pagan burial grounds near the site were used until the early 10th century (Vretemark, 2014; Vretemark and Axelsson, 2008). Thus, suggesting a brief period of overlap between the two belief systems and their burial practices.

It is possible that the establishment of Christianity at Kata Gård attracted people from the larger surrounding area to bury their dead relatives here, according to the 'new' religion. Therefore, a large proportion of the individuals buried here may have been non-local. To investigate this possibility, strontium isotopic analysis of tooth enamel was employed.

2. Strontium isotopes

Strontium is chemically similar to calcium, and it substitutes for calcium in the inorganic fractions of the bones and teeth (Pollard et al., 2017). In skeletal materials, the strontium isotopic ratio, $^{87}Sr/^{86}Sr$, has been used to map and reconstruct mobility patterns in archaeological populations (e.g., Bentley, 2006). This ratio reflects the geological makeup where plants grow, which is then transferred up the food chain, thus providing insight into mobility patterns and life history (Bentley, 2006; Pollard et al., 2017). Strontium isotopes do not fractionate as they are incorporated into the food chain, meaning they could theoretically be matched to geochemical maps (Pollard et al., 2017).

The formation of tooth enamel is complex, involving two distinct stages: secretion and maturation. During both of these stages, calcium and strontium are incorporated, but evidence suggests that the Sr/Ca ratio is higher during secretion than during maturation (Humphrey et al. 2008). Once the tooth enamel is fully mineralized, no more strontium is incorporated, therefore, displaying a snapshot of the childhood dietary $^{87}Sr/^{86}Sr$ values (Smith, 1998; Montgomery, 2010; Müller et al., 2019).

Only a small number of isoscape studies, which map the bioavailable isotopic variation within an area, have been completed in Sweden (Blank et al., 2018; Ladegaard-Pedersen et al., 2021; Sjögren et al., 2009). Varnhem is located on the edge of Falbygden, which consists of Paleozoic sedimentary bedrock surrounded by older Precambrian crystalline bedrock. This creates a distinctive area that is interesting for mobility studies (Fig. 2) (Blank et al., 2018). To read more about the bioavailable Sr data that exists, see Blank et al., 2018.

3. Materials and Methods

The molar teeth of 25 individuals from the Kata Gård burial site were provided for analysis by the Västergötland Museum, and were selected based on availability. We estimated age and sex according to the standards outlined by Buikstra and Ubelaker (Buikstra and Ubelaker, 1994; Vretemark, 2024). These included eight subadults (seven children aged between 1.5 and 7 years, and one adolescent, age 14–15 years), nine adult females (aged 20–60 years), and eight adult males (aged 20–45 years).

Molars were selected since they are preserved *in situ* in the jaw more frequently than other teeth, and they form during childhood. Furthermore, the enamel formation periods of the permanent first, second, and third molars do not overlap, and the crown completes later, with the enamel being mineralized during that period (AlQahtani et al., 2010; Humphrey et al. 2007, Humphrey et al., 2008; Smith, 1998; Robinson et al., 1997). This mineralization period is the portion analyzed here.

When available, the first molar (M1) was selected, as it would reflect the consumed $^{87}Sr/^{86}Sr$ during early childhood. If unavailable, the second (M2) or third (M3) molars were chosen, representing later childhood and adolescence (AlQahtani et al., 2010). One individual, Kata, had only a premolar available (PM^2), which is similar to M2 in regard to age of formation. Among the seven children, deciduous first or second molars (dm1, dm2) were analyzed, which form during infancy. The eighth subadult, an adolescent, had an available M2.

