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Isotopes and human burials at Viking Age Birka and the Mälaren region, east central Sweden

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ABSTRACT

Isotopic proveniencing has been applied to human inhumations and cremations as well as fauna from the Viking Age site of Birka and the surrounding Mälaren region, located in east-central Sweden. Human enamel from inhumations has been measured for strontium, oxygen, and carbon isotope ratios (petrous bone from cremations was measured for strontium only) to obtain information on mobility and diet. Seven graves from the larger Mälaren region and several at Birka had distinctive grave goods thought to have originated in Finland. The isotopic values from these graves indicate that they may have been local individuals. The faunal remains from the Mälaren region corresponded closely with samples from Birka providing a baseline for strontium isotopic ratios in this area. At the site of Birka, two distinct groups of burials can be identified among the measured values, along with several outliers. The data suggest that Birka was a multi-ethnic settlement in the Viking period, consistent with historical sources and concomitant with its role as an important center of economy and trade on the east coast of Sweden.

1. The site of Birka

Lake Mälar is the third largest freshwater lake in Sweden, 150 km from east to west, with an area of 1140 km^2 and a maximum depth of 64 m. It is made up of numerous arms interrupted by islands and peninsulas. The term Mälaren is used for both the lake and the region. The Mälar region is not clearly defined. However, according to one definition it stretches approximately from Stockholm and the Baltic coast in the east, to Kungsör in the west, and from Uppsala in the north to Södertälje in the south (Fig. 1). About one-third of Sweden's present-day population lives within this area. The easternmost bay of the lake lies in central Stockholm and is connected to the Baltic Sea by canals and locks. In the Viking period, Lake Mälaren was a bay of the Baltic and ships could sail for some distance, far into the interior of eastern Sweden. Postglacial rebound of the land from the weight of Pleistocene ice closed the Baltic entrance sometime after CE 1200 as the Mälar Bay became a lake.

Some 30 km west of Stockholm, the remains of the Viking town of Birka sit on a small island called Björkö — today its size is roughly 4 by 1.5 km — in the eastern part of the lake (Fig. 1). The location was both well protected and strategic. A major navigation route passed from Denmark via the southern Swedish coast, along the island of Öland to Birka, a rich trading center. In the 8th and first half of the 9th century CE, goods came to Birka from Frisia, western Europe, regions south of the Baltic Sea, and the rest of Scandinavia. In the late AD 800s, this pattern changed and goods from the Baltic Sea area and further east were predominant. Even items from the Caliphate and Byzantium came to Birka.

Birka was the major Viking Age trading center in eastern middle Sweden, either founded by a king in order to control and expand trade (Ambrosiani, 2002, 2016a) or the settlement emerged from a seasonal trading place (Kalmring, 2016a) around AD 750. Birka was also the site of the first recorded Christian congregation in eastern middle Sweden, established ca. AD 830 by Saint Ansgar in an unsuccessful attempt to bring Christianity to the north. The town flourished for more than 200 years until it was abandoned ca. AD 975. Around the same time, Sigtuna was founded as a Christian town some 35 km to the northeast.

The Viking Age settlement of Birka has been a UNESCO World Heritage Site since 1993. One travels to Birka by boat. The island was smaller in the Viking period and consisted of two smaller islands that

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Fig. 1. The location of Birka, sample sites, modern towns and cities (red dots), and the Mälaren region in east-central Sweden. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

joined together as a result of changes in the elevation of the land. The southern part of the present island was separate as the former island of Grönsö. The rebound of the land surface has raised the island 5 m since the Viking occupation, increased its size, and joined the two smaller islands into one.

The first view of the island from the water is of its highest point, Borgberget, an area of bare rock where an oval hillfort of earth and stone was built (Fig. 2). The walls of this structure are 8–15 m in width, with three gates to the north and south, and one east toward the former town. Just below the north gate of the hillfort was the garrison for the fortress.

Population estimates for Viking Birka are between 500 and 1000 people. The Viking settlement itself was at the foot of Borgberget, at the north end of the island, and covered an area of about 12 ha (Ambrosiani, 2013). This zone of residence, manufacturing, and trade has been described as the Black Earth area because of its dark, sooty soils and heavy organic content, a result of dense human settlement during the Viking period (Fig. 3). The houses found in Birka's town area

Fig. 2. The heights of Borgberget and the hillfort walls on the island of Björkö, home of Birka (Creative Commons, Jan Norman/*Riksantikvarieämbetet*).

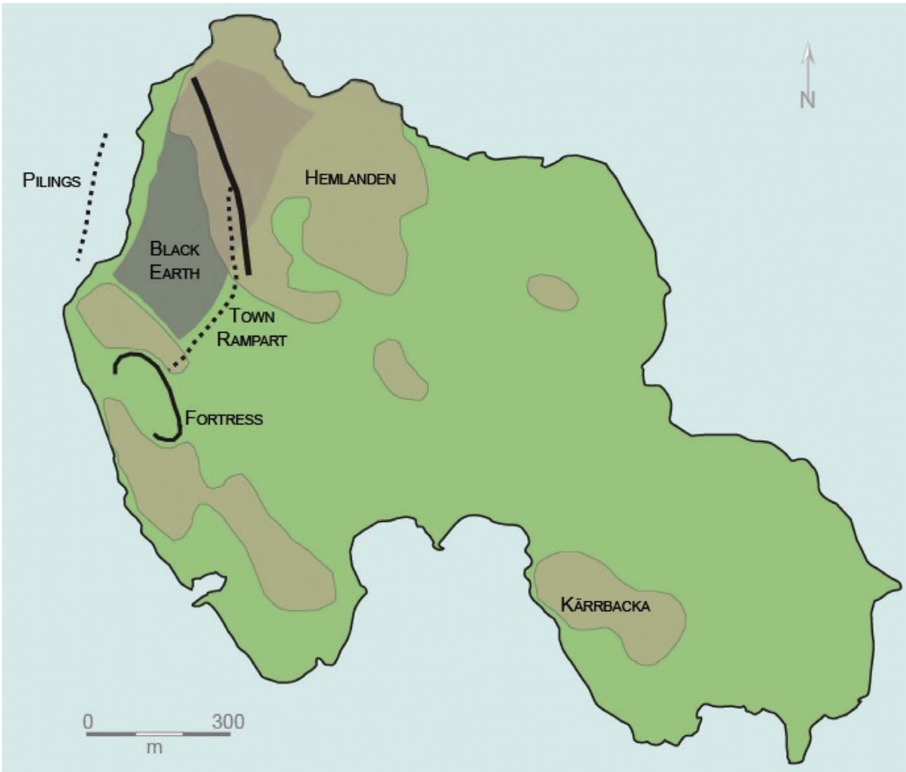

Fig. 3. The island of Björkö and some of the major features. The light brown areas are cemeteries.

used various construction material between the load bearing wall posts: wattle-and-daub, vertical split planks (staves), or horizontal planks. These building techniques could also be mixed. Some of the houses were used for dwelling, while others served as market booths and workshops (Ambrosiani, 2013). Crafts people in the town produced jewelry of bronze and other precious metals, beads, and textiles, as well as bone and horn objects. Adjacent to the town area, stone-built terraces for larger buildings can still be seen on several slopes (Holmquist-Olausson, 1993; 1998; Ambrosiani, 2016b). The nearby island of Adelsö was the location of a magnate estate called Hovgården that probably housed the king and his retinue when they visited Birka. More recently a new manorial estate has been identified on Björkö itself at the bay of Korshamn (Kalmring et al., 2017).

According to early historical descriptions, the town was fortified and the harbor was protected by a dense line of wooden pilings. The rampart around the settlement itself was 7–12 m wide and at least 2 m high. Regular openings in this defensive wall may have held fortified wooden towers in the Viking period. Adjacent to the Black Earth harbor there were at least two harbors, two natural ones to the north of the town and an artificial harbor enclosed by pilings to the garrison on the town's western shore. Yet another harbor might have been situated on the eastern side of Björkö (Bäck, 2012).

The first excavations at Birka were done in the 17th c. AD and have continued sporadically since. The harbor area has recently been a focus of underwater excavations and the discoveries continue. Many well-preserved artifacts are coming from the sea floor. Excavations continue today in the part of the harbour basin situated on dry land (Holmquist and Kalmring, 2015).

As a major center of trade, Birka probably offered furs and iron goods, in addition to craft products, in exchange for various materials from much of Europe and western Asia (Ambrosiani, 2016). These furs were obtained from the Sami, Finns, and people in northwestern Russia as well as local trappers and included bear, fox, marten, otter, beaver and other species. Many examples of foreign goods have been found in the graves at Birka including glass and metal ware, pottery from the Rhineland, clothing and textiles including Chinese silk, Byzantine embroidery with extremely fine gold thread, *passementerie* — heavy gold brocades, and plaited cords of the finest quality. Some of the brocades were imported, while others are clearly Scandinavian of equally fine quality (Larsson, 2007).

Other Scandinavian goods traded at Birka included reindeer antler and items made of antler such as hand-carved combs, walrus teeth, amber, and honey. Coins minted at Haithabu in northern Germany and elsewhere in Scandinavia appear as early as the ninth century at Birka. However the vast majority of the coins found at Birka are dirhams — silver coins from the Caliphate. English and Carolingian coins are rare. A unique find is a counterfeit golden dinar (Gustin, 2004; Rispling, 2004).

Birka disappears from history about AD 975. Political and administrative functions moved northeast to Sigtuna, the medieval successor of Birka, which flourished as a royal town, bishop's seat, and commercial center for the next 250 years. Birka's function as the center of Baltic trade was taken over by the island of Gotland.

2. Skeletons, Burials, and Graves

2.1. Human remains from Birka

There are several aspects of the human remains from the site of Birka that need to be discussed before further consideration or analysis. First of all, preservation of the remains was generally very poor so that identification of sex, age, and pathology was problematic. Chamber graves generally exhibited somewhat better preservation than simple inhumations. Second, both inhumations and cremations were present among the burial remains. Age and sex information was not available from cremated remains as they have not been analyzed.

Third, the human remains used in this study come from only a few of the numerous burial areas at the site. Almost all of the burials came from either Hemlanden or Norr om Berg (Fig. 5). There is one individual from the Borg area, buried beneath the wall of the fortress, excavated in 1997. This burial was in a coffin beneath a large earthen mound, with a platform in front that contained the skeleton of a horse.

