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Food, Mobility, and Health in a 17th and 18th Century Arctic Mining Population in Silbojokk, Swedish Sápmi

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ABSTRACT. Established in 1635, the silver mine of Nasafjäll and the smeltery site in Silbojokk in Swedish Sápmi were used during several phases until the late 19th century. Excavations in Silbojokk, c. 40 km from Nasafjäll, have revealed buildings such as a smeltery, living houses, a bakery, and a church with a churchyard. From the beginning, both local and non-local individuals worked at the mine and the smeltery. Non-locals were recruited to work in the mine and at the smeltery, and the local Sámi population was recruited to transport the silver down to the Swedish coast. Females, males, and children of different ages were represented among the individuals buried at the churchyard in Silbojokk, which was used between c. 1635 and 1770. Here we study diet, mobility, and exposure to lead (Pb) in the smeltery workers, the miners, and the local population. By employing isotopic analysis, $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$, $^{87}Sr/^{86}Sr$ and elemental analysis, we demonstrate that individuals in Silbojokk had a homogenous diet, except for two individuals. In addition, both local and non-local individuals were all exposed to Pb, which in some cases could have been harmful to their health.

Key words: Arctic mining; Sápmi; $\delta^{13}C$; $\delta^{15}N$; $\delta^{34}S$; $^{87}Sr/^{86}Sr$; Pb; diet; mobility; colonialism

RÉSUMÉ. La mine d'argent de Nasafjäll et la fonderie de Silbojokk dans le territoire Sápmi en Suède ont été établies en 1635. Elles ont fait l'objet de plusieurs phases d'utilisation jusque vers la fin du 19[e] siècle. Des fouilles effectuées à Silbojokk, à une quarantaine de kilomètres de Nasafjäll, ont permis de découvrir des structures comme une fonderie, des maisons d'habitation, une boulangerie ainsi qu'une église et un cimetière. Dès le début, des gens de la région ou d'ailleurs ont travaillé à la mine et à la fonderie. Des gens d'ailleurs ont été recrutés pour travailler à la mine et à la fonderie, tandis que la population locale de Sámis a été engagée pour transporter l'argent sur la côte suédoise. Femmes, hommes et enfants d'âges différents figurent parmi les personnes enterrées au cimetière de Silbojokk, utilisé entre les années 1635 et 1770 environ. Ici, nous étudions le régime alimentaire, la mobilité et l'exposition au plomb (Pb) des ouvriers de la fonderie, des mineurs et de la population locale. À l'aide d'une analyse isotopique, $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$, $^{87}Sr/^{86}Sr$ et de l'analyse des éléments, nous démontrons que les personnes de Silbojokk avaient un régime homogène, sauf deux d'entre elles. De plus, les gens de la région et d'ailleurs ont tous été exposés au Pb, ce qui aurait pu nuire à la santé de certains.

Mots clés : exploitation minière dans l'Arctique; Sápmi; $\delta^{13}C$; $\delta^{15}N$; $\delta^{34}S$; $^{87}Sr/^{86}Sr$; Pb; régime alimentaire; mobilité; colonialisme

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INTRODUCTION

The international mining industry exploits natural resources worldwide, often with severe consequences both for the environment and for indigenous populations. This is, however, not a new phenomenon (see The Seed Box, 2020). The seventeenth century was a period of intensified Swedish colonization of Sápmi, the land of the Sámi, and the Sámi population, with respect to both the exploitation of natural resources and the implementation of Lutheranism (Roslund, 1989a; Ojala and Nordin, 2015:10–11; Nordin, 2017:45; Naum, 2018). Sápmi is not delimited by any strict borders; rather, it is constrained by cultural traits and subsistence patterns of different Sámi groups and is geographically defined as stretching from Lake Femunden in Hedmark, Norway, and Idre in Dalarna, Sweden, in the south, north to northernmost Finnmark in Norway, and east from western Norway to the Kola Peninsula in Russia, including northern Finland (Zachrisson, 1997:9; Fjellström, 2020:4).

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From the 13th century onwards, Sweden's iron production played an important part in its economy, and Sweden was a prominent producer and exporter. In the early 1630s, as Sweden entered the Thirty Years' War, the demand for arms became greater, followed shortly by the expansion of mining for copper, iron, and silver in central and northern Sweden as well as in Finland (Nordin, 2015:252, 255; Nurmi, 2019:91). This expansion of mining can be seen as a continuation of the Swedish state's early colonialism of Sápmi. The discovery of silver and lead ores at Nasafjäll brought about the establishment of Silbojokk in 1635, a small mining community with a smeltery, at the creek by Lake Sädvajaure, some 40 km from Nasafjäll (Fig. 1). Nasafjäll is situated north of the Arctic Circle at the Swedish/Norwegian border, c. 1000 m above sea level, in present-day Swedish Sápmi.

According to the historical record, mining specialists of German origin were sent to Nasafjäll and Silbojokk to launch the industry, but also to work in the mines. Some of them came from the Sala silver mine in Bergslagen, farther south in Sweden. It was not uncommon to employ German and Dutch workers in the mines farther south in Sweden (Nurmi, 2019:91). However, because of the need for more labour, Swedish workers from the coast of the Bothnian Bay also came to work in the mines. It is believed that the local Sámi population, on the other hand, did not work in the mines but transported the silver and lead ore from Nasafjäll to the coast, via Silbojokk. Nevertheless, the finds of Sámi-related artefacts within a possible dwelling house in Silbojokk suggest that Sámi people were also involved in the production of silver. Interactions between Sámi and non-Sámi were probably more common than previously thought (Nordin, 2015:261; Nurmi, 2019:106).

As part of his colonial efforts, the Swedish King Charles IX established both marketplaces and churches in Sápmi by 1607 (e.g., Hansen and Olsen, 2014:240; Nordin, 2015:253). He wanted to expand the control of his realm in the north—its resources and indigenous population—and to provide churches for the non-indigenous newly settled population. The first marketplaces and churches in Swedish Sápmi were established in Enontekis, Jokkmokk, Arvidsjaur, and Lycksele.

The anthropogenic impact from the mining industry in Sápmi, starting in the seventeenth century, made the environment highly toxic for all living organisms (Fahlman, 2012; Lundin, 2013:11, 14 – 15). By employing stable isotope analysis ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$, and $^{87}Sr/^{86}Sr$) together with elemental analysis, particularly lead (Pb), we aim to study diet, mobility, and exposure to lead in the smeltery workers, the miners, and the local population buried in Silbojokk.

SILBOJOKK AND NASAFJÄLL

During the autumn of 1634, the Sámi Peder Olofsson, together with the diamond and pearl seeker Jöns Pedersson, discovered silver ore at Nasafjäll in Sápmi (Rheen, 1983 [1897]; Bromé, 1923:62). A year later, in the summer of 1635, silver production was established at Nasafjäll and Silbojokk, by the company Piteå silververk, founded in Piteå on the Bothnian coast. As the inspector of mines, Hans Philip Lybecker moved from Sala silver mine to Silbojokk; a smeltery, a small house, a forging house, and a smithy were built in Silbojokk. The same year a dozen German miners travelled to Silbojokk, and the site was equipped with a storage unit, two living houses, a flour mill and a sawmill. Later, a bakery and a meat-smoking house were built (Bromé, 1923; Awebro, 1986a, 1989:37; Roslund, 1989a:85 – 118, 1992; Hansson, 2015:20).

In November 1636, there were 136 male workers at Silbojokk and Nasafjäll. The local Sámi population was engaged to transport the silver and lead ore to the coast, as well as necessary provisions to the workers. Germans and Swedes with mining industry expertise from the Sala and Lövåsen silver mines were employed to work in the mine and the smeltery (Awebro, 1986b; Nordin, 2015:257). Swedish men from the interior and young males who did not participate in the Thirty Years' War, mostly from the coast, were also employed to work in the smeltery (Bromé, 1923:122, 134; Hansson, 2015:21). There were priests at both Nasafjäll and Silbojokk from as early as 1635 (Awebro, 1986a), and people were buried in both churchyards from that point on, although the church in Nasafjäll was not erected until 1641 (Forskningsarkivet, 1896 – 1971:102 – 104) and in Silbojokk between 1645 and 1647 (Roslund, 1992:40) (Fig. 2). From 1635 to 1659, 981 kg of silver and 255 000 kg of lead were extracted from the mines (Bromé, 1923; Roslund, 1992; Hedström, 2000:63). During this period, two transport routes were established to Silbojokk from the coast: the first from Lillpite and the second from Frostkåge farther south (Hansson, 2015:16) (Fig. 1). In 1659, Silbojokk and Nasafjäll were attacked by Norwegian soldiers under the Danish regime, and the churches and most buildings were burnt down (Bromé, 1923:232 – 252).