The tooth enamel was subjected to strontium isotopic analysis by

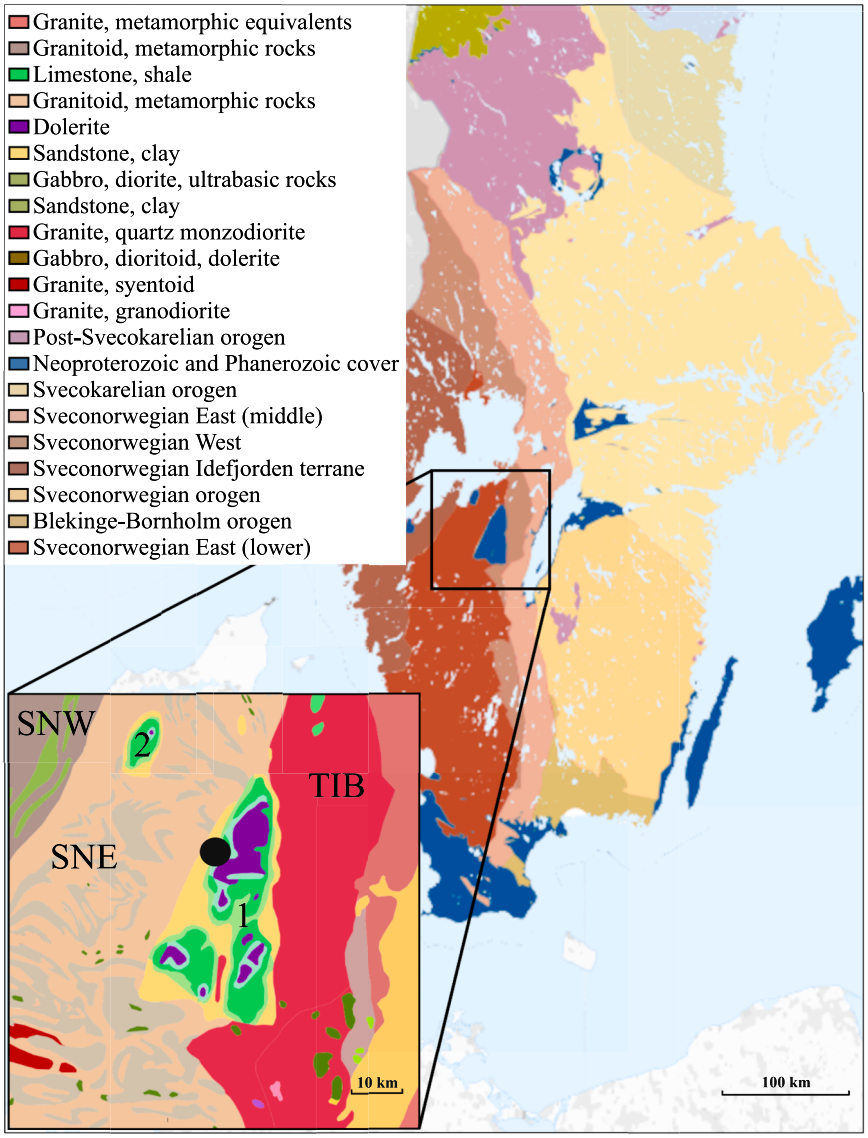

Fig. 2. This map demonstrates the variation in bedrocks in Southern Sweden. A black circle indicates Varnhem's location. Taken from the geological maps by the Geological Survey of Sweden, (Bedrock 1:1 million). 1: Falbygden (0.7110–0.7190), 2: Kinnekulle (0.7110–0.7210), SNW: Sveconorwegian west (0.7110–0.7210), SNE: Sveconorwegian east (0.7150–0.7290), and TIB: Transscandinavian igneous belt (0.7210–0.7290). The bioavailable $^{87}Sr/^{86}Sr$ ranges are from Fig. 3 in Blank et al. (2018).

laser-ablation multi-collector inductively coupled plasma mass spectrometry (LA-MC-ICP-MS). The method is minimally destructive but facilitates micro-sampling to produce multiple isotopic values that are precise to the 4th decimal place (Glykou et al., 2018; Lugli, 2019). Sampling across a larger area of the tooth not only increases the temporal resolution, where mobility can be assessed over a longer period (months vs. weeks), but also produces multiple data points which provide insight into the dietary strontium incorporated at different periods of life. Therefore, in this study, we infer the mobility of the population buried at Kata Gård only to the fourth decimal place. The isoscape of Sweden, with bedrock belonging to the Fennoscandian (Baltic) Shield, exhibits a wide range of $^{87}Sr/^{86}Sr$ values (approx. from 0.70 to > 0.74). Therefore, meaningful differences can still be detected despite the lower precision compared to TIMS measurements (Blank et al. 2018).

Three contemporaneous vole teeth, excavated from the cultural layers at Kata Gård, were provided to establish the bioavailable $^{87}Sr/^{86}Sr$ range for the site. This circumvents the problem of domesticated animals being brought in from other areas, thus not necessarily representing the local bioavailable strontium. Voles are favorable for this purpose, as they have small home ranges and feed on, for example, grass, tree bark, roots, and tubers (Romairone et al., 2018). Furthermore, they have not been brought into the area for a particular purpose, but are wild and represent part of the bioavailable baseline. Two lines were ablated and measured on each of the three vole teeth provided to define the baseline $^{87}Sr/^{86}Sr$ values of the site. To create a more robust range within 5 km of the site, bioavailable $^{87}Sr/^{86}Sr$ values from two spring water sources and an additional vole from the excavations published by Blank et al. (2018)were included. In addition, a broader 30 km range was calculated using bioavailable data published by Blank et al. (2018) and Sjögren et al. (2009).