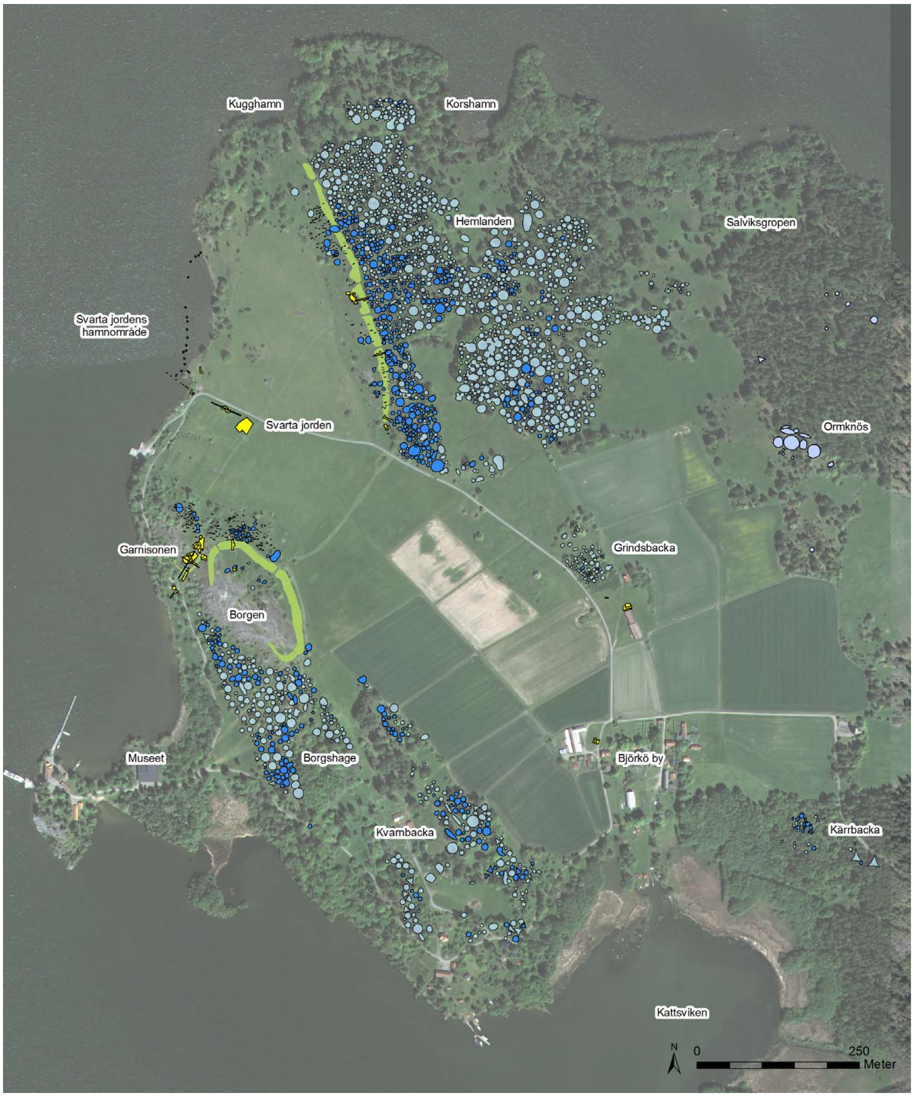

Fig. 4. Satellite photo of Birka with location of major features discussed in the text (image by Sven Kalmring, 2012).

In this study we refer to this burial as a coffin grave although it is very elaborate.

Fourth, the human remains from the site were relocated some years ago and there was an unfortunate mixing of some of the materials. For this reason, the association between the grave context and the actual human remains is not always reliable (Kjellström, 2016). We have indicated in Table 1 those 24 graves for which we are generally confident of an association between the human remains and the grave number. There is a column called Match which indicates a reliable association of grave number and skeletal remains. In these cases the bagged human remains and their grave number match the remains depicted by the excavator Stolpe in the original drawings and plans from the site from the end of the 19th c. (e.g., Stolpe, 1889). However, in spite of this, there will always be uncertainty that cannot be ignored and can never be resolved. Table 2 lists the contents of the graves with a reliable association with the skeletal remains.

According to previous reports, there were thought to be ca. 3000 graves at Birka (Gräslund, 1980). However, the latest investigations with new remote sensing by the Ludwig Boltzmann Institute for Archaeological Prospection in Vienna indicates that the number of graves is much greater, probably between 4500 and 5000 (Gunnar Andersson, personal communication).

Of the approximately 1110 excavated graves, ca. 544 were inhumation graves (Gräslund, 1980). The remainder (570) were cremation burials. Of the 544 inhumations, 246 graves contained preserved bone and dental remains that could be analyzed osteologically. The majority of the excavated inhumation graves originate from the large burial ground at Hemlanden. Unfortunately, the practice of cremation and the poor conditions for the preservation of bones have resulted in few details for most of the burials. Regarding the demography of the population, it has been possible to make only a general characterization based on the 246 individuals.

Table 1 lists the samples used in this study. Osteological age is given for a number of the burials. The age classes used in Table 1 are as follows: Infans I = 1–6 years, Infans II = 7–14 years, Juvenile = 15–19 years, Adult = 20–39 years, Mature = 40–59 years, and Senile = 60+. The latest osteological analysis shows that 11% (28 of 246) are subadult, 89% being adults. There is little information about individuals over 60 years of age (Kjellström, 2016). Male or female identification has been attempted for 96 of the 218 adult individuals and appears evenly distributed with 47 women and 49 men identified (Kjellström, 2016). There is no information regarding stature, again due to poor conditions for preservation.

Identification of the sex of the samples used in our analysis is based on the 37 individuals from inhumation graves, with 13% being juveniles. Nearly half of the children in Birka died before the age of ten. Tooth eruption and wear was employed for ageing the individuals (Buikstra and Ubelaker, 1994). In our sample where sex could be determined, adult males dominate; there were 12 males and 6 females. The estimate was based mainly on secondary sexual characteristics of

Table 1
Samples used in this study. Context provides the grave or field number for the sample. Match indicates a reliable association between grave number and skeletal remains. Type refers to the nature of the burial with the following coding: C = cremation Co = coffin, Ch = chamber grave, I = inhumation, and F = flat grave. Area refers to the location of the burial in the various grave yards at Birka as shown in Fig. 5. Age is given with the following age classes: na = indeterminate, Inf I = child 1–6 years of age, Inf II = 7–14, J/A = Juvenile = 15–19 /Adult = 20–39, M = mature = 40–60. Gender refers to the sex of the individual as suggested by the archaeological contents. When sex determination was not possible from contents we have used the information from the table in Arbman, 1943. Finland? indicates whether the grave included possible contents from Finland, including a distinctive fire starter, pottery, or pegged penannular beads. The isotopic ratios for strontium ($^{87}Sr/^{86}Sr$), carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) appear in the last three columns.

Lab#	Province	Parish	Site	Context	Match	Type	Area	Species	Age	Sex	Gender	Finland?	Sr	C	O
F9796	Uppland	Skuttunge	Eke 6:1			C		Dog					0.7225		
F9954	Uppland	Aliske	Grave XI					Rodent					0.7252		
F9952	Uppland	Norrsunda	Åhusby	anl 514				Rodent					0.7256		
F9794	Uppland	Stavby	Jönninge	2		C		Dog					0.7303		
F9953	Uppland	Fresta	Grimsta	A:5 F 91				Sheep/goat					0.7307		
F9792	Gästrikland	Valbo	Hemlingby	1		C		Dog					0.7316		
F9951	Gästrikland	Valbo	Lund					Sheep/goat					0.7637		
F9791	Gästrikland	Valbo	Hemlingby	1	yes	C		*H.s.*	na	na		F	0.7211		
F9790	Gästrikland	Valbo	Järvsta	Feature 34	yes	C		*H.s.*	na	na		F	0.7235		
F9795	Uppland	Stavby	Jönninge	Grave 2	yes	C		*H.s.*	na	na		F	0.7246		
F9793	Uppland	Alsike	Tuna	Grave XI	yes	I		*H.s.*	na	na		F	0.7249		
F9797	Uppland	Fresta	Grimsta	5	yes	C		*H.s.*	na	na		F	0.7253		
F9798	Uppland	Norrsunda	Valsta	18, 266	yes	C		*H.s.*	J/A	F		F	0.7290		
F7760	Uppland	Adelsö	Birka					Rodent 2 (brown rat?)					0.7251		
F7762	Uppland	Adelsö	Birka					Rodent 4 (black rat?)					0.7265		
F7759	Uppland	Adelsö	Birka					Rodent 1 (black rat?)					0.7272		
F7761	Uppland	Adelsö	Birka					Rodent 3 (vole)					0.7280		
F6564	Uppland	Adelsö	Birka	566:01	No	I	2A	*H.s.*	M	M			0.7103	−14.4	−3.7
F6559	Uppland	Adelsö	Birka	1012:II	No	I	1A	*H.s.*	A	M			0.7110	−14.9	−3.9
F7755	Uppland	Adelsö	Birka	585	Yes	Ch	2B	*H.s.*	A	F?			0.7114	−14.3	−4.0
F8082	Uppland	Adelsö	Birka	Borgvall 1997	Yes	Ch	3	*H.s.*	A	M			0.7127	−12.8	−4.9
F6556	Uppland	Adelsö	Birka	1097	No	I	1A	*H.s.*	A	F?			0.7127	−16.3	−2.2
F6558	Uppland	Adelsö	Birka	1012:I	No	I	1A	*H.s.*	A	?			0.7128	−15.5	−4.4
F7736	Uppland	Adelsö	Birka	869	No	C	1C	*H.s.*	na	F			0.7141		
F7743	Uppland	Adelsö	Birka	605b	No	I	2A	*H.s.*	A	?			0.7148	−14.6	−4.0
F6565	Uppland	Adelsö	Birka	566:02	No	I	2A	*H.s.*	A	M			0.7155	−14.9	−5.3
F6561	Uppland	Adelsö	Birka	275	No	I	?	*H.s.*	A	?			0.7162	−15.0	−4.5
F6560	Uppland	Adelsö	Birka	566:03	No	I	2A	*H.s.*	A	F?			0.7167	−15.1	−5.7
F7749	Uppland	Adelsö	Birka	841	Yes	Co	1C	*H.s.*	A	F			0.7170	−14.0	−3.8
F7752	Uppland	Adelsö	Birka	950	No	I	1A	*H.s.*	Inf II	?			0.7175	−15.1	−4.7
F7742	Uppland	Adelsö	Birka	557:II	No	I	2A	*H.s.*	A	F?			0.7176	−16.1	−7.4
F7753	Uppland	Adelsö	Birka	512b	Yes	unk	2A	*H.s.*	J/A	?	M		0.7176	−15.8	−3.0
F7747	Uppland	Adelsö	Birka	642	No	I	2A	*H.s.*	Inf II	?			0.7178	−14.5	−3.8
F9800	Uppland	Adelsö	Birka	644:I	Yes	I	?	*H.s.*	A	M			0.7181	−15.3	−6.4
F7744	Uppland	Adelsö	Birka	1036	Yes	Co	1A	*H.s.*	Inf I	?			0.7181	−15.1	−6.1
F6557	Uppland	Adelsö	Birka	1030	No	I	1A?	*H.s.*	A	M			0.7185	−16.1	−5.4
F7739	Uppland	Adelsö	Birka	141	Yes	C	1B/E	*H.s.*	na	na			0.7186		
F7754	Uppland	Adelsö	Birka	946	Yes	Ch	1A	*H.s.*	A	?	F		0.7189	−15.2	−6.7
F7748	Uppland	Adelsö	Birka	804	Yes	Ch	1C	*H.s.*	A	?	M		0.7189	−15.9	−4.3
F7735	Uppland	Adelsö	Birka	114	Yes	C	1B/E	*H.s.*	M	na			0.7200		
F7738	Uppland	Adelsö	Birka	930	Yes	C	1B/E	*H.s.*	na	na			0.7201		
F7763	Uppland	Adelsö	Birka	620	No	I	2?	*H.s.*	A	M			0.7209		
F7745	Uppland	Adelsö	Birka	770	Yes	Co	1C	*H.s.*	Inf II	?	F		0.7225	−16.2	−5.8
F7741	Uppland	Adelsö	Birka	638	Yes	Co	2B	*H.s.*	A	?	F		0.7228	−14.6	−6.2
F7737	Uppland	Adelsö	Birka	1015	Yes	C	1A	*H.s.*	na	na			0.7242		
F9801	Uppland	Adelsö	Birka	644:2	Yes	I	2A?	*H.s.*	A	F		F	0.7247	−16.5	−3.6
F6563	Uppland	Adelsö	Birka	967	Yes	Ch	1A	*H.s.*	A	F?			0.7267	−15.0	−5.9
F7751	Uppland	Adelsö	Birka	557:I	No	I	2A	*H.s.*	A	F?			0.7267	−15.5	−5.4
F7740	Uppland	Adelsö	Birka	643	Yes	Ch	2A	*H.s.*	A	?	M		0.7280	−15.6	−4.1
F7746	Uppland	Adelsö	Birka	793	Yes	Co	1C	*H.s.*	Inf I	?			0.7281	−15.3	−6.0
F9802	Uppland	Adelsö	Birka	834	Yes	Ch	?	*H.s.*	A	?		F	0.7285	−9.2	−5.3
F9804	Uppland	Adelsö	Birka	954	Yes	Ch	?	*H.s.*	M	M		F	0.7288		
F9803	Uppland	Adelsö	Birka	860b	No	I	1?	*H.s.*	A	?			0.7295	−15.2	−5.3
F7757	Uppland	Adelsö	Birka	607:II	No	I	2A	*H.s.*	M	?			0.7305	−14.7	−6.0
F9805	Uppland	Adelsö	Birka	1053	Yes	Ch	?	*H.s.*	A	?	M	F	0.7309		
F7756	Uppland	Adelsö	Birka	865	No	I	1C	*H.s.*	A	M			0.7323	−16.0	−4.7
F7750	Uppland	Adelsö	Birka	962	Yes	I	1A	*H.s.*	J/A	M			0.7330	−15.8	−5.3
F6562	Uppland	Adelsö	Birka	496	Yes	Ch	2B	*H.s.*	A	M			0.7335	−15.4	−5.2
F7758	Uppland	Adelsö	Birka	855	Yes	Ch	1B	*H.s.*	A	M			0.7343	−15.3	−3.9