A second church, built in Silbojokk at the end of the 17th century, was burnt down in 1747. Clerical activities took place until the 1770s, and a new church in Lövmokk was erected in 1777 (Awebro, 1986b:46, 48). According to Kenneth Awebro (2005:13), at least 160 individuals were buried in Silbojokk between 1652 and 1770. The names and origin of these individuals have been established from written records, demonstrating that most of the buried individuals were of Sámi origin, from the surrounding Sörvästerbyn, Norrvästerbyn, and Semisjaur Sámi villages (Awebro, 1986a:46, 2005:15). However, it is likely that miners and smeltery workers of different origin were also buried in Silbojokk. Both written sources and archaeological findings reveal a multicultural presence (Nordin, 2015:260).

Several workers died in the summer of 1636 because of illness caused by bad living conditions and were buried at the churchyard in Nasafjäll (Bromé, 1923:123 – 124; Awebro, 2017:14). Moreover, in 1639, several workers died

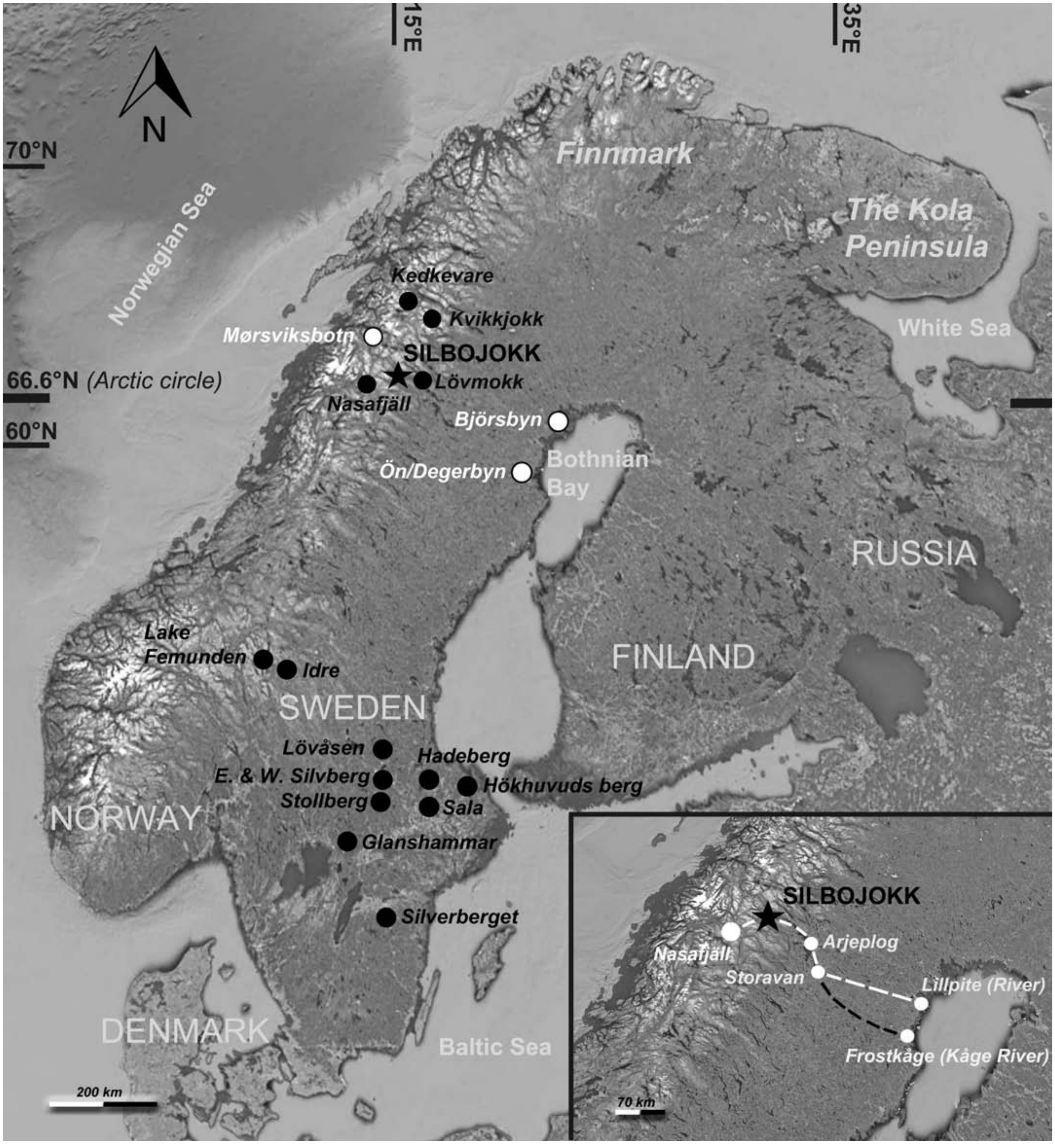

FIG. 1. Map of northern Fennoscandia with Silbojokk (star), Nasafjäll, and other historic silver mines (black dots), and archaeological sites with faunal remains (white dots) marked. The inset shows the two different transport routes between Nasafjäll and the Bothnian coast. Both background maps were remodelled by the authors and screenshot from © 2020 Google, Map data: Google, DigitalGlobe.

from suspected poisoning by lead smoke and arsenic from the industry (Bromé, 1923:110; Hansson, 2015:21); however, there is little information on where they were buried.

In 1942, a dam constructed on Lake Sädvajaure in connection with a power plant construction caused the water level to increase by 15 m (Norrman, 1989:13), which resulted in erosion of the shores and destruction of the site of Silbojokk. The National Board of Antiquities performed archaeological excavations in the 1980s, revealing the remains of buildings, a smeltery, a church, and a churchyard, some of which connected the site to a Sámi context. An osteological analysis of 160 kg of

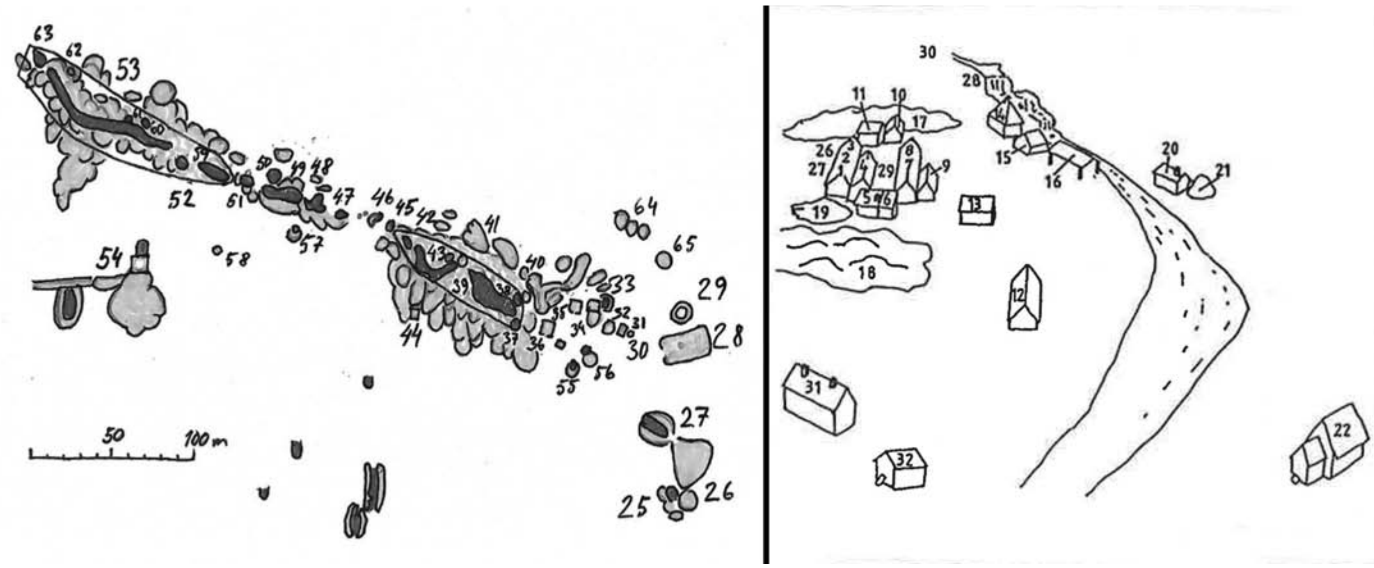

FIG. 2. Schematic maps of Nasafjäll and Silbojokk. Left: part of the mine at Nasafjäll and remains from buildings, the chapel (no. 31) and the churchyard (no. 29) (Berg Nilsson and Klang, 2016:25). Right: remains of the buildings in Silbojokk, the smeltery (no. 20), the church (no. 22), and the churchyard (Roslund, 1989b:186).

unburnt faunal skeletal remains found in a waste heap provide information of animals utilized and indicated there were both domesticated and wild animals present at the site. The most abundant animals represented are reindeer, followed by ptarmigan. Other animals found were cattle, sheep, goat, pig, and dog. Among the wild animals found were hare, otter, squirrel and various other rodents, forest birds, and seabirds. Finally, both marine and freshwater fish were present: salmon, cod, pike, and perch (Sten, 1989:174 – 176). The animal resources were both local and non-local (Sten, 1989:174; Awebro, 2017:16 – 17). Among the artefacts recovered were some typical Sámi items, such as bone spoons with ornaments typical of the south and central Sámi area, a Sámi drum hammer, and an Ave Maria pendant (Roslund, 1989a).