Isotopic data were acquired *in situ* using LA-MC-ICP-MS at the Vegacenter at the Swedish Museum of Natural History using a NWR193 excimer laser ablation system (Elemental Scientific Lasers) coupled to a Nu Plasma (II) MC- ICP-MS (Nu Instruments Ltd). For a detailed method description, see Glykou et al. (2018) and Boethius et al. (2021). Since no contamination was suspected, the teeth did not undergo any chemical

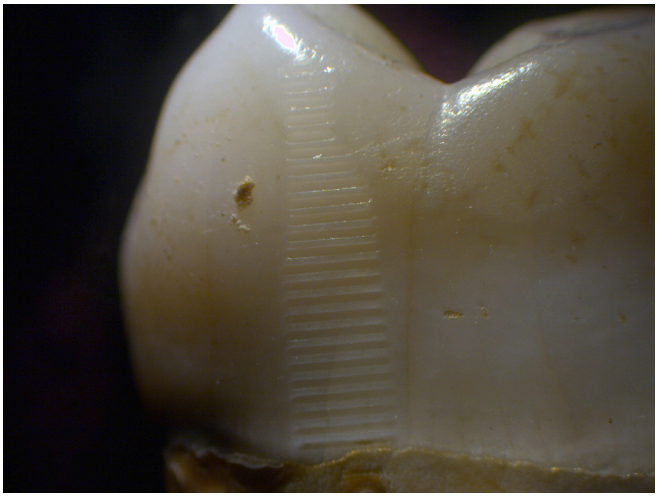

Fig. 3. Tooth from Individual 110, showing multiple ablated lines for analysis.

pretreatment, but a simple cleaning. The teeth were mounted so that the non-occlusal surface faced upwards, and the enamel could be analyzed in the direction of growth, from the tip of the crown towards the cervix (commonly referred to as the ERJ, i.e., the enamel-root junction). The enamel was pre-ablated to remove any potential surface contamination. Line spacing was approximately 200 μm and the number of ablated lines on each tooth varied between 14 and 24, depending on enamel length (Fig. 3 and Supplementary 1). Possible isobaric and polyatomic interferences were monitored and corrected. To ensure accuracy, two in-house references, a hare tooth (0.71000 ± 0.00023) and a rodent tooth (*Otomys* 26-r52; 0.72049 ± 0.00021) were measured between samples.

4. Results and Discussion

4.1. Local bioavailable $^{87}Sr/^{86}Sr$ range

The results of the analysis are reported in Figs. 4 and 5, Supplementary Table 1, and summarized in Tables 1 and 2. The local (≤5 km) bioavailable $^{87}Sr/^{86}Sr$ range, calculated from the minimum and maximum values of the voles and the water, was 0.7142–0.7207 (Table 1). The difference between the minimum and maximum of the local $^{87}Sr/^{86}Sr$ range is 0.007, which is a range comparable to other studies in Sweden that have defined ranges of 0.002–0.014 (cf. Eriksson et al., 2018; Larsson et al., 2020; Price et al., 2018; Sjögren et al., 2009; Sjögren and Price, 2013). This range should be considered in light of the local geology. Varnhem is situated on the edge of the Falbygden area, with sedimentary bedrock, surrounded by older, Precambrian bedrock; consequently, there is a wider range of $^{87}Sr/^{86}Sr$ in the immediate vicinity. Accordingly, within a 30 km radius from Varnhem, the bioavailable $^{87}Sr/^{86}Sr$ range is 0.7118–0.7280 (Blank et al., 2018; Sjögren et al., 2009) (Fig. 2).

4.2. Human enamel $^{87}Sr/^{86}Sr$ range

The total range of individual ablated lines from the human teeth varied between 0.7093 and 0.7322 (mean 0.7187 ± 0.0056 (1SD)), i.e., including values both below and above the local range. Since the use of LA-MC-ICP-MS makes it possible to obtain multiple isotopic values for one individual, the categories of non-local vs. local were insufficient for any specific individual, therefore, additional categories were necessary. These categories were as follows: non-local during tooth formation (n = 12, 6 males, 6 females), local during tooth formation (n = 4, 1 female, 1 adolescent, 2 subadults), and mixed values (n = 9, 2 males, 2 females, 5 subadults). Of those with mixed values, one individual (1 subadult) moved out of the local range, three individuals (1 female, 2 subadult) moved into the local range, and finally, five individuals (2 males, 1 females, 2 subadults) were moving in and out of the local range (see Fig. 6). This could indicate movement across the landscape due to