the cranium.

2.2. Birka cemeteries and graves

In spite of these limitations, the many graves on the island are a rich source of information. There are a number of different graveyards (Figs. 4 and 5). Hemlanden, just outside the settlement to the northeast, is the largest Viking period cemetery in Scandinavia and contains at least 1600 earthen mounds of varying size. Approximately 670 of these have been excavated (Figs. 6 and 7). North of the Borgberget fortress, on the slope of hill, lies the cemetery of Norr om Borg (Fig. 6), an area of numerous graves and mounds in a prominent and elevated, visible position at the site. The Kärrbacka cemetery lies 1 km southeast of Hemlanden and contains more than 30 stone settings, 14 of which have

Table 2
Graves with associated skeletal remains. Contents.

Grave	Weapons					Horse			Dress & Jewelry					
Object	Arrowhead	Sword	Spear head	Axe	Shield	Horse skeleton	Horse equipment	Stirrup	Oval brooch	Round brooch	Other brooches	Penannular brooch	Beads	Passementeri-e
Mälaren														
Järvsta 34												x		
Hemlingby 1									x		x	x	x	
Tuna i Alsike	x					x						x		
XI														
Jönninge 2													x	
Grimsta 5													x	
Valsta 18							x						x	
Birka														
114	x			x										
141														
496	x	x	x		x		x							x
512b	x													
585									x				x	
638										x				
643		x	x		x							x		x
644:I, II	x	x	x	x	x		x	x	x	x		x	x	
770													x	
793														
804 A												x		
834	x	x	x		x	x	x		x	x	x	x	x	
841										x	x			
855	x	x	x		x							x	x	
930														
946									x	x			x	x
954							x		x		x	x	x	
962												x		x
967									x	x			x	
1015													x	
1036	x											x		
1053	x				x							x		
Borgvall 1997						x								

Grave				Miscellaneous Equipment										
Object	Pendant	Ringed pin	Belt Buckle	Strike-a-lite	Crampons	Whetstone	Pottery	Scissors	Bucket	Key	Awl	Knife	Button	Mount
Mälaren														
Järvsta 34														
Hemlingby 1					x		x	x	x	x		x		
Tuna i Alsike				x		x						x		
XI														
Jönninge 2					x		x							
Grimsta 5							x							
Valsta 18				x	x		x							
Birka														
114							x					x		
141							x							
496	x	x				x	x					x		
512b		x										x		
585							x	x		x		x		
638												x		

(continued on next page)

Table 2 *(continued)*

Grave				Miscellaneous Equipment										
Object	Pendant	Ringed pin	Belt Buckle	Strike-a-lite	Crampons	Whetstone	Pottery	Scissors	Bucket	Key	Awl	Knife	Button	Mount
643		x										x		
644:I, II				x		x	x	x	x		x			
770								x				x		
793												x		
804 A						x						x		
834							x	x	x		x	x		
841												x		
855					x		x					x		
930							x							
946	x							x		x				
954	x					x				x	x	x		x
962				x								x	x	
967	x			x				x	x	x		x		
1015							x				x			
1036												x		
1053												x		
Borgvall 1997			x									x		x

Grave					Various								Other Objects
Object	Balance	Weights	Tweezers	Needle Case	Coins	Comb	Glass	Dog	Bird	Gaming Piece	Pouch	Finnish Connection	
Mälaren													
Järvsta 34						x						x	Pegged Penannular Brooch
Hemlingby 1			x	x		x						x	Pegged Penannular Brooch, Baltic Finnish pottery, ear pick, strap fitting, strap divider, shrine, iron hook,
Tuna i Alsike XI						x		x	x	x		x	Permian strike-a-lite
Jönninge 2												x	Baltic Finnish pottery, 5 bronze rings, silver plate, bronze chain
Grimsta 5												x	Baltic Finnish pottery
Valsta 18					x	x						x	Permian strike-a-lite
Birka													
114						x							
141													
496		x			x		x						
512b													wooden box lock, wooden lid, shrine
585				x									
638													

(continued on next page)

Table 2 *(continued)*

Grave					Various								
Object	Balance	Weights	Tweezers	Needle Case	Coins	Comb	Glass	Dog	Bird	Gaming Piece	Pouch	Finnish Connection	Other Objects
643		x											
644:I, II	x	x			x	x	x				x	x	Permian strike-a-lite, gaming pieces, mirror, bronze vessel, wooden box, silver top for hat
770													
793		x				x							
804 A		x			x						x		
834			x	x	x						x	x	Baltic Finnish pottery, Rod, box, chain, hooks
841				x									
855		x									x		
930													
946			x										bronze needle, silver ribbon around the head
954		x			x							x	Pegged Penannular Brooch (Thor's Hammer)
962		x											
967		x	x	x	x								wooden box
1015					x	x							
1036		x											bronze armlet
1053					x							x	Pegged Penannular Brooch
Borgvall 1997			x								x		Fragments of Tatinger jug, West Slavonic pottery, wasp bead

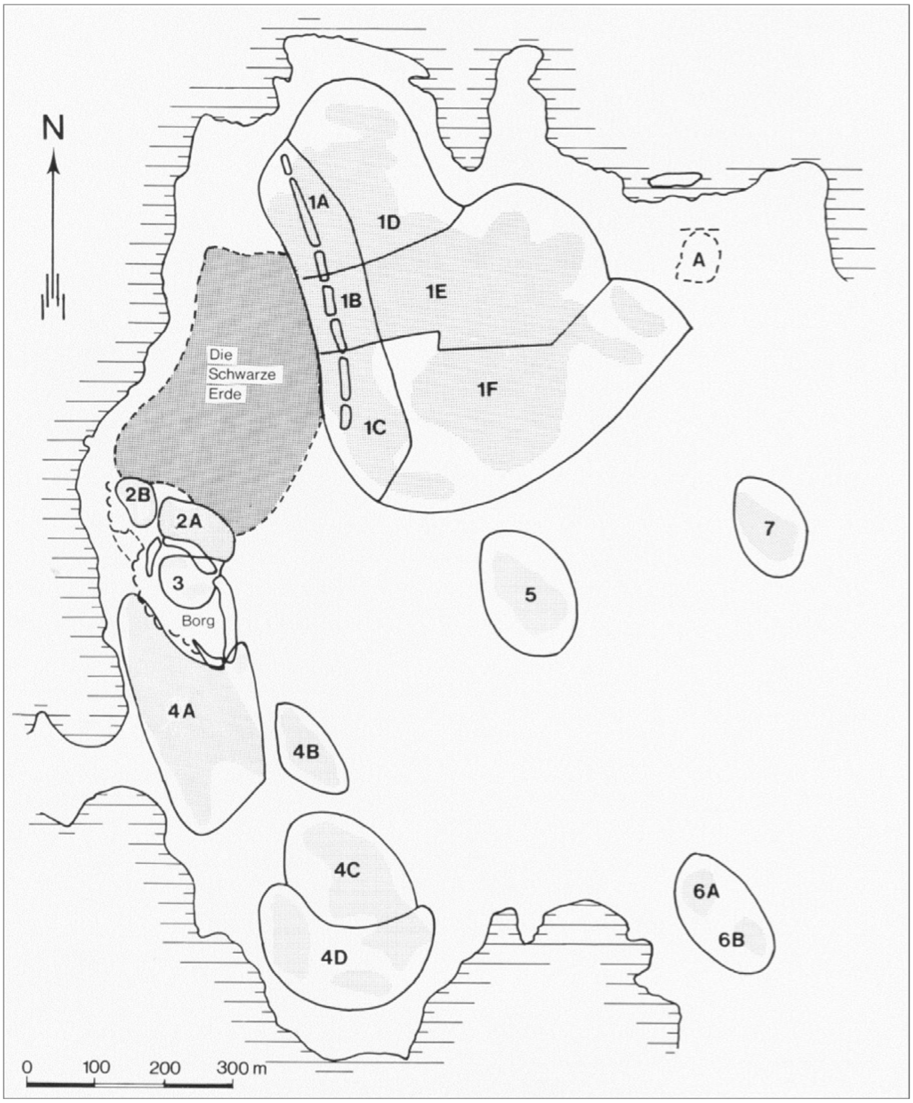

Fig. 5. Graveyards and burial areas at Birka (after Arwidsson, 1984, preface): (1) Hemlanden, (2) Norr om Borg, (3) Borg, (4) Borgshage/ Kvarnbacka, (5) Grindsbacka, (6, Kärrbacka, and (7) Ormknös. Numbered subareas indicated on the map are listed for grave location in Table 1.

Fig. 6. A multitude of burial mounds at Hemlanden. (Creative Commons, photo by Jonathan Olsson).