Since 2003, the Norrbotten County Museum has excavated the church and the churchyard areas, including 74 burials (Lindgren, 2019). Of the 37 analysed human skeletons, 22 were buried within the walls of the church. Some individuals were wrapped in cloth, and some were buried in coffins. There were grave goods in some burials, which is quite common in the pre-Christian Sámi burial tradition. Among the grave goods were items such as an axe, knives, fire steels, a ring, crooks, hooks, buttons, a needle, and unidentified iron fragments (Backman and Lindgren, 2004; Lindgren et al., 2007:10 – 11; Lindgren and Backman, 2007; Lindgren, 2014, 2015, 2016, 2017, 2018, 2019), which are common finds in Sámi burials (Manker, 1961:193). Moreover, an ornamented antler fragment, interpreted as a possible driving stick (SaP. *vuodjemsåbbe*, Sw. *körstav*) or walking staff (Sw. *vandringsstav*), was found in grave XLVII (Lindgren, 2018).

The harsh working conditions and the polluted environment most probably lead to illness and the death of many miners during the first years of activity in the silver mine (Bromé, 1923:73 – 75). There is little information on whether or not miners were sent back to their parishes to be buried. There are, however, records of German workers who died at Nasafjäll being buried at a churchyard close to the mine (Awebro, 2017:14).

MATERIAL

Human Skeletal Remains

Thirty-seven human individuals from Silbojokk, represented by 35 bone samples and 55 teeth (total = 90 samples) have been analyzed for stable carbon, nitrogen, and sulphur isotopes. Of these individuals, eight were males, nine were females, and four were infants. The biological sex of 16 individuals, aged 1 – 50 years, was not determined (Lindgren, 2015, 2016). Bone samples from all 37 individuals were also subjected to elemental analysis. In addition, teeth (first or second molars) from 11 individuals were analyzed with regard to strontium isotopes. The selection of samples (n = 11) was firstly based on financial constraints and then on available skeletal element where we aimed to target the second molar. In order to also include younger individuals, one first molar was selected (Table 1).

Faunal Skeletal Material, Soil, Water, and Plants

Seventy-three faunal skeletal elements from waste heaps in Silbojokk and the medieval sites of Ön, Skellefteå, and Björsbyn, Luleå were subjected to stable isotope analysis (Liedgren, 2014; Liedgren and Bergman, 2015). An additional eight faunal samples derive from the Sámi offering place in Mørsvikbotn in Norway, dated to the 16th and 17th centuries (Andersen, 2018) (Fig. 1). The different

TABLE 1. Results from the stable carbon, nitrogen, and sulphur isotope analyses of human bone and teeth from Silbojokk. Struck-out samples did not fulfill the quality criteria.

Grave	Sex	Age (years)	Skeletal element[a]	% Collagen	δ¹³C (‰)	δ¹⁵N (‰)	δ³⁴S (‰)	% C	% N	% S	C/N	C/S	N/S	Lab sulphur analysis
lösfynd (a)	–	–	Pars petrosa	1.0	−18.7	10.2	–	26.0	8.8	–	3.5	–	–	SIL
lösfynd (b)	–	–	M^1 sin	4.3	−18.2	9.7	10.1	41.2	14.9	0.21	3.2	524	189	SIL
lösfynd (b)	–	–	M^3 dx	8.0	−17.8	9.8	–	37.2	13.5	~~0.09~~	3.2	~~1102~~	~~399~~	SIL
lösfynd (c)	–	17–25	M_1 sin	6.7	−18.1	11.3	11.4	39.4	14.1	~~0.12~~	3.3	~~876~~	314	SIL
lösfynd (c)	–	17–25	M_2 sin	7.1	−17.8	10.7	–	36.4	13.2	~~0.08~~	3.2	~~1215~~	440	SIL
lösfynd (c)	–	17–25	M_3 sin	6.1	−18.3	11.2	–	38.7	14.1	~~0.07~~	3.2	~~1477~~	537	SIL
lösfynd (c)	–	17–25	Mandible	5.4	−18.4	10.3	9.5	38.4	13.7	~~0.14~~	3.3	~~733~~	–	SIL
lösfynd	F?	17–25	M_1	6.6	−17.8	9.5	–	38.7	14.4	~~0.05~~	3.1	~~2066~~	770	SIL
lösfynd	F?	17–25	M_2	1.0	−17.7	9.6	–	23.7	8.8	–	3.1	–	–	SIL
lösfynd	F?	17–25	M_3	6.0	−17.7	9.6	–	39.0	14.6	~~0.05~~	3.1	~~2082~~	778	SIL
lösfynd	F?	17–25	Mandible sin	6.2	−18.0	9.5	~~11.0~~	38.6	14.3	~~0.09~~	3.2	~~1144~~	424	SIL
lösfynd 2012	–	–	M_1 dx	5.8	−18.3	9.4	9.4	35.0	12.6	0.2	3.2	467	168	SIL
lösfynd 2012	–	–	M_2 sin	4.2	−18.1	9.8	10.3	36.1	13.2	0.28	3.2	344	126	SIL
lösfynd 2012	–	–	Mandible	1.0	−18.7	10	9.4	37.3	13.1	0.26	3.3	338	134	UC Davis
lösfynd 2014	–	25–40	M1 sin	4.6	−18.6	8.9	8.5	41.4	15.1	0.23	3.2	480	175	SIL
lösfynd 2014	–	25–40	M2 sin	4.0	−18.3	8.8	8.8	33.3	12.0	0.27	3.2	329	119	SIL
lösfynd 2014	–	25–40	M3 sin	5.4	−18.6	8.9	–	39.3	14.2	~~0.29~~	3.2	~~362~~	131	SIL
lösfynd 2014	–	25–40	Mandible	5.4	−18.9	9.1	9.1	39.0	14.3	0.19	3.2	548	201	SIL
Individual 2a	–	> 20	M^2 dx	1.9	−18.4	11.9	–	37.1	13.3	–	3.3	–	–	SIL
Individual 2a	–	> 20	M^3 dx	8.0	−17.8	12.3	–	37.1	13.3	~~0.02~~	3.3	~~4954~~	~~1772~~	SIL
Individual 2a	–	> 20	Pars petrosa	1.1	–	–	–	–	–	–	–	–	–	SIL
Individual 2b	–	14–20, alt. > 20	Long bone	7.7	−18.6	9.6	10.1	38.9	14.0	0.26	3.2	399	144	UC Davis
Grave I	–	2–4	M^1 dx	–	–	–	–	–	–	–	–	–	–	–
Grave I	–	2–4	dm^1 sin	0.5	–	–	–	–	–	–	–	–	–	–
Grave I	–	2–4	dm^2 sin	6.1	−19.7	11.7	–	28.3	10.1	~~0.01~~	3.2	~~7546~~	~~2707~~	SIL
Grave I	–	2–4	Long bone	7.7	−20.6	11.8	7.2	37.8	13.6	0.26	3.3	388	140	SIL
Grave III	–	14–20, alt. > 20	Humerus	11.0	−18.2	9.2	11.3	37.7	13.7	0.23	3.2	437	159	UC Davis
Grave IV	M(?)	>20	M^1 dx	1.9	−19.4	13.0	–	37.4	13.3	–	3.3	–	–	SIL
Grave IV	M(?)	>20	M^2 dx	3.3	−19.5	13.2	–	33.3	11.9	–	3.3	–	–	SIL
Grave IV	M(?)	>20	M^3 dx	2.1	−19.2	13.7	–	32.9	11.8	–	3.2	–	–	SIL
Grave IV	M(?)	>20	Long bone	4.0	−19.8	12.7	8.0	36.1	13.1	0.31	3.2	311	113	UC Davis
Grave VI	–	>20	Long bone	0.4	–	–	–	–	–	–	–	–	–	–
Grave VII:I	–	> 20	Bone fragm.	0.6	~~−19.9~~	~~10.4~~	–	~~30.8~~	~~9.3~~	–	~~3.9~~	–	–	SIL
Grave VII:II	F(?)	> 20	M^1 dx	–	–	–	–	–	–	–	–	–	–	–
Grave VII:II	F(?)	> 20	M^2 dx	–	–	–	–	–	–	–	–	–	–	–
Grave VII:II	F(?)	> 20	M^3 dx	–	–	–	–	–	–	–	–	–	–	–
Grave VII:II	F(?)	> 20	Femur	0.2	–	–	–	–	–	–	–	–	–	–
Grave IX	–	12–16	M^1 dx	8.3	~~−20.6~~	~~10.5~~	–	~~31~~	~~8.5~~	–	~~4.3~~	–	–	SIL
Grave IX	–	12–16	M_2 sin	–	–	–	–	–	–	–	–	–	–	–
Grave X	M(?)	> 20	M1	–	–	–	–	–	–	–	–	–	–	–
Grave X	M(?)	> 20	P2	–	–	–	–	–	–	–	–	–	–	–
Grave X	M(?)	> 20	Femur dx	3.5	−18.3	9.5	–	38.4	13.7	~~0.03~~	3.3	~~3415~~	~~1217~~	SIL
Grave XII	M	50+	M^1	3.6	~~−22.6~~	~~8.4~~	–	~~38.6~~	~~8.5~~	~~0.01~~	~~5.3~~	~~10308~~	~~2261~~	SIL
Grave XII	M	50+	M^2	6.8	~~−21.8~~	~~8.4~~	~~14.9~~	~~39.0~~	~~9.5~~	~~0.08~~	~~4.8~~	~~1300~~	~~315~~	SIL
Grave XII	M	50+	Long bone	4.4	−18.4	9.3	9.7	39.5	14.6	0.17	3.2	621	229	SIL
Grave XIII	–	14–20, alt. > 20	Long bone	8.4	−17.8	12.6	11.9	36.5	13.2	0.27	3.2	361	130	UC Davis
Grave XIV	–	14–20, alt. > 20	M_1 dx	1.6	~~−19.6~~	~~8.9~~	–	~~16.7~~	~~11.4~~	–	~~1.7~~	–	–	SIL
Grave XIV	–	14–20, alt. > 20	M2	1.6	–	–	–	–	–	–	–	–	–	–
Grave XIV	–	14–20, alt. > 20	Long bone	7.1	~~−21.9~~	~~8.7~~	–	~~36.3~~	~~8.6~~	~~0.06~~	~~4.9~~	~~1614~~	381	SIL
Grave XV	–	12–17	Long bone	1.5	−18.3	9.2	–	42.8	15.3	~~0.03~~	3.3	~~3810~~	1357	SIL
Grave XVII	–	–	Long bone	–	–	–	–	–	–	–	–	–	–	–
Grave XX	–	> 20	Long bone	14.3	−18.5	8.7	9.7	34.0	12.3	0.28	3.2	324	117	UC Davis