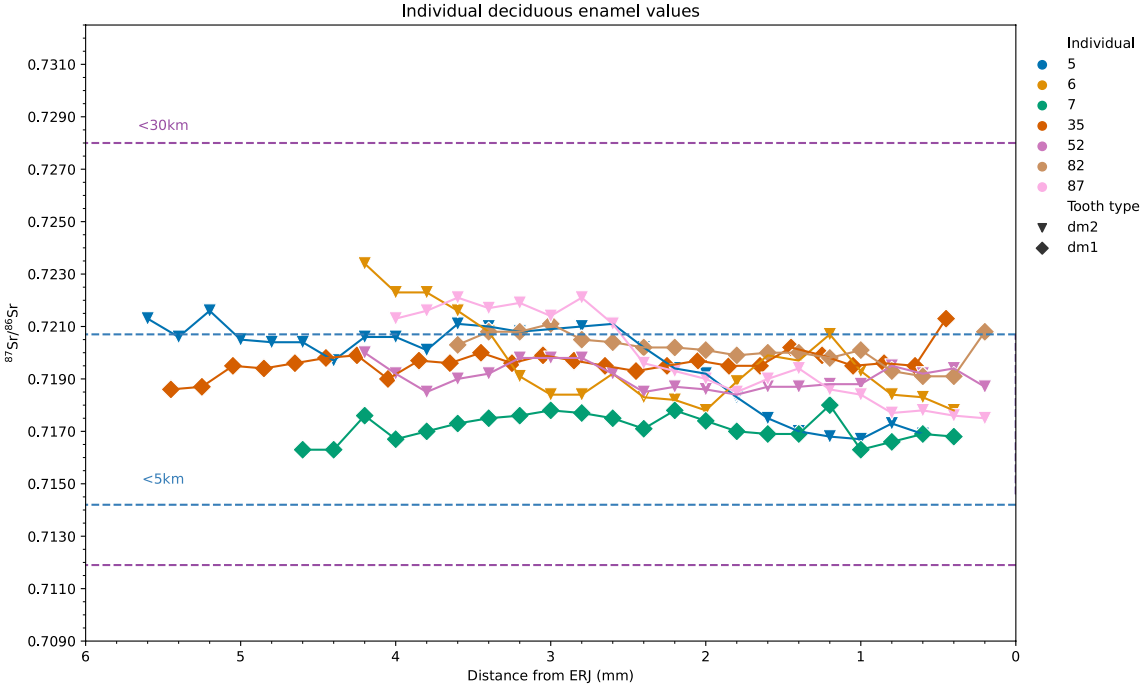

Fig. 4. LA-MC-ICP-MS $^{87}Sr/^{86}Sr$ data from deciduous molar enamel plotted against distance from the ERJ. Dotted boxes indicate two ranges: the bioavailable $^{87}Sr/^{86}Sr$ range of Varnhem, and the 30 km range. Approximate crown formation time for deciduous first molars (dm1), 30 weeks in utero – 7.5 months, and deciduous second molars (dm2), 38 weeks in utero – 10.5 months (AlQahtani et al., 2010).

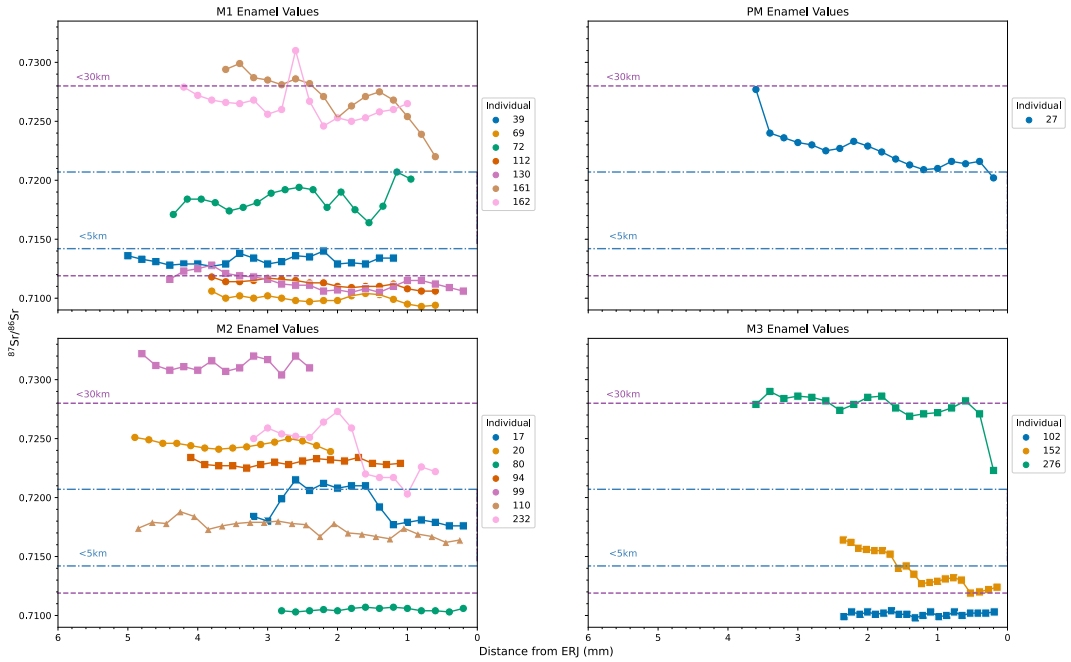

Fig. 5. LA-MC-ICP-MS $^{87}Sr/^{86}Sr$ data of permanent molar enamel, plotted against distance from the ERJ. Dotted boxes indicate two ranges: the bioavailable $^{87}Sr/^{86}Sr$ range of 5 km and the 30 km range around Kata Gård, Varnhem. ■ =Male, ● = Female, ▲ = Subadult Adolescent. The crown formation times for M1 (4.5 months – 3.5 years), PM and M2 (2.5 – 7.5 years), and M3 (8.5 – 15 years) are approximate and based on data from AlQahtani et al. 2010.