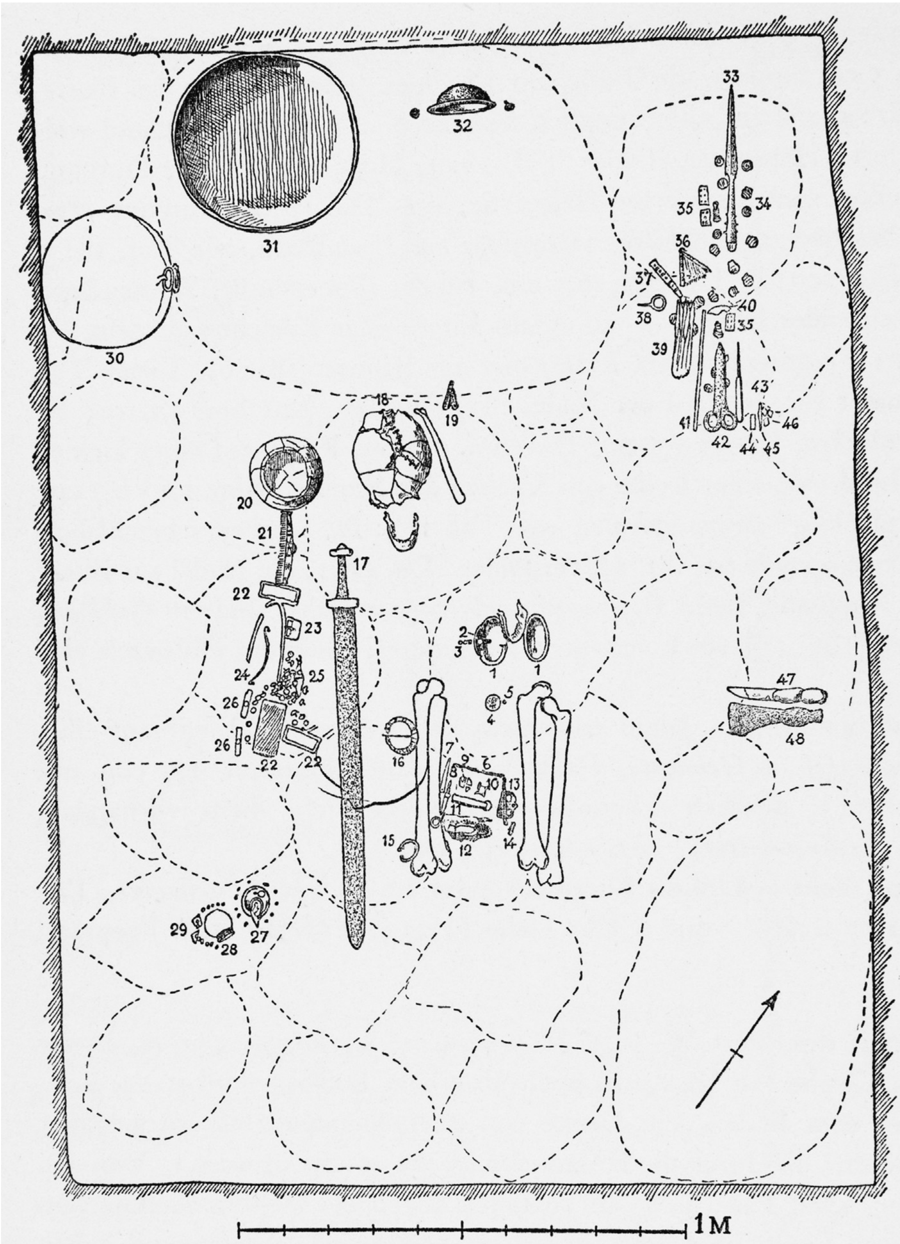

Fig. 7. Chamber grave 644 at Birka. (Original drawing from Arbman, 1943).

been excavated (Arbman, 1939; Gräslund, 1980; Kyhlberg, 1980). There are several other cemeteries, as well as isolated graves, in various parts of the island (Fig. 6). There are designated areas within these cemeteries shown in Fig. 6 and listed in Table 1 for grave location.

There were several types of burials found, reflecting a variety of traditions. Cremations were a common treatment of the dead, with the ashes placed under a small mound or ship-shaped stone enclosure. More than half the excavated burials at Birka were cremations (Gräslund, 1980). Generally cremations have been thought to represent a pre-Christian tradition common in Central Sweden during the period of Birka's occupation (Gräslund, 1980; Ambrosiani, 2005a, 2005b). Thus, it has been argued that the cremation burials on Björkö represent members of the local population (e.g., Leciejewicz, 1956).

In her thesis regarding burial customs at Gräslund (1980), Gräslund maintained that both those buried in cremation graves and many of those in inhumation graves belonged to the indigenous population. According to her, it was also likely that some of those buried in inhumation graves were foreigners, either from other parts of Scandinavia or from countries outside Scandinavia. It was, however, not possible to identify specific graves as non-local (Gräslund, 1980).

There is a general problem involved in the identification of burials of non-local people based on burial customs and grave goods. This can be illustrated by the chamber graves. It has sometimes been suggested that these graves represent foreign merchants and their families. However, oval brooches were found in nearly all the excavated chamber graves containing women. This type of jewelry indicates that the women were dressed according to the local Scandinavian tradition when they were buried (Gräslund, 1980). For males in chamber graves, it is generally harder to suggest regional affiliations based on dress and other grave goods. It is actually not clear if the persons buried in chamber graves, as Gräslund rightly pointed out, were distinguished by ethnic, economic, political or other considerations compared to other burials on Björkö (Gräslund, 1980). This ambiguity emphasizes the need for new methods and information in order to learn about the origins of the people interred on this island.

Various types of inhumation burials have been identified — graves with coffins, graves without coffins (flat graves), and chamber graves (Gräslund, 1980), sometimes with rich content (Fig. 7), sometimes with very few or no grave goods. There are chamber graves with and without accompanying mounds. The chamber graves are usually found in prestigious areas of the site, north of the hillfort and near the town rampart. The large, timber burial chambers often contained the bodies of men, but nearly as many women were buried in this type of grave (Gräslund, 1980). Some of the most well-equipped chamber graves contained a man and a woman, perhaps a wife. In these graves weapons, female jewelry, boxes, buckets, weights, game boards, horse gear, as well the remains of horses and dogs were found (Arbman, 1939). A number of examples of bone ice skates, iron ice picks, and crampons for shoes were found in the burials, documenting the long winter in eastern Middle Sweden.

Graves with wooden coffins occur primarily in Hemlanden and Norr om Borg. Women are in the majority In these inhumation graves (Gräslund, 1980). In some cases, a Christian cross and Thor's Hammer were found in the same grave, reflecting this transitional period in the religious life of the Vikings. It is hard to find evidence, however, for completely Christian graves or a Christian cemetery at Birka. However, there are some 15 distinct coffin and chamber graves found at the edge of the town. These burials are thought to be Christian interments because of a general absence of grave goods and the occasional presence of small crosses (Gräslund, 1980; Ambrosiani, 2005a, 2005b).

2.3. Graves with objects connected to Finland

The Mälaren area clearly had connections to a variety of other areas. One place of special interest for this study is Western Finland, since artifacts associated with that area have been found in graves at Birka and in the Mälaren valley. Several studies have also documented that pottery made according to a Finnish tradition (Baltic Finnish Pottery) was produced in Birka and other places in the Mälaren region. It seems likely that people familiar with the production of this ceramic material had moved to the Mälaren region (Gustin, 2017). Thus, one aspect of our study was to examine this possible connection to Western Finland. There were two other markers of possible Finnish connections. Permian strike-a-lights may have come from further east, but they appear to have passed through Finland before being exported to Sweden. Pegged penannular brooches ("penannular brooches with faceted and pegged knobs on the terminals", Fig. 8) are a distinctive dress ornament known to have been produced and worn in Western Finland, also recorded in the Mälaren region (Gustin, 2015, 2016, 2017; Roslund, 2017).

Most of the graves in the larger Mälaren region from this period are cremations and such burials provided five of the six samples with artifacts connected to Western Finland. There was one inhumation grave in the sample. At Birka, on the other hand, the four burials with Finnish artifacts (644:II, 834, 954 and 1053) were in chamber graves. Burials with artifacts with Finnish connections are indicated in Table 2.

Fig. 8. Penannular brooch with pegged knobs from grave 1053. Diameter of brooch is approximately 65 mm. (Photo by Eva Vedin, SHMM).

The one inhumation in the Mälaren region with an object related to the Finnish mainland was a male, found in *Tuna i Alsike* grave XI. In addition to more ordinary grave goods, this boat grave contained a strike-a-light with Finnish connections as well as a horse, a dog, and a bird.

Among the cremation graves with objects related to Finland, a very rich boat grave from Hemlingby in Gästrikland stands out. The grave was found in a big mound, together with other burials. The boat grave contained female dress details and additional equipment known from other richly furnished Mälaren graves. This boat grave also contained a pegged penannular brooch as well as Baltic Finnish pottery, both generally associated with Finland.

The graves at Birka with artifacts related to Finland include 644:II, 834, 954, and 1053. All of these were chamber graves. Grave 644 is located in the Norr om Borg cemetery, while the remaining three were found in Hemlanden. Grave 644 is one of the most spectacular chamber graves at Birka and includes both a man and a woman. The woman, 644:II, was buried with a strike-a-light with parallels in Finland. Grave 664:II is described in more detail in the section on local graves.

Grave 834 is a richly furnished chamber grave. Tooth wear suggested that the buried woman was between 20 and 39 years of age. In addition to the adult human, this grave contained the skeletons of two horses, many weapons, and a variety of female dress accouterments well known from the Mälaren region. In the grave there were also a number of other objects, including Baltic Finnish pottery and a very special long iron rod (Gustin, 2010). It has been assumed that rods of this type were either used for measurement or in connection with sorcery and witchcraft.

Grave 954, another rich chamber grave, contained a large number of female dress and personal items of the Mälaren region type, as well as a pegged penannular brooch. From dress style and tooth wear it can be concluded that the individual in this grave was a woman between 40 and 59 years old.

Grave 1053, another chamber grave, was less well equipped compared to the previously mentioned graves from Birka. However it contained a knife, a comb and comb case, and a pegged penannular brooch of Finnish type, as well weapons that included a shield buckle and arrows. In this case the buried individual was a male aged between 20 and 39 years old.

Of the items related to Finland in this study, penannular brooches with pegs have the strongest connection to that region. In western Finland pegged penannular brooches were closely linked to male graves with weapons and seem to have been an important symbol for this group. Of those buried with items relating to the Finnish mainland in this study, the individual in grave 1053 is perhaps the one most likely to have migrated from this region, since this male had a pegged penannular brooch and was buried together with weapons. Isotopic evidence for the origins of these individuals is presented along with the discussion of the results from this study.

3. Isotopic analyses

Direct information on human mobility can be obtained from the measurement of certain isotopes in human tooth enamel and petrous bone. Strontium, lead, and oxygen are most commonly used in such studies. Human enamel has generally been used in isotopic proveniencing studies, but enamel is largely destroyed by high temperature in cremation fires and difficult to identify. The petrous bone often survives the fire and heat of cremation and can be retrievable in the remains. The petrous portion of the temporal bone forms during early childhood and is one of the hardest bones in the body. Harvig et al. (2014) documented a strong correlation between $^{87}Sr/^{86}Sr$ values in enamel and petrous bone. On the other hand, cremated remains are generally not reliable for light isotope measurements as the heat often fractionates carbon and oxygen isotopes. For this reason, carbon and oxygen isotope ratios were usually not measured on cremated individuals.

Strontium isotope ratios are measured as a signal of the geology of the area where an individual was born. Virtually all strontium in vertebrate organisms is found in the skeleton. Strontium is incorporated into bone and tooth as a substitute for calcium in hydroxyapatite. The enamel in teeth (and petrous bone) forms during infancy and early childhood and undergoes relatively little subsequent change. In geologically varied areas, differences in strontium isotope ratios between human teeth (and petrous bone) and local, baseline values can distinguish the presence of non-local individuals. Local strontium isotope baseline values can be determined by measuring archaeological fauna or even modern specimens in areas where preservation is poor. This information is compared to the isotope ratios in the archaeological tooth enamel or petrous bone. If the ratios are different then in all probability the individual in question was not born locally. The specific place of origin is often difficult to determine as different places can have the same or similar strontium isotope ratios, but it is sometimes possible to constrain a potential homeland using a combination of isotopic and archaeological information.