TABLE 1. Results from the stable carbon, nitrogen, and sulphur isotope analyses of human bone and teeth from Silbojokk. Struck-out samples did not fulfill the quality criteria – *continued:*

Grave	Sex	Age (years)	Skeletal element[a]	% Collagen	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{34}S$ (‰)	% C	% N	% S	C/N	C/S	N/S	Lab sulphur analysis
Grave XXI	–	14–20, alt. > 20	Long bone	11.8	−18.5	9.4	9.8	37.3	13.6	0.27	3.2	369	134	UC Davis
Grave XXIII	F	>20	M_1	4.0	−18.2	9.8	–	35.1	12.6	~~0.02~~	3.3	~~4680~~	1678	SIL
Grave XXIII	F	>20	M_2	5.7	−18.6	9.7	–	39.7	14.0	~~0.07~~	3.3	~~1513~~	533	SIL
Grave XXIII	F	>20	M_3	1.1	−18.2	10.0	–	35.5	12.6	~~0.01~~	3.3	~~9470~~	3371	SIL
Grave XXIII	F	>20	Long bone	14.6	−18.3	8.9	9.9	35.9	13.1	0.25	3.2	383	140	UC Davis
Grave XXV	–	12–15	M1	3.5	−18.4	8.6	–	39.2	14.4	~~0.32~~	3.2	~~327~~	120	SIL
Grave XXV	–	12–15	M2	3.5	−18.3	8.8	–	38.2	14.1	~~0.23~~	3.2	~~444~~	164	SIL
Grave XXV	–	12–15	Long bone	2.1	~~−19.5~~	~~9.4~~	–	~~16.7~~	~~4.9~~	–	~~4.0~~	–	–	SIL
Grave XXVI	M(?)	50+	M^3	9.6	−17.9	9.9	–	40.2	15.0	–	3.1	–	–	SIL
Grave XXVI	M(?)	50+	P_2 sin	2.4	−17.7	10.2	–	31.5	11.7	–	3.1	–	–	SIL
Grave XXVI	M(?)	50+	Pars petrosa	4.7	−18.3	10.2	–	41.6	15.4	~~0.02~~	3.2	~~5551~~	2053	SIL
Grave XXVII:I	F(?)	> 20	Humerus	7.7	−18.9	10.0	7.9	38.5	14.0	0.21	3.2	489	178	SIL
Grave XXVII:II	F(?)	50+	I1 dx	3.2	−18.0	9.3	–	34.5	12.9	–	3.1	–	–	SIL
Grave XXVII:II	F(?)	50+	P1 dx	5.5	−17.9	9.4	–	37.5	14.1	–	3.1	–	–	SIL
Grave XXVII:II	F(?)	50+	Long bone	6.0	−18.4	9.3	8.1	39.0	14.3	0.19	3.2	548	201	SIL
Grave XXVIII	M(?)	> 20	Rib	2.7	−18.9	9.6	–	32.3	11.5	–	3.3	–	–	SIL
Grave XXX	F(?)	> 20	M_1 dx	9.1	−18.5	8.3	11.0	41.8	15.2	0.21	3.2	531	193	SIL
Grave XXX	F(?)	> 20	M_2 dx	5.6	−18.3	8.3	11.2	38.2	14.0	0.20	3.2	510	187	SIL
Grave XXX	F(?)	> 20	M_3 dx	3.9	−18.3	8.6	–	32.5	11.5	–	3.3	–	–	SIL
Grave XXX	F(?)	> 20	Humerus	3.3	−18.5	8.0	10.1	41.1	14.9	0.21	3.2	523	189	SIL
Grave XXXI	F(?)	> 20	M^1 sin	0.8	−18.6	11.1	–	35.5	12.5	–	3.3	–	–	SIL
Grave XXXI	F(?)	> 20	M^2 dx	0.9	−18.5	10.8	–	35.7	12.7	–	3.3	–	–	SIL
Grave XXXI	F(?)	> 20	M^3 sin	1.8	−18.2	10.5	–	35.8	12.8	–	3.3	–	–	SIL
Grave XXXI	F(?)	> 20	Long bone	3.6	−18.5	10.3	7.6	40.1	14.5	0.24	3.2	446	161	SIL
Grave XXXII	M(?)	20–35	Pars petrosa	–	–	–	–	–	–	–	–	–	–	SIL
Grave XXXIII	M(?)	35–50	Long bone	–	–	–	–	–	–	–	–	–	–	SIL
Grave XXXV	F(?)	> 20	M1	5.8	−18.4	8.5	–	44.4	15.4	–	3.4	–	–	SIL
Grave XXXV	F(?)	> 20	M2	8.7	−18.2	8.8	–	41.0	14.4	–	3.3	–	–	SIL
Grave XXXV	F(?)	> 20	M3	4.6	−18.1	9.1	10.7	39.9	14.2	0.25	3.3	426	152	Iso Analytical
Grave XXXV	F(?)	> 20	Femur	5.0	−18.6	8.6	9.9	44.4	15.4	0.27	3.4	439	152	Iso Analytical
Grave XXXVI	–	>20	Pars petrosa	5.0	−18.4	9.2	9.5	41.1	14.5	0.23	3.3	477	168	Iso Analytical
Grave XXXVII	M	50+	M_1	2.5	−18.9	9.7	–	40.0	13.8	–	3.4	–	–	–
Grave XXXVII	M	50+	P_2	1.4	−18.2	10.0	–	32.5	11.2	–	3.4	–	–	–
Grave XXXVII	M	50+	Maxilla	6.8	−18.3	10.0	8.9	41.4	14.5	0.26	3.3	425	149	Iso Analytical
Grave XLI	F	50+	M1	3.3	−18.2	9.9	10.0	39.4	13.8	0.23	3.3	458	160	Iso Analytical
Grave XLI	F	50+	M2	3.5	−18.1	9.5	10.0	38.5	13.5	0.25	3.3	411	144	Iso Analytical
Grave XLI	F	50+	M3	4.9	−18.2	9.7	9.0	40.5	14.1	0.25	3.4	348	151	Iso Analytical
Grave XLI	F	50+	Femur	5.1	−18.5	9.9	9.0	41.4	14.7	0.23	3.3	481	171	Iso Analytical
			Mean value		−18.4	9.9	9.6							
			SD human		0.5	1.2	1.1							

[a] sin = sinistra (left) and dx = dextra (right).

species are categorized as domesticated (i.e., cattle, sheep, goat, dog, pig, and horse), semi-domesticated (i.e., reindeer), wild (i.e., squirrel, hare, otter, mouse and fox), birds (e.g., different kind of forest birds), marine fish and mammals (i.e., salmon, cod, and seal) and freshwater fish (i.e., pike, perch, Arctic char, trout, and whitefish). Ten faunal samples from Silbojokk were also subjected to elemental analyses (Table 2), and three faunal samples (salmon, otter and rodent) were subjected to strontium isotope analysis.