Table 1
Bioavailable $^{87}Sr/^{86}Sr$ of the area produced from LA-MC-ICP-MS in this study and Blank et al., 2018, using High-Resolution Multi-Collector-ICP-MS for the vole and waters, respectively.

Sample Number	Type	Source	Line number	$^{87}Sr/^{86}Sr$	Avg. prec. 2 σ	Reference
C442	Enamel	Vole	1	0.7165	0.00033	current work
			2	0.7161	0.00038	current work
C10278	Enamel	Vole	1	0.7207	0.00035	current work
			2	0.7205	0.00044	current work
C31029	Enamel	Vole	1	0.7152	0.00031	current work
			2	0.7150	0.00030	current work
MA-167585	Enamel	Vole		0.71551	0.00001	Blank et al., 2018
MA-147963	Water	Spring		0.71461	0.00001	Blank et al., 2018
MA-147962	Water	Spring		0.71421	0.00001	Blank et al., 2018

agricultural and herding activities or consumption of non-local foodstuffs. Subadults had the smallest range of values, between 0.7162 and 0.7234 (mean 0.7190 ± 0.0015 (1 SD)), with almost all values within the local range (Fig. 4). Male adults ranged between 0.7098 and 0.7322 (mean 0.7177 ± 0.0072 (1 SD)), i.e., with both minimum and maximum values outside the local range. Female adults ranged between 0.7093 and 0.7310 (mean 0.7194 ± 0.0068 (1 SD)), also with both minimum and maximum values outside the local range. The intra-tooth variation, with fluctuating values during tooth formation, emphasizes the importance of the additional information that is obtainable through LA-MC-ICP-MS analysis (Figs. 4 and 5).

4.3. Chronology and LA-MC-ICP-MS data

The additional information obtained through LA-MC-ICP-MS does not include the ability to link individual ablation lines to an exact biological age since the incremental growth of enamel is a complex process. However, for each tooth type, formation is initiated at a specific age, with the crown formation completing at a later age. Within that time frame, the enamel is laid down and mineralized incrementally (AlQahtani et al., 2010; Humphrey et al. 2007, Humphrey et al., 2008; Smith, 1998; Robinson et al., 1997).

That the variation in bioavailable strontium is reflected in a chronologically meaningful way in molar enamel has been demonstrated, for example, by Boethius et al. (2022), who applied LA-MC-ICP-MS analysis to both prehistoric and modern teeth. The ablations, ordered from the tip to the cervix, were shown to represent temporal changes rather than being the result of random averaging of the incorporated strontium. Consequently, for each tooth type, the $^{87}Sr/^{86}Sr$ values represent changes occurring within the enamel-formation time frame. Accordingly, while the time frame for the deciduous first molar is from birth to approximately seven months of age, the third permanent molar represents c. 8.5–15 years of age, and the other molars represent ages between those extremes (AlQahtani et al., 2010; Humphrey et al. 2007, Humphrey et al., 2008). Two out of the seven children (Ind. 7, 52) had local values during the entirety of tooth formation, whereas Ind. 35 had local values except for the final data point (Fig. 4). Three subadults (Ind. 5, 6, 87) initially had non-local $^{87}Sr/^{86}Sr$ values that later equilibrated to the local range, indicating an early life mobility. The $^{87}Sr/^{86}Sr$ values for Ind. 82 start within the local range, followed by fluctuations in and out of the range, with the final value being outside of the local range. Even though deciduous tooth formation starts prior to birth, it is unlikely that the measurements represent this period. In this study, the measurements were made on the lateral of the tooth, whereas the earliest-formed

Table 2
Summary and interpretation of the $^{87}Sr/^{86}Sr$ data produced by LA-MC-ICP-MS on tooth enamel from human teeth. Individuals with non-local signatures that are outside of the > 30 km range from Varnhem are marked with an upper-case X.