Oxygen isotopes have been used in a number of archaeological investigations of human mobility in Europe and elsewhere (e.g., Chenery et al., 2012; Evans et al., 2006). Oxygen isotopes enter human metabolism largely from drinking water, which comes primarily from rainwater. The oxygen isotope content of rainwater depends on climatic and environmental variables such as temperature, humidity, altitude, and distance from the large bodies of water which gave rise to the rainwater. Changes in the isotope proportions occur through the loss of ^{16}O with increased evaporation (Ayliffe and Chivas, 1990; Yurtsaver and Gat, 1981). Thus, oxygen isotope ratios in prehistoric human bone and enamel vary regionally due primarily to differences in rainwater.

Oxygen isotopes are measured as a ratio between ^{18}O and ^{16}O and the ratio (δ^{18}O) is reported relative to VSMOW (Vienna Standard Mean Ocean Water), expressed in parts per thousand (‰). Variation in δ^{18}O within sites is generally less than among sites, thus demonstrating a potential for the investigation of mobility and provenience (Pellegrini et al., 2016). At the same time there is a good deal of variation in oxygen isotopes in human enamel that is not understood, making this a less reliable method for examining movement (Lightfoot and O'Connell, 2016; Tuross et al., 2017).

Carbon is a major constituent of skeletal tissue, both bone and enamel. The isotopes of interest in studies of past diet are carbon 12 (98.89% in nature) and carbon 13 (1.1% in nature). The ratio of these two isotopes is recorded as δ^{13}C‰, a value in parts per thousand or per mil. This ratio in human tissue should reflect the relative importance of C_4 plants or marine foods as a dietary component. C_4 plants comprise those species that utilize a photosynthetic pathway that incorporates more of the heavier isotope (^{13}C). The majority of plants are C_3. As there are few C_4 species present in early European agriculture, with the exception of millet, variation in δ^{13}C is expected to indicate marine foods in the diet. Values in bone collagen reflect long-term diet in the individual. Values in tooth enamel reflect the diet of early childhood. In addition, collagen carbon in bone and dentine comes largely from the protein portion of the diet, while apatite carbon in enamel or bone offers a better reflection of whole diet (Ambrose and Norr, 1993).

A study by Linderholm et al. (2008) of a number of buried individuals at Birka examined the relationship between diet and status by comparing grave goods with carbon and nitrogen isotope ratios in the bone collagen. Nitrogen isotope ratios provide information on trophic level. A total of 24 burials were sampled —12 female, 9 males, and 3 of unknown sex. All were inhumation graves and 13 were found in chamber graves. Seven of the graves included weapons. The study concluded that there was substantial variation in diet within the categories of sex and status and some significant differences between categories. For example, individuals with weapons had slightly less negative carbon ratios, suggesting a somewhat higher marine component in their diet. Neither carbon nor nitrogen showed differences between the chamber and simple inhumation graves; thus status differences were argued not to be reflected in diet.

Isotopic analyses of tooth enamel and cremated bone from human burials at Birka were undertaken in the present study for information on both provenience and diet. Isotope ratios for strontium, oxygen, and carbon were measured in enamel. Only strontium was measured in the cremation burials, due to potential fractionation of the lighter isotopes. In addition archaeological faunal remains were measured for ^{87}Sr/^{86}Sr to determine baseline levels of this ratio at the site and in the surrounding region.

Samples were mechanically cleaned. For the bone, small fragments weighing approximately 0.25 g were repeatedly sonicated for 10 min at a time until the distilled water was clear. The process was then repeated in 5% acetic acid. The cleaned fragments were then ashed to powder for eight hours at 750 °C. For both bone and enamel samples, 2–5 mg of clean powder were dissolved in 5 M HNO_3 and the Sr fraction was purified using EiChrom SrSpec resin and elution with HNO_3 followed by H_2O. The Sr was then placed on single Re filaments and analyzed using a VG (Micromass) Sector 54 thermal ionization mass spectrometer (TIMS) at the University of North Carolina-Chapel Hill. Internal precision for ^{87}Sr/^{86}Sr analyses is typically 0.0006 to 0.0009 percent standard error, < ± 0.000006 > .

Several mg of powdered enamel of each sample was sent to the University of Arizona Isotope Geochemistry Laboratory where oxygen and carbon isotopes in enamel carbonate are measured simultaneously using an automated carbonate preparation device (KIEL-III) coupled to a gas-ratio mass spectrometer (Finnigan MAT 252). Powdered samples were reacted with dehydrated phosphoric acid under vacuum at 70 °C in the presence of silver foil. The isotope ratio measurement is calibrated based on repeated measurements of NBS-19 and NBS-18, The precision for these analyses is ± 0.1‰ for δ^{18}O and ± 0.06‰ for δ^{13}C (1 s.d.).

3.1. Baseline information from Sweden

The oldest rocks in Sweden are Archean (> 2500 million years old), but they occur only to a limited extent in the northernmost part of the country. Most of the northern and central parts of Sweden consist of Precambrian materials belonging to the Fennoscandian Shield, an ancient craton of mantle rock with generally high strontium isotope ratios. The Swedish Geological Service has measured ^{87}Sr/^{86}Sr across the country and reports very high rock values from much of this region, generally greater than 0.722. Further to the south, Phanerozoic sedimentary rocks rest on top of the Precambrian shield area. They are less than 545 million years old and cover large parts of the province of Skåne, the islands of Öland and Gotland, and several other small regions in Sweden. These deposits are often composed of marine sediments with ^{87}Sr/^{86}Sr values between 0.708 and 0.710. The youngest rocks in Sweden are Tertiary, formed about 55 million years ago. They occur in the most southerly and southwestern parts of Skåne.

In sum, the older rocks of the Fennoscandian Shield dominate most of Sweden and have high ^{87}Sr/^{86}Sr, above 0.711 and as high as 0.735 or more. These rocks are surficial and contribute to soil nutrients and hence to bioavailable strontium isotopes. Lower values around 0.710–0.711 are found only in the southernmost part of the country in the province of Scania, on the island of Gotland in the Baltic, and in a few areas along the coasts.

There are a few published ^{87}Sr/^{86}Sr values that provide some baseline information. Two sites reported by Frei et al. (2009) were measured on sheep wool from Dannås and Boserup in central-southern Sweden. The Dannås sheep (0.716) was grazing on pastures with soils developed on very old Precambrian basement gneisses typical of Swedish bedrock, while the Boserup sheep (0.711) fed on soils developed in sedimentary rocks from a Late Triassic–Early Jurassic marine flooding event. There is also some information from the remarkable

Mesolithic sites at Motala, ca.180 km southwest of the Mälaren region (Eriksson et al., 2016). Soil samples from the larger area north of Motala ranged from 0.731 to 0.743, ratios typical of a Precambrian bedrock environment. Motala itself is situated on younger Cambro-Silurian bedrock, mainly limestone, sandstone and shale, covered by glacial deposits. The local baseline at Motala was measured on soil and archaeological faunal samples and had a large range between 0.714 and 0.728.

Bäckström and Price (2016) report human and fauna $^{87}Sr/^{86}Sr$ values from Sala, a burial ground and mining town dating to the 16th c. in east-central Sweden, approximately 60 km west of Uppsala in an area known as Bergslagen. The Bergslagen domain hosts a variety of different ore deposits and is interpreted as a microcraton that docked to the Northern craton ca. 1.88–1.87 Ga (Weihed et al., 2005). Four faunal samples from the medieval village (bones of hare, chicken and cow, incisor of boar) were characterized by $^{87}Sr/^{86}Sr$ values > 0.7337 (average $^{87}Sr/^{86}Sr = 0.7364 \pm 0.0022$, 1 s.d.). Average $^{87}Sr/^{86}Sr$ in the local inhabitants buried at Sala was between approximately 0.720 and 0.725.

Lama (2015) used laser ablation to measure $^{87}Sr/^{86}Sr$ values in enamel from a human tooth from two boats graves at Tuna near Alsike, less than 10 km SSE of Uppsala and reports an average between 0.7189 and 0.7210 for the measurements which likely reflect the local baseline. Price (2013) reported several $^{87}Sr/^{86}Sr$ values in human enamel from east-central Sweden. Although the sample size was small and some of these humans may have been non-local, the results are informative. Values ranged from 0.732 at Björklinge (n = 3) (Fig. 1) to 0.715 in Stockholm (n = 2). Three values from Uppsala averaged 0.726. These mixed values were measured on samples from skeletons designated as 46 (0.7152), 62 (0.7261), and 133 (0.7388) from the site of Kv. Kroken, a medieval cemetery.

For this project we measured local archaeological fauna to obtain estimates of the strontium baseline at Birka and in the larger Mälaren region. From Björkö, the small island where Birka is located, we measured 4 archaeological rodents that averaged 0.7267 ± 0.0012 (1 s.d.) and provide a local baseline value for the island. Six of the seven faunal samples from the larger Mälaren region had an average value of 0.7277 ± 0.0037 and ranged between 0.7225 and 0.7316, similar in value to the rodents from Björkö. There was a single sheep tooth from the Mälaren region with an aberrant value of 0.7637 that has not been included in these calculations. These samples are described in more detail in Table 1 and their location is shown on the regional map in Fig. 1. A baseline for bioavailable strontium in the Mälaren region, including Birka, was established at 0.723–0.733 based on the distribution of faunal values seen in Fig. 9.

There is little information on ancient baseline oxygen isotope values. Modern oxygen isotope ratios vary from north to south in Sweden. Burgman et al. (1987) measured $\delta^{18}O_{SMOV}$ in precipitation and run-off from a number of sites in Sweden and published a map of estimated ratios for the entire country (Fig. 9). Values range from −14‰ in the north to −8‰ in the southwest. These $\delta^{18}O_{SMOW}$ values in Scania correspond to a range in $\delta^{18}O_{PDB}$ in enamel between approximately −5‰ and −9‰ (Chenery et al., 2012). Thus, more negative $\delta^{18}0$ values should be expected to the north.

3.2. Baseline information from Finland

Finland is composed largely of Precambrian rock and sediments, like much of northern Sweden, providing a basement of very old rocks over which Pleistocene ice developed and left a thick ground moraine. Northern Finland has some of the oldest rocks in Europe, dating to 3.5 Ga years ago. Typical types of rocks in that region are gneisses with greenstone. Most of the southern half of the country is composed of Svecofennian bedrock which originated in a period of mountain building ca. 1800 mya (Nironen, 1997), but has since eroded into a rather low, rolling landscape with basements composed of crystalline schists like quartzite, phyllites, and mica schist.

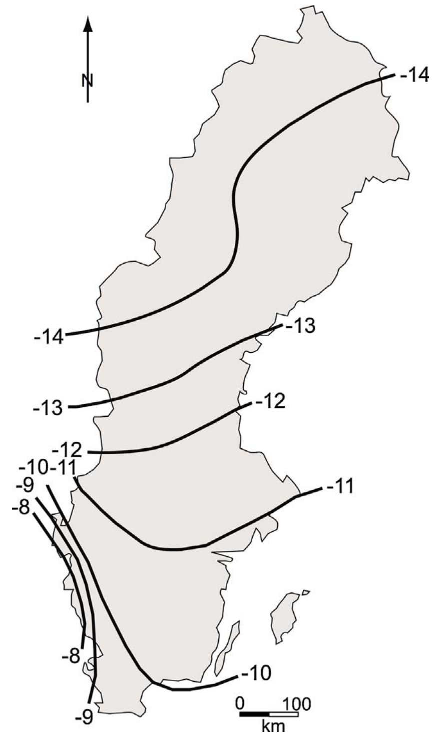

Fig. 9. Burgman et al. (1987) plot of $\delta^{18}0_{SMOW}$ from precipitation and run-off in Sweden.