Nine soil samples were collected from within and in close proximity to the outer side of the burials. In addition, two soil samples were collected outside the settlement and outside the churchyard, one 0 – 10 cm below the turf and another from the bleached horizon. These samples were used as local references for the strontium isotope and elemental analyses. Moreover, slag and a lead lump from the smeltery were also subjected to elemental analysis. Four water samples were collected from Lake Sädvajaure, at different distances from the smeltery, as well as a plant (fern), for strontium isotope analysis.

METHODS

Stable Isotope Analysis of $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$

Bone and dentine powder were obtained using a dentist's drill. Collagen for the stable isotope analysis was extracted according to Brown et al. (1988) and analyzed for $\delta^{13}C$ and $\delta^{15}N$ at the Stable Isotope Laboratory (SIL) at the Department for Geological Sciences, Stockholm University, in a CarboErba NC2500 elemental analyser, connected to a mass spectrometer (continuous flow IRMS)—a Finnigan Delta V Advantage, with a precision of ± 0.15‰ for both $\delta^{13}C$ and $\delta^{15}N$ (Supplementary Appendix: Internal Standards). Sulphur isotopes were measured at three different laboratories. After the first laboratory closed down, we then had to send the second batch of samples to University of California (UC) Davis. The third batch of samples, from newly excavated skeletal material, was sent to ISO Analytical, Crewe, United Kingdom. However, we included our own internal standards (bone collagen of 1 reindeer and 1 seal) in all three batches to check for consistency. All measurements of the internal standards were within acceptable limits, and all samples complied with the quality criteria. At SIL, a Finnigan Delta Plus connected to a CarloErba NC2500 elemental analyser through a ConfloII with a precision of 0.2‰ was used (Supplementary Appendix: Internal Standards). At ISO-Analytical a Sercon CNS-EA elemental analyser auto-sampler linked with a Europa Scientific 20-20 isotope ratio mass spectrometer with a precision of 0.3‰ was used. At UC Davis, samples were measured using an Elementar vario ISOTOPE cube interfaced to a SerCon 20-22 IRMS with a precision of 0.4‰. All δ values for the stable isotopes used in this study are expressed in permil (‰).

Strontium Isotope Analysis

LA-MC-ICP-MS Analysis: Eleven human teeth (first and second molars) from different individuals were analyzed for $^{87}Sr/^{86}Sr$ using laser ablation (LA) at the Vegacenter at the Museum of Natural History in Stockholm. The analyses were performed using a Nu plasma (II) MC-ICP-MS mass spectrometer coupled to an ESI NWR193 ArF eximer-based laser ablation system, according to the method described in Glykou et al. (2018). A modern rodent tooth (*Otomys* 26-r52), with a known and homogenous $^{87}Sr/^{86}Sr$ signature (Le Roux et al., 2014), was used as reference material to evaluate the accuracy of the data. Each sample was pre-ablated before the analysis to remove potential surface contamination. Multiple line scans (from 13 to 17) with a spotsize of 148 µm, varying length perpendicular to the growth direction, and a spacing of ~200 µm in between them were ablated in order to obtain a time-resolved profile of the strontium uptake during tooth growth. The formation age for each line was then estimated based on Beaumont and Montgomery (2015), assuming linear growth of the enamel and estimating the original length of the crown, if worn. Although we are aware of the somewhat simplified approach, the different measurements do represent different biological ages.

TIMS Analysis: For reference, the $^{87}Sr/^{86}Sr$ ratio of four soil and four water samples, as well as a plant (fern), were analyzed at the Swedish Museum of Natural History. They were analyzed with a Thermo Scientific TRITON TIMS using a load of purified sample mixed with tantalum activator on a single rhenium filament. Measured ^{87}Sr intensities were corrected for Rb interference using $^{87}Rb/^{85}Rb$ = 0.38600, and ratios were reduced using the exponential fractionation law and $^{88}Sr/^{86}Sr$ = 8.375209. The external precision for $^{87}Sr/^{86}Sr$ as judged from running the NBS 987 standard was 20 mg/kg (n = 12). The values were normalized against the NBS 987 standard.

Three faunal skeletal remains were analysed at the Faculty of Geographical and Geological Sciences at the Poznan University in Poland. Strontium was separated from matrix elements on PFA columns filled with strontium-specific resin using a miniaturized chromatographic technique (Pin et al., 1994). Strontium was then loaded with a TaCl5 activator on a single W filament and analyzed in dynamic collection mode on a Finnigan MAT 261 mass spectrometer. The measured ratios were normalized against the NBS 987 standard. The strontium concentrations were determined by inductively coupled plasma (ICP) mass spectrometry with an ICP−QQQ spectrometer (8800 Triple Quad, Agilent Technologies).

Elemental Analysis

To understand the pre- and post-mortem incorporation of metals derived from mining and smeltery activities, such as Pb, As, and Cu, we analyzed the elemental composition in bones, soil, slag, and a lead lump. The different elements

TABLE 2. Results from the stable carbon, nitrogen, and sulphur isotope analyses of faunal bone material from Silbojokk, Mørsviksbotn, Degerbyn, and Björsbyn. Additional data on Arctic trout and char are from Dury et al. (2018). Struck-out samples did not fulfill the quality criteria.