Ind.	Sex	Age (years)	Age group	Tooth analyzed	Local	Non-local	Mixed, moving in	Mixed, moving out	Mixed, moving both in and out
5	I	6–7		dm2					x
6	I	2		dm2			x		
7	I	6		dm2	x				
35	I	1.5		dm1				x	
52	I	5		dm2	x				
82	I	6		dm1					x
87	I	6–7		dm2			x		
110	I	14–15	I	M2	x				
20	F	25–35	II	M2		x			
27	F (Kata)	30–35	II	PM2			x		
69	F	45–60	III	M1		X			
72	F	20–30	I	M1	x				
80	F	45–60	III	M2		X			
112	F	20–25	I	M1		X			
161	F	30–35	II	M1		x			
162	F	20–25	I	M1		x			
232	F	20–30	I	M2					x
17	M	35–45	III	M2					x
39	M	20–25	I	M1		x			
94	M	25–30	I	M2		x			
99	M	30–40	II	M2		X			
102	M	35–45	III	M3		X			
130	M	35–40	II	M1		x			
152	M	35–40	II	M3					x
276	M	20–25	I	M3		x			

enamel in the molars is on the occlusal surface. However, stable nitrogen isotope analysis of the same teeth indicates that they were breastfed (Wathen et al., xxxx), and thus the strontium signal derives from the mother, thereby providing insight into two lives rather than one. Furthermore, it is unlikely that the children moved to Varnhem on their own, considering their age-at-death (c. 1.5–7 years).

4.4. Subadult vs. Adult variation in $^{87}Sr/^{86}Sr$ values

Only two of the permanent teeth had exclusively local values (female Ind. 72 and adolescent Ind. 110), indicating a local origin. Four individuals had mixed values, either moving into the local range (Ind. 27, Kata), or moving in and out (male Ind. 17, male Ind. 152, and female Ind. 232). In total, 12 out of the 18 adults (67 %) had exclusively non-local values during tooth formation. As none of the children had exclusively non-local values, the percentage for the whole analyzed population is 48 % (12 out of 25 individuals). However, taking the wider 30 km radius range into account, seven individuals (Ind. 20, 39, 94, 130, 161, 162, 276) are within this range, while five (20 % of the analyzed population) are outside the range – Ind. 69, 80, 102, 112 (below), and 99 (above) (Fig. 5). There is no obvious sex-based pattern of mobility in the analyzed population.

4.5. Mobility patterns grouped by age-at-death

To study whether there was any age-based form of mobility, the adult individuals (including the adolescent) were assigned to three age groups based on their median age-at-death, I (15–29 years, n = 8), II (30–39 years, n = 6), and III (40 + years, n = 4), and their $^{87}Sr/^{86}Sr$ values were compared (Fig. 7). Group I contained one individual with values outside of the 30 km range (female Ind. 112), and only two individuals (adolescent Ind. 110, and female Ind. 72) with exclusively local values. Group II also contained one individual with values outside of the 30 km range (male Ind. 99). In Group III, three out of four individuals had values outside the wider range (females Ind. 69, 80, and male Ind. 102). There is evidence of an age-based form of mobility, where the oldest individuals originated from further away.

4.6. Spatial distribution of burials and mobility

The five individuals with values outside the 30 km range (Ind. 69, 80, 99, 102, and 112) were all buried at least 10 m from the church (Fig. 6). Only one (male Ind. 99) had an $^{87}Sr/^{86}Sr$ value above this range, whereas the others had values below the range, that is, from areas with younger bedrock. Does this mean that all four individuals originated from the same area and then migrated to Varnhem together? The radiocarbon dates of Ind. 69, 80, and 112 neither exclude nor support such a scenario (Vretemark and Axelsson, 2025).

Of the other seven non-locals (within the 30 km range but outside of the Varnhem local range), two had values below the Varnhem range – both were buried at least 10 m from the church. The remaining five all had values above the Varnhem range, of which three were buried close to the church, one far away, and one at an intermediate distance.

All values from Kata (Ind. 27), the church's namesake, were non-local, with values outside of the 5 km range, except the final value, which was within it. However, all her values were within the broader 30 km range. This likely indicates a childhood move to the immediate area. Considering the founding dates of the estate stone church, and the contextual dates of her burial, she is likely related to, or is, one of the founders herself, and perhaps was already Christian when she came to Varnhem (Vretemark and Axelsson, 2008; Vretemark et al., 2020). Since she probably came to Varnhem already as a child, what attracted her parents to Varnhem? Was it that the Christian religion was already established here, or did they establish it? The fact that Kata was of non-local origin and buried in a limestone coffin with a lid bearing runic inscriptions, suggests that she was part of the local aristocracy. This may suggest that Kata was brought to Varnhem to consolidate elite alliances through marriage.

4.7. Comparison with early Christian sites: Alvastra and Sigtuna

It could be argued that this estate church served a larger area, especially for individuals who wished for a Christian burial but did not have a nearby church, as there were few in the Swedish countryside during this period (Kjellström et al., 2005; Vretemark and Axelsson, 2008; Vretemark, 2020). This argument is also strengthened by the large number of individuals buried at the cemetery. Varnhem is not the only