The Finnish Geological Survey has compiled strontium isotope ratios in bedrock along with many other chemical values in its Rock Geochemical Database. Kaislaniemi (2011) described a range of values between 0.7135 and 0.7637 with a weighted average of 0.7293 for all of Finland. He noted that no systematic difference between Archaean and younger rocks can be seen in the estimated isotope ratios. At the same time, there is very little information on bioavailable values for $^{87}Sr/^{86}Sr$. Åberg et al. (1990; Åberg, 1995) reported values between 0.71–0.80 from lakes, rivers, soil, and trees of Finland and Sweden. The average $^{87}Sr/^{86}Sr$ ratio in the rivers on the Precambrian shield of Fennoscandia is estimated to be 0.730 (Löfvendahl et al., 1990). Negrel et al. (2003) report values between 0.720 and 0.735 in most of the samples from a lake in southwest Finland. In general, $^{87}Sr/^{86}Sr$ values around 0.730 would appear to be common in Finland.

Only a few archaeological strontium isotope ratios have been published from prehistoric Finland. From western Finland analyses have been made on an unburnt Bronze Age cattle tooth from Selkäkangas in Nakkila county. The Sr isotope value of ca. 0.730 was considered consistent with the expected range of $^{87}Sr/^{86}Sr$ for the region estimated from bedrock age and rock contents of Rb and Sr (Bläuer et al., 2013:13–17). Another analysis was made on a human dental sample from grave 7 in Maaria Kärsämäki cemetery in southwestern Finland. This was an inhumation grave dated to the 6th or 7th century CE. The $^{87}Sr/^{86}Sr$ value for this sample was 0.7292. According to this study, the value for the buried individual corresponds to ratios for northern Finland and Norrland or Svealand in Sweden rather than to values from southern Finland. According to a compilation of various studies, the Sr ratios for water and plants in southwestern Finland range from 0.7295 to 0.7450 (Moisio, 2015, appendix 20). Lower values in this range are similar to ratios reported from the Mälaren region.

4. Results of analyses

Two sets of human and faunal remains have been analyzed in this investigation, from the site of Birka itself and from the larger Mälaren region. The seven faunal samples from the Mälaren region were

Table 3
$\delta^{18}O_{enamel}$ values at other sites in Scandinavia (enamel PDB).

Statistic	$^{87}Sr/^{86}Sr$	$\delta^{13}C$‰	$\delta^{18}O$‰
Mean	0.72125	−14.99709	−4.96010
sd	0.0069	1.2595	1.1756
min	0.71026	−16.50000	−7.35201
max	0.73425	−9.19000	−2.15439
count	42	35	35

collected to provide a baseline for the larger area. The six human graves from the Mälaren region were selected because some of their contents likely originated in Finland and we attempted to determine if these individuals indeed came from that country. Several of the graves we investigated at Birka as part of this study also contained materials from Finland as previously discussed.

A total of 4 faunal and 42 human samples (5 cremations and 37 inhumations) from Birka were measured in this study. Basic information and isotope values for these samples are listed in Table 1. Carbon and oxygen isotope ratios were measured only on the enamel from 35 inhumations because of problems of contamination in cremated bone and potential fractionation of these lighter isotopes under conditions of heat.

4.1. Birka humans

The isotopic analysis of the Birka human remains produced 42 strontium isotope ratios and 35 values each for carbon and oxygen isotope ratios. Descriptive statistics for these measurements are provided in Table 3.

The strontium isotope analysis resulted in a wide range of values. The 4 samples of bone from archaeological rodents at Birka produced a mean of 0.7256 ± 0.0028. The 42 human samples averaged 0.7213 ± 0.0100. The 37 inhumation burials had an average $^{87}Sr/^{86}Sr$ value of 0.7215 ± 0.0072. The 5 cremation burials had an average $^{87}Sr/^{86}Sr$ value of 0.7194 ± 0.0036. A bar graph of these ratios appears in Fig. 10 and shows the variation that is present. The fauna and human graves from the Mälaren region with content related to Finland also appear in this graph.

The transparent red band in the graph marks the local bioavailable baseline for strontium isotope ratios at Birka and in the larger Mälaren region. Individuals within the band are likely local to Birka or at least the larger Mälaren region. The six individuals from the greater Mälaren region had a mean value of 0.7247 with a range from 0.7211 to 0.7290. The mean for these humans from the greater Mälaren region is similar to, only slightly higher than, the average from Birka.

The graph suggests that there were a number of non-local individuals buried at Birka. Cremation burials are slightly lower than the inhumations in terms of average $^{87}Sr/^{86}Sr$. The cremation graves show a range from 0.7141 to 0.7242, with three intermediate values around 0.720. The values from the inhumation burials are highly variable, with a large range from 0.7103 to 0.7343. There are two distinct groups among the inhumations, lower values below 0.723, and higher values above that break point. The higher group is the best candidate for the local population and fits nicely with the baseline bioavailable range. The geology in this part of Sweden is ancient and $^{87}Sr/^{86}Sr$ values in general are quite high. The higher group of values appears to have several subsets, three pairs of similar values. Among the sample of inhumations, 14 of 37 individuals would appear to be local to the general Mälaren area around Björkö, while 20 are likely non-local. There are a number of graves in this group of individuals including 496, 638, 643, 644:2, 770, 793, 834, 954, 967, 1015 and 1053). Some of these graves are considered in more detail below. There are also three individuals with $^{87}Sr/^{86}Sr$ values above the Mälaren baseline range (496, 855, 962).

The lower group of values in the bar graph has a number of values below 0.713 and then a larger set from 0.7123 to 0.723. Values around 0.710–0.713 are rare in most of Sweden and typical only of a few regions such as the island of Gotland and the extreme southwest corner of Scania in the south of the country. These low values are also characteristic of Denmark and much of the North European Plain (Frei and Price, 2012; Price et al., 2018). Individuals within this range are clearly non-local. There are two known graves associated with this group of low values. These are a chamber grave, 585, and a likely coffin grave, Borgvallen 1997. These graves are discussed in more detail below.

The group of individuals between 0.713 and 0.723 are a bit more difficult to assess, as there are a few other similar values known from the Mälaren and the Stockholm region. It is important to recall that the baseline bioavailable range for local $^{87}Sr/^{86}Sr$ values incorporates both Birka and the larger Mälaren region and is higher than 0.723. These individuals between 0.713 and 0.723 more than likely have their origins some distance from the Mälaren region. Three of the five cremation graves fall within this range of values. Discussion of specific graves in this group (141, 512b, 644:I, 804, 841, 930, 946 and 1036) appears below.

Another way to look at the data is with a histogram of $^{87}Sr/^{86}Sr$ values (Fig. 11). The highest mode around 0.717 reflects the large group of non-locals at Birka with similar $^{87}Sr/^{86}Sr$ values. The skew to the left marks the very low values discussed above. The two modes to the right of the highest mode represent the higher strontium values that are occur in two groups around 0.728 and values greater than 0.730.

Oxygen isotope ratios were measured in 35 inhumation burials from the Birka graves. These values ranged from −7.4‰ to −2.2‰ and had

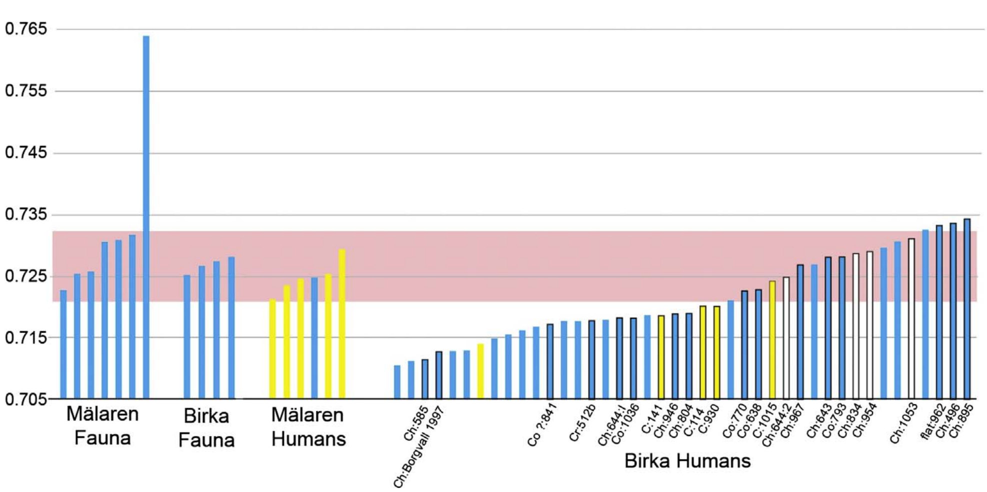

Fig. 10. Bar graph of ranked $^{87}Sr/^{86}Sr$ values for Mälaren and Birka fauna, Mälaren humans, and Birka humans. The red band marks the local baseline range for Mälaren and Birka. The very high value for a sheep/goat in the Mälaren fauna was considered aberrant and not used in other calculations in this study. The type of burial is indicated with the burial numbers: C = cremation Co = coffin, Ch = chamber grave, F = flat grave, ? = unknown. The white bars at Birka indicate graves with Finnish artifacts; the yellow bars indicate cremations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

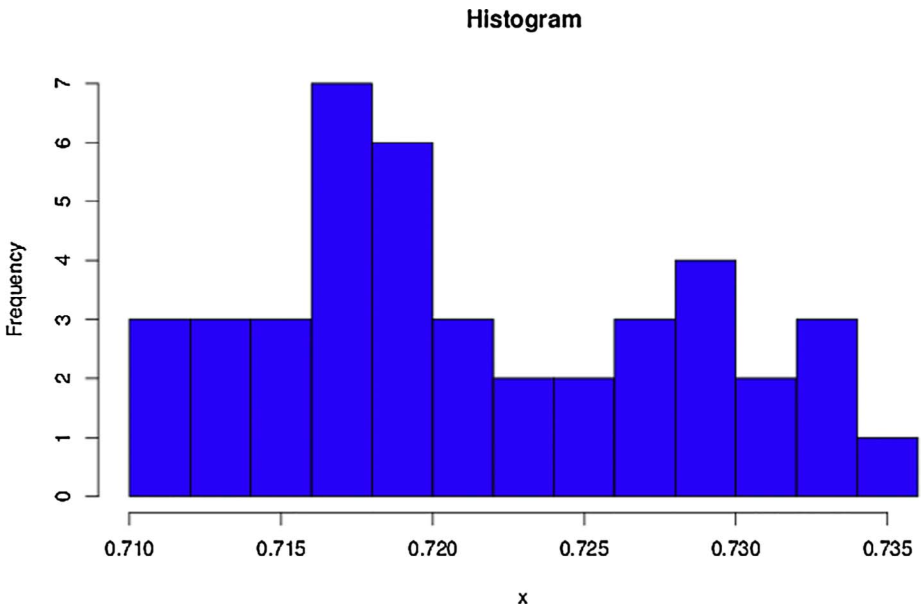

Fig. 11. Histogram for strontium values from human tooth enamel and petrous bone at Birka (n = 42).

a mean ± 1 s.d. of −5.0‰ ± 1.2. This is a wide range of variation and suggests that there were a number of non-local individuals among the sampled burials. The relationship between strontium and oxygen isotope ratios was examined using a bivariate kernel density estimate plot of both variables, shown in Fig. 12. Two groups and a number of outliers can be observed in this plot. $^{87}Sr/^{86}Sr$ values sort the two groups on the x-axis while $\delta^{18}O$ values appear to be similar, if slightly lower, in the group with higher strontium isotope values. These two large groups support the interpretation of local and non-local individuals and the slightly lower oxygen values in the non-local group point to a more southerly origin.