Species	Common name	Site	Skeletal element[a]	% Collagen	δ^{13}C (‰)	δ^{15}N (‰)	δ^{34}S (‰)	% C	% N	% S	C/N	C/S	N/S	Lab S analysis
Bos taurus (juvenilis)	Cattle (Calf)	Silbojokk	Humerus sin	9.4	−21.5	7.6	8.7	41.2	14.7	0.17	3.3	646	231	SIL
Bos taurus (juvenilis)	Cattle (Calf)	Silbojokk	Humerus sin	7.1	−20.5	6.7	8.1	40.1	14.4	0.17	3.2	629	226	SIL
Bos taurus	Cattle	Silbojokk	Mt/Mc sin	6.2	−22.0	5.6	8.2	40.0	14.2	0.17	3.3	629	223	SIL
Bos taurus	Cattle	Silbojokk	Mt/Mc sin	8.9	−20.8	6.2	6.6	41.0	14.8	0.18	3.2	608	219	SIL
Bos taurus	Cattle	Silbojokk	Mt/Mc sin	10.2	−22.2	4.8	12.3	41.3	14.8	0.18	3.2	612	220	SIL
Ovis aries	Sheep	Silbojokk	Mt/Mc sin	2.5	−21.3	4.7	10.4	39.0	14.0	0.15	3.3	694	248	SIL
Ovis aries	Sheep	Silbojokk	Mt/Mc sin	7.1	−21.2	5.5	9.7	40.9	14.6	0.26	3.3	420	150	SIL
Ovis aries	Sheep	Silbojokk	Mt/Mc sin	6.8	−21.3	4.8	9.9	41.3	14.8	0.19	3.3	580	208	SIL
Ovis aries	Sheep	Silbojokk	Mt/Mc sin	6.6	−22.0	3.9	12.3	39.7	14.2	0.16	3.3	662	238	SIL
Ovis aries	Sheep	Silbojokk	Mt/Mc sin	10.8	−21.7	5.3	10.3	40.0	14.3	0.19	3.3	562	201	SIL
Ovis aries	Sheep	Silbojokk	Mt/Mc sin	7.4	−22.1	3.7	14.9	41.9	15.0	0.18	3.2	621	223	SIL
Ovis aries	Sheep	Silbojokk	Mt/Mc sin	5.9	−21.9	4.6	9.5	39.2	14.1	0.20	3.2	523	188	SIL
Sus scrofa	Pig	Silbojokk	mt III sin	7.1	−21.4	9.6	7.8	42.2	15.4	0.18	3.2	625	228	SIL
Sus scrofa	Pig	Silbojokk	mt III sin	11	−21.1	9.1	7.5	42.3	15.4	0.17	3.2	664	242	SIL
Canis familiaris	Dog	Silbojokk	Bone	6.2	−18.0	6.1	11.8	37.0	13.4	0.18	3.2	550	199	SIL
Rangifer tarandus	Reindeer	Silbojokk	Tibia dx	~~10.5~~	~~−21.3~~	~~2.4~~	~~8.8~~	~~41.1~~	~~10.7~~	~~0.18~~	~~4.5~~	~~609~~	~~159~~	~~SIL~~
Rangifer tarandus	Reindeer	Silbojokk	Tibia dx	2.4	−17.7	2.2	–	40.8	14.4	–	3.3	–	–	SIL
Rangifer tarandus	Reindeer	Silbojokk	Tibia dx	6.3	−18.3	1.7	10.7	42.4	15.0	0.26	3.3	435	154	SIL
Rangifer tarandus	Reindeer	Silbojokk	Tibia dx	6.6	−19.0	1.1	13.1	42.8	15.0	0.27	3.3	423	148	SIL
Rangifer tarandus	Reindeer	Silbojokk	Tibia dx	7.2	−18.7	1.8	11.3	42.2	15.0	0.26	3.3	433	154	SIL
Rangifer tarandus	Reindeer	Silbojokk	Tibia dx	4.9	−18.8	2.7	12.7	37.1	13.1	0.22	3.3	450	159	SIL
Mus sp.	Mouse	Silbojokk	Maxilla	3.4	−22.5	7.8	10.0	40.8	14.6	0.27	3.3	403	144	UC Davis
Sciurus vulgaris	Squirrel	Silbojokk	Long bone	4.1	−18.9	6.3	12.4	38.0	13.6	0.14	3.3	725	260	SIL
Lepus timidus	Hare	Silbojokk	Long bone	6.1	−22.8	1.7	9.3	39.2	14.1	0.19	3.2	550	198	SIL
Anser fabalis	Bean goose	Silbojokk	Long bone	7.8	−20.4	5.2	9.9	36.5	13.3	0.19	3.2	513	186	SIL
Lagopus sp.	Ptarmigan	Silbojokk	Long bone	8.3	−21.8	2.7	12.2	41.4	14.8	0.21	3.3	526	188	SIL
Lagopus sp.	Ptarmigan	Silbojokk	Long bone	9.4	−21.2	3.0	10.2	34.5	12.5	0.23	3.2	400	145	SIL
Lagopus sp.	Ptarmigan	Silbojokk	Long bone	4.3	−21.8	3.1	10.8	42.2	15.4	0.19	3.2	593	216	SIL
Lagopus sp.	Ptarmigan	Silbojokk	Long bone	2.8	−21.6	2.3	10.8	37.2	13.5	0.14	3.2	708	256	SIL
Tetrao urogallus	Great grouse	Silbojokk	Long bone	2.0	−21.5	1.9	11.6	40.6	14.6	0.20	3.3	541	194	SIL
Tetrao urogallus	Great grouse	Silbojokk	Long bone	7.8	−20.5	2.7	10.7	41.7	15.1	0.18	3.2	619	223	SIL
Tetrao urogallus	Great grouse	Silbojokk	Long bone	5.5	−20.5	2.0	9.8	41.2	15.0	0.21	3.2	524	191	SIL
Lyrurus tetrix	Black grouse	Silbojokk	Long bone	5.4	−21.1	3.0	7.1	37.0	13.1	0.16	3.3	617	219	SIL
Perca fluviatilis	Perch	Silbojokk	Auricle?	2.4	−20.3	10.8	–	36.6	13.2	0.24	3.2	~~407~~	~~147~~	~~SIL~~
Esox lucius	Pike	Silbojokk	Vertebra	2.5	−18.1	10.7	~~8.7~~	~~29.3~~	10.4	~~0.26~~	~~3.3~~	~~301~~	~~106~~	~~SIL~~
Salmo salar	Salmon	Silbojokk	Mandible dx	0.1	–	–	–	–	–	–	–	–	–	–
Salmo salar	Salmon	Silbojokk	Mandible dx	0.2	–	–	–	–	–	–	–	–	–	–
Salmo salar	Salmon	Silbojokk	Mandible dx	0.6	–	–	–	–	–	–	–	–	–	–
Salmo salar	Salmon	Silbojokk	Mandible dx	–	–	–	–	–	–	–	–	–	–	–
Salmo salar	Salmon	Silbojokk	Mandible dx	0.6	–	–	–	–	–	–	–	–	–	–
Salmo salar	Salmon	Silbojokk	Vertebra	–	–	–	–	v	–	–	–	–	–	–
Salmo salar	Salmon	Silbojokk	Vertebra	–	–	–	–	–	–	–	–	–	–	–
Gadus morhua	Cod	Silbojokk	Vertebra	–	–	–	–	–	–	–	–	–	–	–
Lutra lutra	Otter	Silbojokk	Maxilla	5.8	−18.1	13.2	8.9	40.1	14.6	0.26	3.2	412	150	UC Davis
Salvelinus alpinus	Arctic char	Riebnisjaure	Vertebra	2.3	−24.0	6.0	8.9	43.9	16.8	0.51	3.1	230	88	UC Davis
Salvelinus alpinus	Arctic char	Riebnisjaure	Vertebra	3.9	−24.1	5.8	9.2	44.9	16.7	0.51	3.1	235	88	UC Davis
Salmo trutta alpinus	Arctic trout	Riebnisjaure	Vertebra	6.3	−23.1	7.0	9.2	44.9	17.2	0.50	3.1	240	92	UC Davis
Salvelinus alpinus	Arctic char	"Laisan"	Vertebra	8.4	−20.5	6.9	8.2	44.8	17.0	0.51	3.1	235	89	UC Davis
Bos taurus	Cattle	Mørsviksbotn	Long bone	9.0	−21.8	4.4	16.3	35.7	13.1	0.24	3.2	397	146	UC Davis
Bos taurus	Cattle	Mørsviksbotn	Long bone	7.5	−21.7	4.9	16.2	36.9	13.4	0.23	3.2	428	156	UC Davis
Ovis aries/Capra hircus	Sheep/Goat	Mørsviksbotn	Long bone	10.3	−21.2	5.4	15.9	34.5	12.6	0.24	3.2	384	140	UC Davis

TABLE 2. Results from the stable carbon, nitrogen, and sulphur isotope analyses of faunal bone material from Silbojokk, Mørsviksbotn, Degerbyn, and Björsbyn. Additional data on Arctic trout and char are from Dury et al. (2018). Struck-out samples did not fulfill the quality criteria – *continued*:

Species	Common name	Site	Skeletal element[a]	% Collagen	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{34}S$ (‰)	% C	% N	% S	C/N	C/S	N/S	Lab S analysis
Ovis aries/Capra hircus	Sheep/Goat	Mørsviksbotn	Long bone	10.3	−21.3	3.5	16.0	37.9	13.8	0.26	3.2	389	142	UC Davis
Ovis aries/Capra hircus	Sheep/Goat	Mørsviksbotn	Long bone	8.5	−21.0	4.7	16.0	33.5	12.2	0.21	3.2	426	155	UC Davis
Ovis aries	Sheep	Mørsviksbotn	Long bone	10.9	−21.5	4.9	15.8	37.7	13.8	0.24	3.2	420	154	UC Davis
Rangifer tarandus	Reindeer	Mørsviksbotn	Long bone	10.2	−21.8	6.2	15.4	36.8	13.4	0.27	3.2	363	132	UC Davis
Rangifer tarandus	Reindeer	Mørsviksbotn	Long bone	5.3	−21.8	4.8	15.9	34.3	12.5	0.23	3.2	398	145	UC Davis
Bos taurus	Cattle	Björsbyn	Mandible	3.1	−22.2	7.0	2.4	36.4	13.1	0.23	3.3	423	151	UC Davis
Bos taurus	Cattle	Björsbyn	Mandible	5.7	−22.1	5.5	2.2	37.6	13.7	0.22	3.2	456	166	UC Davis
Bos taurus	Cattle	Björsbyn	Mandible	9.3	−21.7	5.3	1.0	38.4	14.1	0.21	3.2	489	179	UC Davis
Bos taurus	Cattle	Björsbyn	Mandible	3.6	−21.9	5.0	2.6	38.7	14.2	0.21	3.2	491	180	UC Davis
Ovis aries/Capra hircus	Sheep/Goat	Björsbyn	Mandible	5.1	−21.4	3.3	2.0	40.3	14.7	0.23	3.2	468	170	UC Davis
Ovis aries/Capra hircus	Sheep/Goat	Björsbyn	Mandible	10.2	−21.8	3.6	7.0	42.7	15.6	0.27	3.2	422	154	UC Davis
Ovis aries/Capra hircus	Sheep/Goat	Björsbyn	Mandible	6.1	−22.2	3.2	5.5	39.9	14.3	0.26	3.3	409	146	UC Davis
Ovis aries/Capra hircus	Sheep/Goat	Björsbyn	Mandible	5.1	−22.4	7.0	4.4	40.7	14.7	0.23	3.2	472	170	UC Davis
Sciurus vulgaris	Squirrel	Björsbyn	Mandible	~~7.0~~	~~−19.1~~	~~1.3~~	~~8.1~~	~~9.0~~	~~2.9~~	~~0.16~~	~~3.6~~	~~150~~	~~48~~	UC Davis
Tetrao urogallus	Great grouse	Björsbyn	Long bone	3.3	−22.0	1.1	9.6	40.6	14.7	0.26	3.2	417	151	UC Davis
Gadus morhua	Cod	Björsbyn	Costae	4.7	–	–	–	–	–	–	–	–	–	–
Perca fluviatilis	Perch	Björsbyn	Operculum	1.0	–	–	–	–	–	–	–	–	–	–
Coregonus maraena	Whitefish	Björsbyn	Costae	11.3	–	–	–	–	–	–	–	–	–	–
Phoca	Seal	Björsbyn	Pars petrosa	0.9	–	–	–	–	–	–	–	–	–	–
Phoca	Seal	Björsbyn	Pars petrosa	1.1	−17.5	12.3	–	35.5	11.9	–	3.5	–	–	SIL
Phoca	Seal	Björsbyn	Pars petrosa	2.7	−18.3	13.2	–	32.3	10.6	–	3.6	–	–	SIL
Phoca	Seal	Björsbyn	Pars petrosa	2.5	−16.6	12.5	16.1	41.7	14.9	0.26	3.3	428	153	UC Davis
Phoca	Seal	Björsbyn	Pars petrosa	~~1.0~~	~~−19.2~~	~~12.7~~	~~–~~	~~41.6~~	~~11.7~~	~~–~~	~~4.1~~	~~–~~	~~–~~	SIL
Bos taurus	Cattle	Degerbyn	Mandible	2.2	−22.5	7.0	–	29.1	10.0	–	3.4	–	–	SIL
Bos taurus	Cattle	Degerbyn	Mandible	10.5	−22.0	6.7	5.6	40.7	14.4	0.25	3.3	435	154	UC Davis
Bos taurus	Cattle	Degerbyn	Long bone	4.1	−22.1	5.8	9.6	43.3	15.3	0.16	3.3	722	256	UC Davis
Ovis aries/Capra hircus	Sheep/Goat	Degerbyn	Long bone	3.1	−22.6	6.9	7.9	42.0	14.7	0.24	3.3	467	164	UC Davis
Ovis aries/Capra hircus	Sheep/Goat	Degerbyn	Long bone	7.5	−22.3	6.4	5.6	38.1	13.8	0.17	3.2	508	216	UC Davis
Ovis aries/Capra hircus	Sheep/Goat	Degerbyn	Long bone	3.0	−22.1	6.5	5.0	42.0	14.7	0.17	3.3	660	231	UC Davis
Ovis aries	Sheep	Degerbyn	Mandible	5.3	−22.6	6.9	4.7	41.3	14.4	0.24	3.3	459	160	UC Davis
Equus caballus	Horse	Degerbyn	Long bone	4.3	−23.1	5.6	5.7	36.4	12.8	0.17	3.3	572	200	UC Davis
Vulpes sp.	Fox	Degerbyn	Fibula	12.5	-21.4	6.9	8.3	44.2	15.7	0.32	3.3	368	131	UC Davis
Tetrao urogallus	Great grouse	Degerbyn	Long bone	4.2	-21.6	1.7	14.4	40.8	14.3	0.23	3.3	474	166	UC Davis
			Mean value		−21.2	5.2	9.9							
			SD		3.3	2.6	4.2							

[a] sin = sinistra (left) and dx = dextra (right).

were grouped into metal/metalloid pollution elements (Pb, As, Cu), bone constituent elements (Ca, P, Sr, S), elements abundant in soil/sediment (Al, K, Ti, Zr), elements with redox-behaviour (Fe, Mn), and other metals (Mg, Cr, Zn, Cd, U). Thirty-five human individuals and 10 animals representing the fauna at Silbojokk were analyzed. Bone chunks (c. 1 g) were rinsed several times with deionized water and then dried at 50˚C for 3 h. The chunks were degreased for 4 h with diethyl-ether, $(C_2H_5)_2O$, in a Soxhlet extractor. They were then cleaned for 3 to 5 min in an ultrasonic bath with 99% formic acid (CH_2O_2). Finally, each sample was rinsed with deionized water until reaching a neutral pH (Schutkowski, 1995; Ščančar et al., 2000). The bone chunks were then crushed in a mortar and milled to less than 50 µm and analyzed by ICP-MS at the RIAIDT facility, Universidade de Santiago de Compostela, Spain. Samples were digested with 1 mL of HNO_3 2% (Hiperpur, Panreac) and 0.5 mL H_2O_2 (Panreac) in a microwave system (Milestone Ethos1) at 190˚C for 30 min. After digestion, MilliQ water was added to a final volume of 5 mL. Elements were analyzed by ICP-MS (Agilent 7700x) equipped with an introduction system with a Micromist glass low-flow nebulizer, Scott spray chamber with Peltier (2˚C), and a quartz torch. Calibration standards were prepared in a matrix–matched acid solution with concentrations for Ti, Cr, Mn, Fe, Cu, Zn, Zr, As, Mg, Al, K, Sr, Cd, Pb, and U (Multi IV-MERCK) between 0.2 and 10 000 µg/L, and for Ca, S, and P (Panreac) with concentrations from 1 to 100 mg/L. Samples were analyzed together with three procedural blanks. All samples and blanks were analyzed in triplicate, with Ir 20 µg/L as the internal standard. Calibration curves were constructed daily by analysis of fresh standard solutions. In all cases, linear responses were obtained with correlation coefficients higher than 0.999, and a relative standard deviation (RSD) lower than 5%. To monitor the overall performance of the system, an internal standard sample (a homogenized Roman bone) was analyzed along with the samples.

Principal component analyses (PCA) were performed by applying a varimax rotation (Hotelling, 1933) to understand the relationship between different elements. Loadings greater than 0.7 or lower than −0.7 are considered to be "high" (at least 50% of the element variance is accounted for by the PCA). Concentrations were transformed to centred log-ratios (clr) before analysis, following the procedure in López-Costas et al. (2016). Non-parametric Mann-Whitney U (2 groups) and Kruskal-Wallis (> 2 groups) tests were carried out on the scores of the extracted components, according to the sex and age of the individuals and burial characteristics. The statistical analyses were performed using the software package IBM SPSS 24.0. Soil, slag, and the lead lump were measured in triplicate together with one standard (SRM 277a) and a blank using a pXRF to obtain Pb concentration. Human samples were also measured using this method obtaining a correlation of r = 0.97 for Pb between pXRF and ICP-MS.

RESULTS

Carbon, Nitrogen, and Sulphur Isotopes

Human Remains: Sixty-eight samples from 28 individuals fulfilled the criteria for well-preserved collagen with regard to carbon (15.3%–47.0%) and nitrogen (5.5%–17.3%) concentrations as well as C/N ratio (2.9–3.6) (DeNiro, 1985; Ambrose, 1990). Two of them, with yields slightly below the limit of 1% (van Klinken, 1999) but fulfilling the above quality criteria, were included. Fifty-two samples with a collagen yield greater than 1% were analyzed for $\delta^{34}S$, which equated to 21 individuals. Thirty-two of these samples complied with the quality criteria for sulphur with regard to concentration (0.15%–0.35% for mammals and birds, 0.40%–0.80% for fish), C/S ratio (300–900 for mammals and birds, 125–225 for fish) and N/S ratio (100–300 for mammals and birds, 40–80 for fish) (Nehlich and Richards, 2009).

The $\delta^{13}C$ values range from −20.6‰ to −17.7‰ with a mean and standard deviation of −18.4 ± 0.5‰. The $\delta^{15}N$ values range from 8.0‰ to 13.7‰ with a mean and standard deviation of 9.9 ± 1.2‰. The $\delta^{34}S$ values range from 7.2‰ to 11.9‰ with a mean and standard deviation of 9.6 ± 1.1‰ (Table 1, Figs. 3–6).

Faunal Remains: In total, 72 samples yielded enough collagen (> 1%) for stable isotope analysis. Of these, 69 complied with the quality criteria for carbon and nitrogen, while 67 samples were analysed for sulphur and 63 fulfilled the quality criteria for sulphur. The $\delta^{13}C$ values range from −24.1‰ to −16.6‰ with a mean and standard deviation of −21.2 ± 3.3‰. The $\delta^{15}N$ values range from 1.1‰ to 13.2‰ with a mean and standard deviation of 5.2 ± 2.6‰, and the $\delta^{34}S$ values range from 1.0‰ to 16.3‰ with a mean and standard deviation of 9.9 ± 4.2‰ (Table 2, Figs. 3–6).