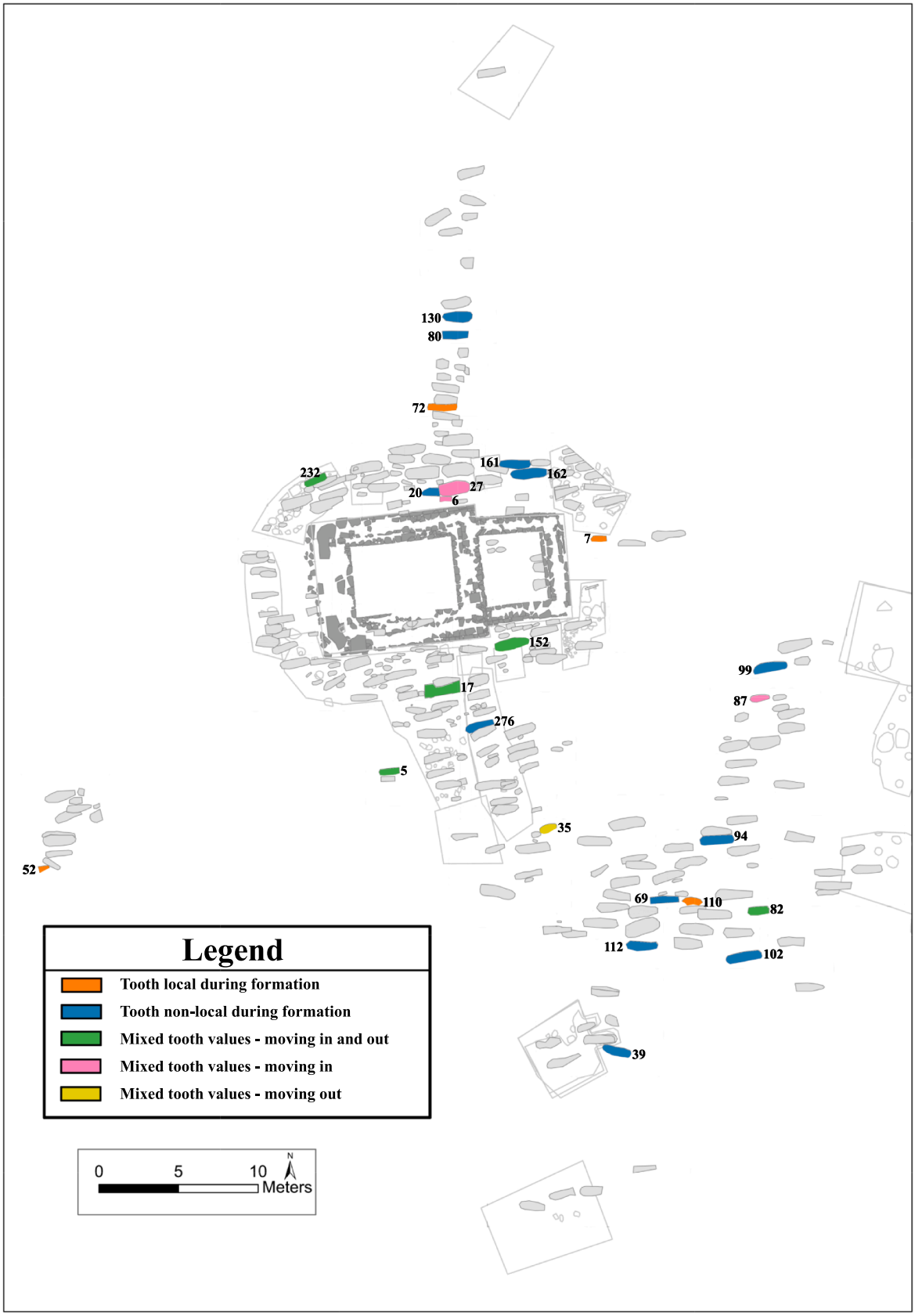

Fig. 6. The cemetery surrounding the estate church, showing those graves that have been excavated in gray and those analyzed for this study are shown in various colors according to their mobility status based on their $^{87}Sr/^{86}Sr$ values. Permission granted by Västergötlands museum, courtesy of Maria Vretemark and Tony Axelsson.

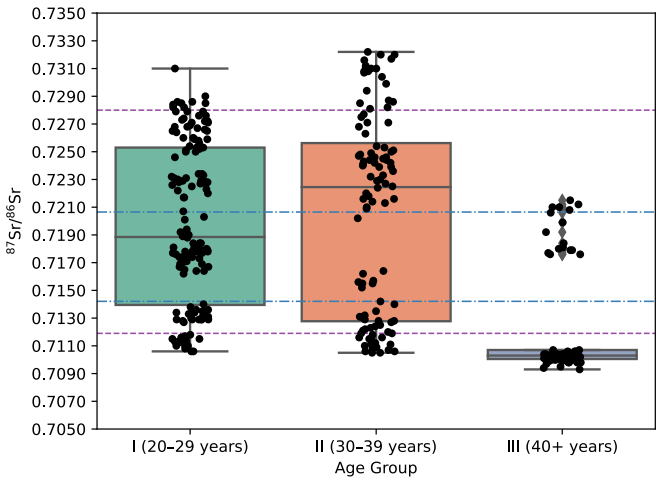

Fig. 7. Comparison of the $^{87}Sr/^{86}Sr$ values, see Supplementary Table 1, for three age groups using their median age-at-death, I (15–29 years, n = 8), II (30–39 years, n = 6), and III (40 + years, n = 4). The bioavailable ranges are depicted as '–' for < 30 km and '-.' for 5 km range around Varnhem.