Wilhelmson and Price (2017) provided $\delta^{18}0_{en\ PDB}$ values for human enamel from various sites that provide some indication of the variation present in the past in northern Europe (Table 4). These values from Norway, Denmark and Sweden range from −4.0‰ to −6.3‰ and show relatively little variation across Scandinavia. There is a slight tendency toward more negative values to the north (Trondhiem, Hamar, Sala) as expected, but in general there is surprisingly little variation. The average for humans at Birka was −5.0‰.

In terms of carbon isotopes, the mean $\delta^{13}C_{enamel\ PDB}$ for the 35 samples was −15.0‰ ± 1.5. The low variation suggests a relatively homogeneous diet of largely terrestrial foods. Values were generally normally distributed with a range from −9.2‰ to −16.5‰ with one very aberrant outlier (−9.2‰, Burial 834). A standard scatterplot of strontium and carbon isotope ratios from the inhumations at Birka (Fig. 13) also shows two groups as well as the outlier, but these groupings primarily reflect the $^{87}Sr/^{86}Sr$ values, as the carbon isotope ratios are largely the same between the two groups, reflecting a similar childhood diet. There is somewhat greater variation in $\delta^{13}C$ among the group with lower $^{87}Sr/^{86}Sr$ values, suggesting more varied origins. The one individual with a much higher $\delta^{13}C_{en}$ (ca. −9.2‰) has a $^{87}Sr/^{86}Sr$ value that could be local to the Mälaren region, but the carbon value suggests a largely marine diet. The average $\delta^{13}C$ value at Birka of −15‰ is similar to other reported values from several sites in Scandinavia (Table 5), suggesting a largely terrestrial diet of domestic plants and animals. These results are in general agreement with the study of carbon and nitrogen isotope ratios in bone collagen by Linderholm et al. (2008).

5. Discussion

Birka was an important trading center during the early and middle part of the Viking period, located on a sheltered island in Lake Mälaren. It seems highly likely that human mobility would have been pronounced at Birka with the presence of sailors, traders, merchants, warriors, slaves, and others from various parts of the known world.

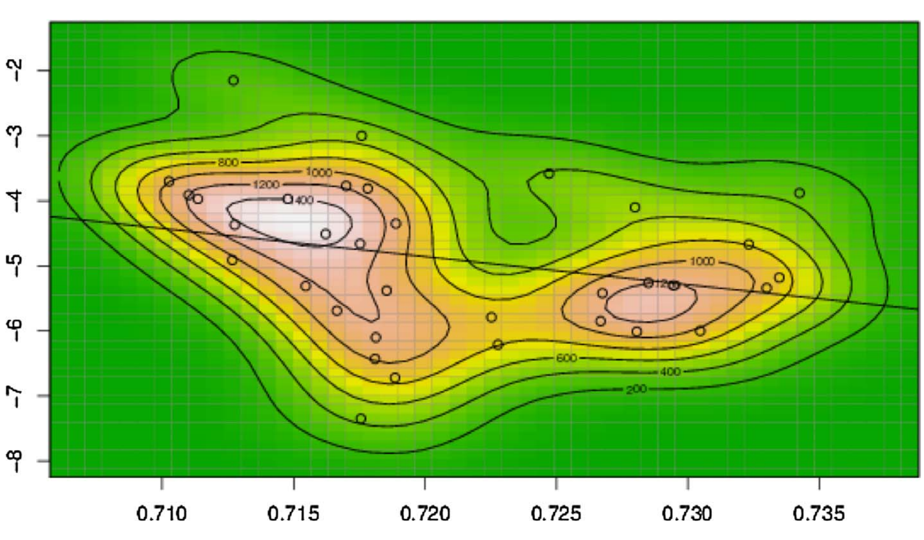

Fig. 12. Bivariate plot of kernel density estimates of oxygen (y-axis) vs. strontium isotope ratios for Birka burials (n = 35).

Table 4
Descriptive statistics for isotope measurements from Birka human remains.

Site	Co.	Age	n	Min‰	Max‰	Mean ± 1s.d.	Source
Hamar	N	IA	17	−7.7	−4.9	−6.3‰ ± 0.8	Unpubs.
Bryggen	N	IA	15	−5.3	−3.2	−4.3‰ ± 0.7	Unpubs.
Trondheim	N	IA	9	−7.6	−4.5	−6.0‰ ± 1.1	Unpubs.
Kopparsvik	S	V	44	−6.4	−2.5	−4.7‰ ± 1.1	Price et al. (2016)
Uppåkra	S	LIA	10	−6.8	−3.3	−5.0‰ ± 0.9	Price (2013)
Sala	S	Med	19	−8.3	−3.9	−6.3‰ ± 1.1	Price (2013)
Sebbersund	D	V	7	−4.7	−3.3	−4.0‰ ± 1.5	Price et al. (2012)
Trelleborg	D	V	41	−5.8	−1.7	−4.4‰ ± 0.7	Price et al. (2011)
Galgedil	D	LIA	34	−6.0	−2.5	−4.2‰ ± 0.7	Price et al. (2015)
Ndr. Grødbygaard	D	Med	36	−6.4	−3.6	−4.9‰ ± 0.6	Price et al. (2013)
Haithabu	G	V	53	−6.8	−2.7	−4.0‰ ± 0.8	Unpubs.

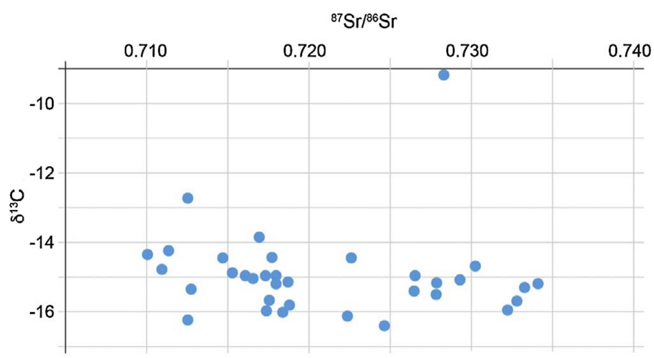

Fig. 13. Scatterplot of carbon vs. strontium isotope ratios for human enamel from Birka (n = 35).

Björko was a small island and it is likely that a number of the individuals buried at the site had come there during their lifetime. Moreover, it seems equally likely that the food supply for the island population must have come from a larger area than just the island itself. The baseline for $^{87}Sr/^{86}Sr$ is generally similar across this region of rather old geology, ranging between 0.723 and 0.733. Burials with values greater than 0.723 were likely local to Birka or the Mälaren region. Individuals with values below 0.723 were likely not local to the area, but rather foreigners who died and were buried among the other inhabitants of the island. In the following pages we describe and discuss some of the graves found at Birka and the likely origin of their inhabitants.

5.1. Local graves

There are a number of reliably identified graves in the group of local individuals including 496, 638, 643, 644:2, 770, 855, 967 and 1053. This group is comprised of chamber graves and two coffin graves (638 and 770). These graves contain men and women alike and they are found in both Hemlanden and Norr om Borg.

5.1.1. Grave 644

Among this group, Grave 644 stands out. It is a lavishly equipped chamber grave (Fig. 7) at Norr om Borg containing both a man (I) and a woman (II) buried with extraordinary grave goods (Fig. 14). The locations of the objects and skeletal remains in the grave indicate that the woman had been placed at the knees of the man (Arbman, 1943). Burial 644:I is a non-local adult male ($^{87}Sr/^{86}Sr$ = 0.7181). Among the objects accompanying him were several weapons (including a sword), horse gear and penannular brooches; a balance, a glass beaker and a mirror were found near the tip of the sword. Burial 644:II, the women in this grave, was a younger person, local to the Mälaren region ($^{87}Sr/^{86}Sr$ = 0.7247), wearing an elaborate dress design well known from eastern middle Sweden with gilded oval brooches, gilded round brooches, silver and gold passementerie, and golden bands. This individual was also buried with beads, an awl, a weight, a comb, a whetstone and a knife. In this case the number of objects was very high and included an exceptional number of gilded pieces of jewelry, indicating that the woman belonged to the elite. Moreover, this grave documents connections between the elite in Birka and Eastern Europe. A leather bag with gilded silver mounts, found in Grave 644, appears to have belonged to this woman. The same type of mounts are known from southeastern Europe (Gräslund, 1984). Yet another object indicating eastern contacts was a strike-a-light with a bronze handle in the form of two animal heads. Parallels are known from Finland and the area south of Lake Ladoga in Russia (Hårdh, 1984).

A local origin is also indicated for grave 638 and 770, both coffin graves. Most coffin graves found in Birka were women's graves

Table 5
$\delta^{13}C$ enamel from various sites in Scandinavia.

Site	Country	n	Min	Max	Mean ± sd	Source
Bryggen	Norway	24	−16.9	−11.3	−14.7 ± 1.7	Unpublished
Trondheim	Norway	9	−16.1	−14.5	−15.5 ± 0.6	Unpublished
Birka	Sweden	35	−16.5	−9.2	−15.0 ± 1.3	This Study
Fäslegården	Sweden	42	−15.5	−13.4	−14.4 ± 0.6	Sjögren et al. (2009)
Kopparsvik	Gotland, Sweden	44	−16.8	−10.2	−14.5 ± 1.4	Unpublished
Uppakra	Sweden	10	−15.8	−13.9	−14.5 ± 0.5	Price (2013)
Sebbersund	Denmark	7	−15.7	−12.0	−13.5 ± 1.4	Price et al. (2012)
Trelleborg	Denmark	41	−15.5	−12.8	−14.0 ± 0.7	Price et al. (2011)
Galgedil	Denmark	29	−15.5	−12.8	−19.7 ± 0.4	Unpublished
Ndr. Grodbygaard	Bornholm, Denmark	36	−15.3	−9.4	−13.6 ± 1.2	Price et al. (2013)
Haithabu	Germany	53	−16.9	−11.3	−14.4 ± 0.1	Unpublished
Fäslegården	Sweden	42	−15.5	−13.4	−14.4 ± 0.6	Sjögren et al. (2009)
Kopparsvik	Gotland, Sweden	44	−16.8	−10.2	−14.5 ± 1.4	Unpublished
Uppakra	Sweden	10	−15.8	−13.9	−14.5 ± 0.5	Price (2013)