early Christian site to support this argument; for example, Sverkersgården near Alvastra monastery in Östergötland, a site containing nearly 6000 graves dating to the mid-11th century, has been interpreted in a similar way (Ersgård, 2006; Vretemark, 2020). The high number of non-local measurements (86.6 % of all ablated lines outside of 5 km and 39.3 % outside of 30 km) in the teeth of the Varnhem adults is evidence of a move into this early Christian area. This high rate of total non-locality, especially outside of 5 km, is exclusive to the adult population, as the subadults produced values that indicated either movement into the site earlier in life or that they were born locally (85.3 % of the individual ablated lines of the subadults were local within 5 km and 100.0 % were local within 30 km). These subadults are possibly evidence of first-generation migrants, especially those who showed non-local values soon after birth and then began to equilibrate to the local range. This also suggests that the cemetery was not exclusively used for the interment of people living in a wider area, but that both single adults and families were living nearby or at Varnhem. The high number of non-local values is further supported by the high genetic diversity demonstrated by Margaryan et al. (2020).

When compared to Sigtuna, which has been characterized as an important hub for commercial and religious activity (Tesch and Vincent, 2003), Varnhem is both genetically more diverse, and has a higher number of non-locals or mixed values as determined by $^{87}Sr/^{86}Sr$ analysis (86.6 % vs. 50 % in Sigtuna) (see Fig. 8; Krzewińska et al., 2018). This is somewhat surprising, considering the lack of commercial activity evidenced in Varnhem, suggesting that the Christian religion, rather than commercial activities, appealed to a great number of people from a wide area.

5. Conclusion

This study suggests that a large proportion of the individuals buried at Varnhem were Christian pioneers and that non-locals were attracted by the establishment of the new church and religion. The high rate of mobility identified at this site is unique in Sweden during this period and perhaps indicates the importance of the conversion to Christianity for the societal development in the area. Finally, our interpretations of Kata as a first-generation migrant provide further support for her being one of the founders of the stone church that replaced the earlier wooden one.

Overall, the well-preserved skeletons of Kata Gård tell the story of a large non-local population, one where many individuals moved to Varnhem after tooth formation. In addition, this study highlights the valuable information that the analytical method, LA-MC-ICP-MS, provides when analyzing inter- and intra-tooth variation, providing insight into the early-life mobility of an individual.

Ethical Approval

All necessary permissions were obtained from the relevant heritage and research authorities in Sweden for sampling and analysis of the human remains.

CRediT authorship contribution statement

Crista Wathen-Avila: Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Formal analysis, Data curation, Conceptualization. **Fanny Bengtsson:** Writing – review & editing, Formal analysis. **Sven Isaksson:** Writing – review & editing, Supervision, Conceptualization. **Maria Vretemark:** Writing – review & editing, Validation, Resources, Conceptualization. **Gunilla Eriksson:** Writing – review & editing, Writing – original draft, Validation, Formal analysis. **Kerstin Lidén:** Writing – review & editing, Writing – original draft, Supervision, Resources, Conceptualization.

Declaration of Competing Interest

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

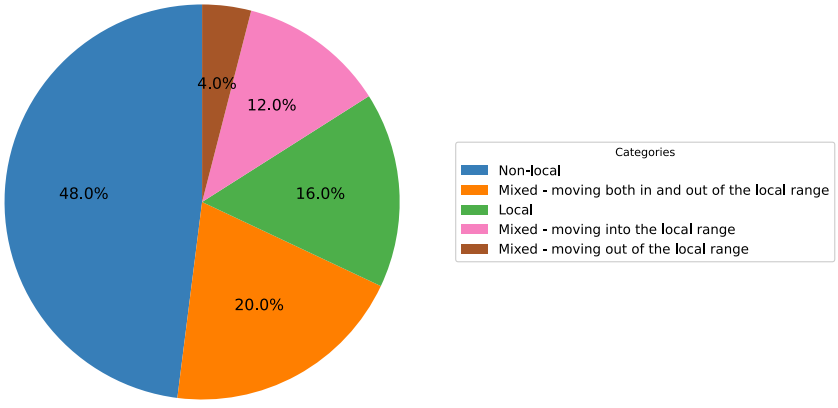

Fig. 8. Percentage of individuals categorized by 5 km range as local, non-local, mixed – moving into the local range, mixed – moving out of the local range, mixed – moving both in and out of the local range, based on their molar enamel $^{87}Sr/^{86}Sr$ values.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2025.105387.

Data availability

Data will be made available on request.

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