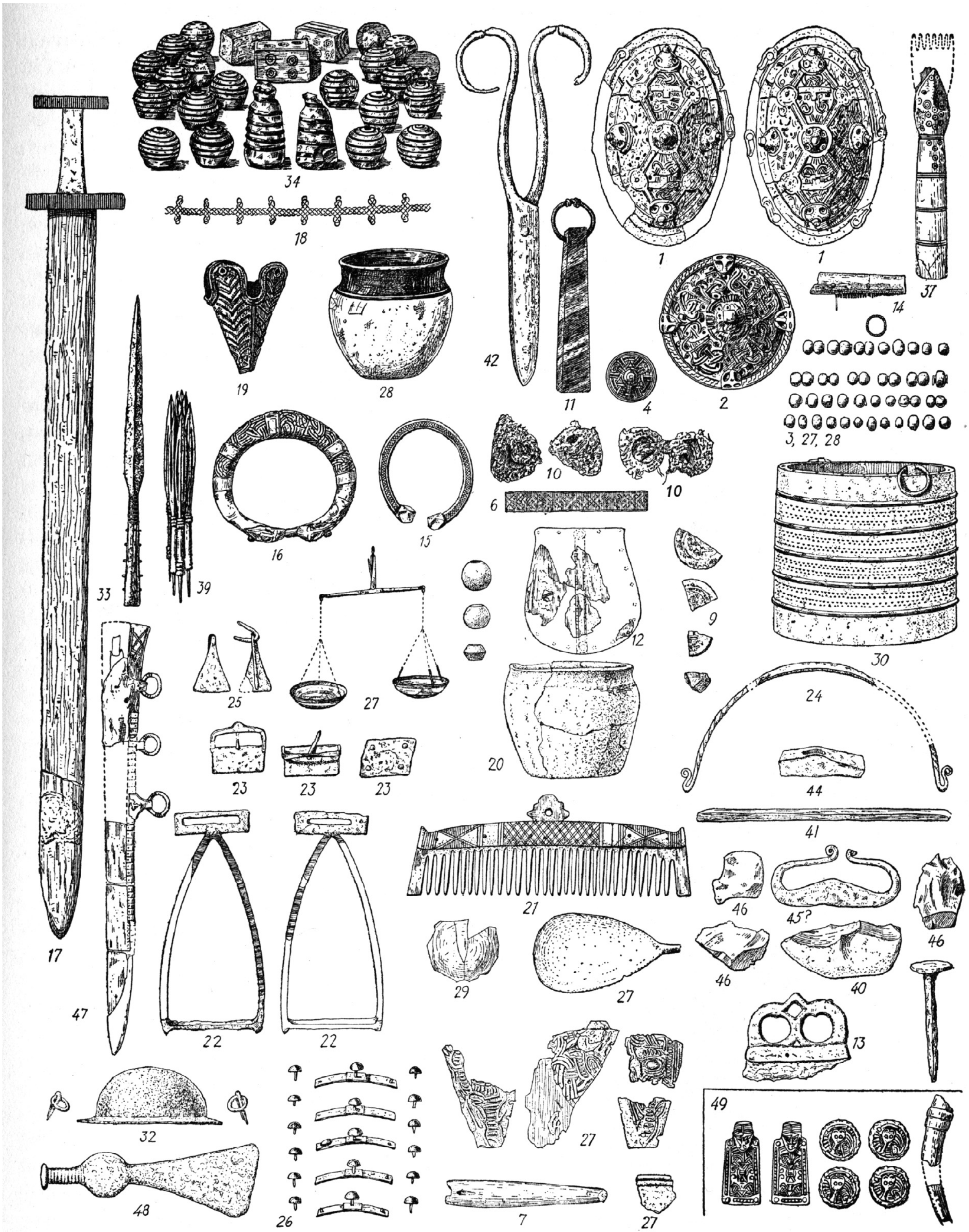

Fig. 14. Some of the contents of Chamber Grave 644. (Original drawing from Arbman, 1943).

(Gräslund, 1980). This was also the case for grave 638 and 770. However, many children and somewhat fewer men were buried in this type of grave as well.

Grave 638 was situated in Norr om Borg. The woman in this coffin was between 20 and 39 years of age. She was accompanied only by a few items: a gilded round brooch, a smaller gilded round brooch and a knife. Coffin burials with few or no grave goods have usually been interpreted as due to Christian influence (Gräslund, 1980).

The second coffin grave, 770, was found in Hemlanden. In this case, the coffin was placed beneath a mound. The buried individual of indeterminate biological sex was young, between 7 and 11 years of age. Though scanty, the grave goods - 9 beads, a knife and scissors – suggest that the buried individual was female.

5.2. Non-local graves

It is important to recall that the baseline bioavailable range for local $^{87}Sr/^{86}Sr$ values incorporates both Birka and the larger Mälaren region and is greater than 0.723. A number of individual teeth were identified as non-local through the isotopic analyses using this cutoff point. There are two groups of values below 0.723 with a break at 0.713. Unfortunately there were few reliable grave associations with human remains in the group with strontium values below 0.713. These values between 0.707 and 0.713 correspond well with known baselines in southern Scandinavia and on the island of Gotland.

Individuals between 0.713 and 0.723 more than likely have their origins some distance from the Mälaren region. This group consists of graves 114, 141, 512b, 644:I, 804, 841, 869, 930, 946, and 1036 — three cremation graves, three chamber graves, and four coffin graves. Five out of eight graves of these non-locals have been identified as females from the grave goods, while only two were identified as males. One grave in this group had no reliable sex information. Two of these graves came from the Borg area (one included in the fortress rampart, Borgvallen 1997, and one from Norr om Borg) and the remainder were from Hemlanden. Some of these tombs and graves are discussed in more detail below.

5.2.1. Borgvallen 1997

This unique grave contained an inhumation under a mound with a huge white stone on top. It existed before the fortress at Borgvallen was built and was incorporated into the rampart when that wall was erected. The grave held a body most likely buried in a coffin as well as a horse skeleton on a platform at the foot of the inhumation. The individual was oriented east–west and lay on his back. aDNA-analysis showed that this individual was probably male (Holmquist-Olausson and Götherström, 1998). The individual was likely to have been in his fifties, 165 cm tall, with a small head. The tooth enamel from this individual had a low $^{87}Sr/^{86}Sr$ value of 0.7127, an average $\delta^{18}O$ value of −4.9‰, and seems to be clearly non-local based on the strontium. A few personal objects were retrieved from the grave including a wooden box, an iron knife, bronze tweezers, a leather purse with silver mountings, and a belt with mountings. There were also remains of feathers, cloth and silk. In contrast to most chamber graves with horses at Birka, this grave did not contain any weapons.

On top of the grave mound there was a layer with pottery sherds and animal bone suggesting a ritual meal took place in connection with the burial. There were also fragments of a glass beaker and a diagnostic Tatinger jug from Central Europe, as well as a so-called wasp bead. The grave goods and these particular objects date the grave to the second half of the 8th century, early in the settlement history of Birka. Parts of another male skeleton in the fill of the grave have been interpreted as the remains of a sacrifice (Fennö Muyingo, 2000). The prominent location of this grave, the sacrifice, and the high status costume, personal belongings, and other gifts indicate that this individual held a special position at Birka. The fact that the huge stone on top of the grave remained visible even after the rampart was erected around it reinforces the importance of the memory of this individual to the community.

5.3. Other non-local graves

In Chamber Grave 585, one of the grave goods suggests a southern connection for the buried female. Most of the objects in the grave do not differ from other female graves from eastern middle Sweden and include gilded oval brooches, beads, a knife and a needle box. However, this woman was also accompanied by a low, round wooden box made of oak with wedge-shaped bronze mounts covering the lid. The mounts were decorated with animal figures in the Jelling style from Denmark. A parallel to this special box is known from Ketting, Denmark (Arbman, 1943). The Danish similarity strengthens the southern Scandinavian association indicated by the $^{87}Sr/^{86}Sr$ value (0.7114) for the tooth enamel from this woman.

5.4. The Finnish connection

In the group of higher $^{87}Sr/^{86}Sr$ values at Birka, there are three individuals, all males according to grave goods, with ratios over 0.733–496, 855, and 962—values slightly higher than the baseline range for the Mälaren that fit with the higher range of values expected from northern Sweden or western Finland. Two of the identified graves, 496 and 855 are chamber graves with weapons and 855 included weights. Grave 962 was a flat grave with an inhumation burial. This grave held a young adult male without weapons. The few dress details found in these graves were similar to others known from Birka and the Mälaren region.

Chamber Grave 1053 contained a pegged penannular brooch typical of western Finland, suggesting a possible connection to the Finnish mainland. The individual, while buried with a Finnish brooch, had a high $^{87}Sr/^{86}Sr$ value (0.7309) that, nonetheless, fell within the local baseline range as well as with expected values from western Finland. In sum, while the evidence for individuals from Finland buried at Birka or in the larger Mälaren region is intriguing, it is not conclusive.

6. Conclusions

It is probably worthwhile to reiterate some of the cautions associated with this study. Preservation of human remains was poor at Birka, making it difficult to discuss mobility in terms of age and sex. Cremation was the common type of burial in more than half of the graves recorded at Birka and yet forms a very small part of our sample. Our initial selection of samples focused on teeth, which do not survive well in cremation burials. We are uncertain about the presence of baseline $^{87}Sr/^{86}Sr$ values between 0.719 and 0.723 in the Mälaren region. The strontium isotope baseline is not well documented for such a large area, particularly along the Baltic coast from Gävle to Stockholm. There may be areas in central Sweden with such values; parts of the landscape with Holocene marine deposits on or near the surface may have lower $^{87}Sr/^{86}Sr$ values. An expansion of the baseline range of values for the Mälaren region would greatly reduce the proportion of estimated non-locals at Birka.

In spite of these caveats, we find the results of our investigations to be intriguing and informative. Our results indicate that a little more than half (20) of the 37 inhumations and 5 of 6 cremation burials at Birka were probably non-local individuals, not from the Mälaren region, perhaps not even from central Sweden, but from some distance. One of the cremation graves at Birka, however, was probably a local individual. Previous studies have generally assumed the cremation graves to hold local individuals (e.g., Gräslund, 1980; Kalmring, 2016b). The cremation graves in our small sample at Birka were occupied primarily by non-local individuals, in contrast to the cremation graves from the greater Mälaren region which are thought to be local. However, it is difficult to generalize about differences in the origins of the individuals who ended as cremations or inhumations without more data.

Based on our sample, it appears that chamber graves usually contained local individuals buried with a rich assemblage of grave goods. At the same time it is necessary to ask if there were changes in burial practices over time at Birka or if our sample is representative of the various kinds of graves present at Birka.

The identification of the burial from Borgvallen 1997 as non-local is particularly interesting because of the location and richness of this early grave and the fact that the burial mound remained intact and visible after the construction of the Bergborget fortress. This must have been an especially important person in the history of Birka. The combination of local female and non-local male in the very rich Chamber Grave 644 is also of interest.

Our results also indicate that while some of the individuals buried in graves with objects from Western Finland may have originated in that region, their isotope values for the most part suggest that they were local to the Mälaren region, perhaps simply buried with rare and exotic goods from a distant land. Most of the graves with Finnish contents were richer graves in general. The question of cultural vs. isotopic evidence for provenience is an essential one in a study such as this. In spite of the presence of obvious exotic goods such as the pegged penannular brooches from Finland, there was no definitive evidence that the individuals in possession of these goods were of foreign origin.

Clearly there is more to be done in terms of isotopic proveniencing at Birka and in the Mälaren region. Certainly, where possible, it would be important to sample other cemeteries at Birka. It would be of interest to examine human remains from the area of potential Christian graves in the northern part of the Norr om Borg area. It would be useful to examine more of the cremations at Birka to determine if there is a more general pattern for local and non-local graves. Our present sample is not sufficient to resolve this question. More ^{14}C dates on the burials would be very helpful in determining changes in burial practices over time. It is very important to measure more baseline samples in the greater Mälaren region in order to establish a more reliable local isotope range. Coastal areas where there has been uplift may be characterized by lower $^{87}Sr/^{86}Sr$ marine deposits. The measurement of lead isotopes might provide some additional insight on the origin of the individuals buried at Birka and in the greater Mälaren region and might help to distinguish Finland and Northern Sweden from Central Sweden and Birka. There is much to do in terms of isotopic proveniencing of human remains from this area and, as usual, many questions to be answered.

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