Strontium Isotopes

Samples targeted for analysis of human tooth enamel in this study were the first and second molars, formed between the age of c. 0–3.5 and c. 2–8.5 years, respectively (Beaumont and Montgomery, 2015:409). The $^{87}Sr/^{86}Sr$ values varied between 0.7121 and 0.7220 (Fig. 7, Tables S1–S3). In addition, water, plant, soil, and faunal samples were analyzed using TIMS, with values ranging from 0.7165 to 0.7232 (plant and water), from 0.7297 to 0.7501 (soil), and from 0.7170 to 0.7225 (fauna) (Fig. 7, Table S4).

Elemental Analysis

The Pb concentrations in the Silbojokk humans range from 7.9 to 827.0 mg/kg with a mean and standard deviation of 72.7 ± 142.9 mg/kg. Arsenic concentrations range from 0.1 to 8.5 mg/kg with a mean and standard deviation of 0.8 ± 1.4 mg/kg, and copper concentrations range from 0.8 to 18.0 mg/kg with a mean and standard deviation of 6.4 ± 4.8 mg/kg (Table S5).

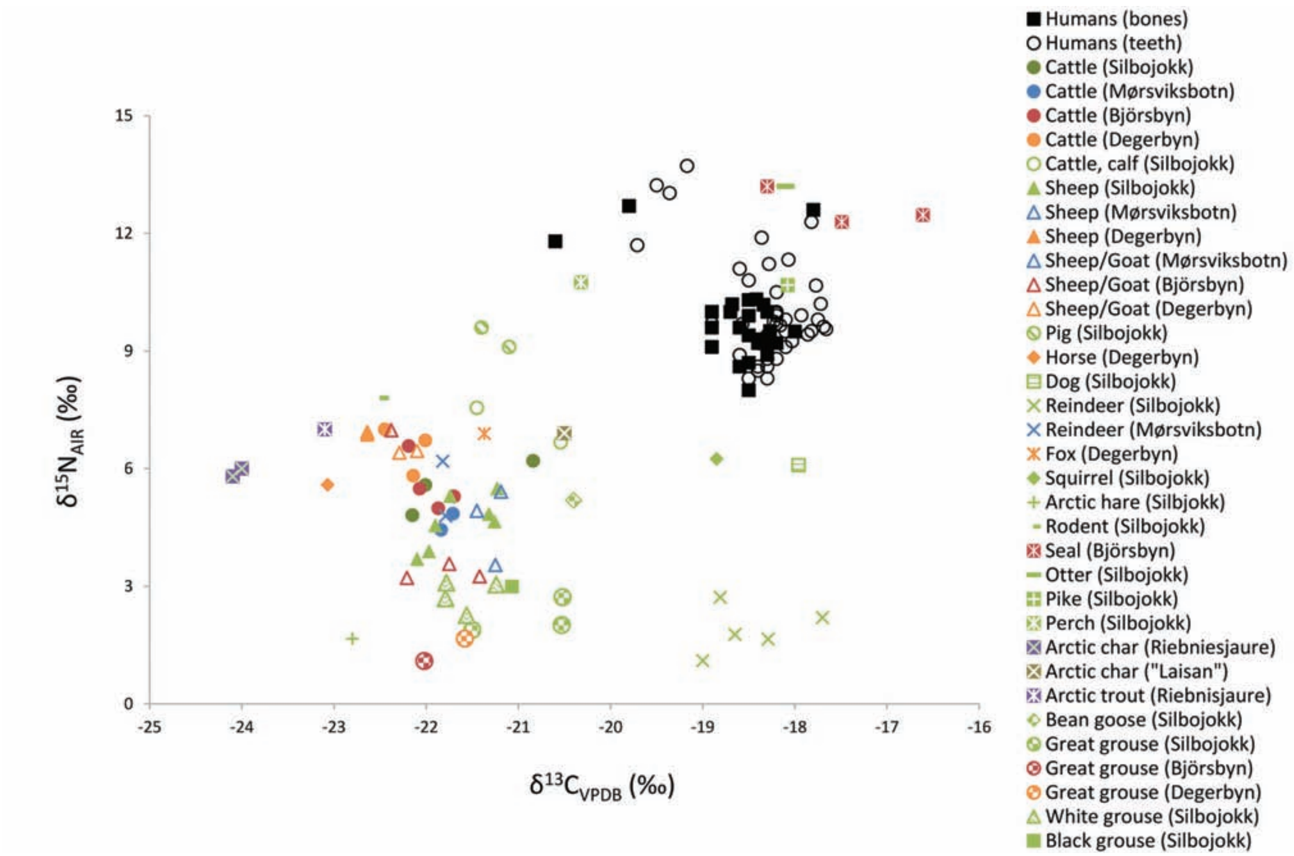

FIG. 3. Stable carbon and nitrogen isotope values for human individuals from Silbojokk, faunal samples from Silbojokk, Björsbyn, Degerbyn, and Mørsviksbotn, and additional freshwater fish data on Arctic trout and char from Dury et al. (2018).

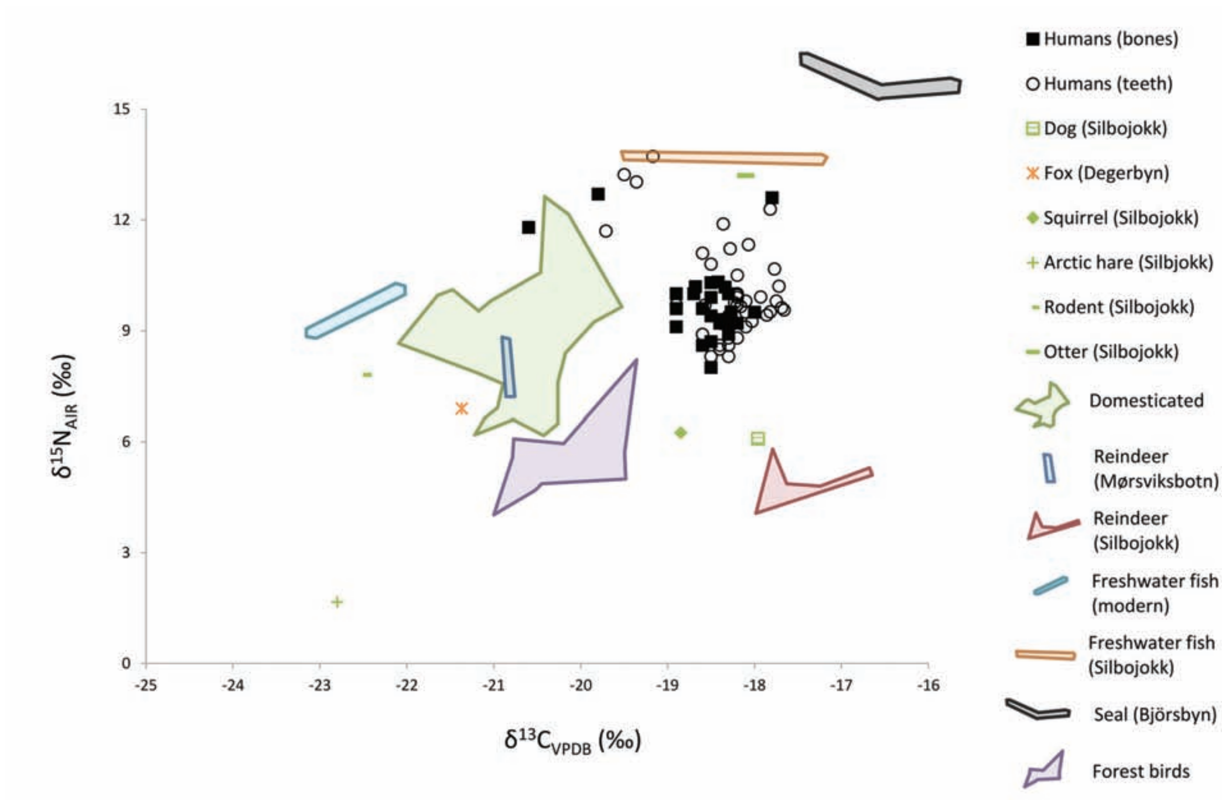

FIG. 4. Prediction of dietary intake for humans, calculated from the faunal data from Figure 3 with a fractionation factor of +1‰ for $\delta^{13}C$ and +3‰ for $\delta^{15}N$ (DeNiro and Epstein, 1978; Minagawa and Wada, 1984; Schoeninger and DeNiro, 1984). Although larger intervals have been suggested (see Drucker and Bocherens, 2004; O'Connell et al., 2012), we have chosen to use the more conservative estimate.

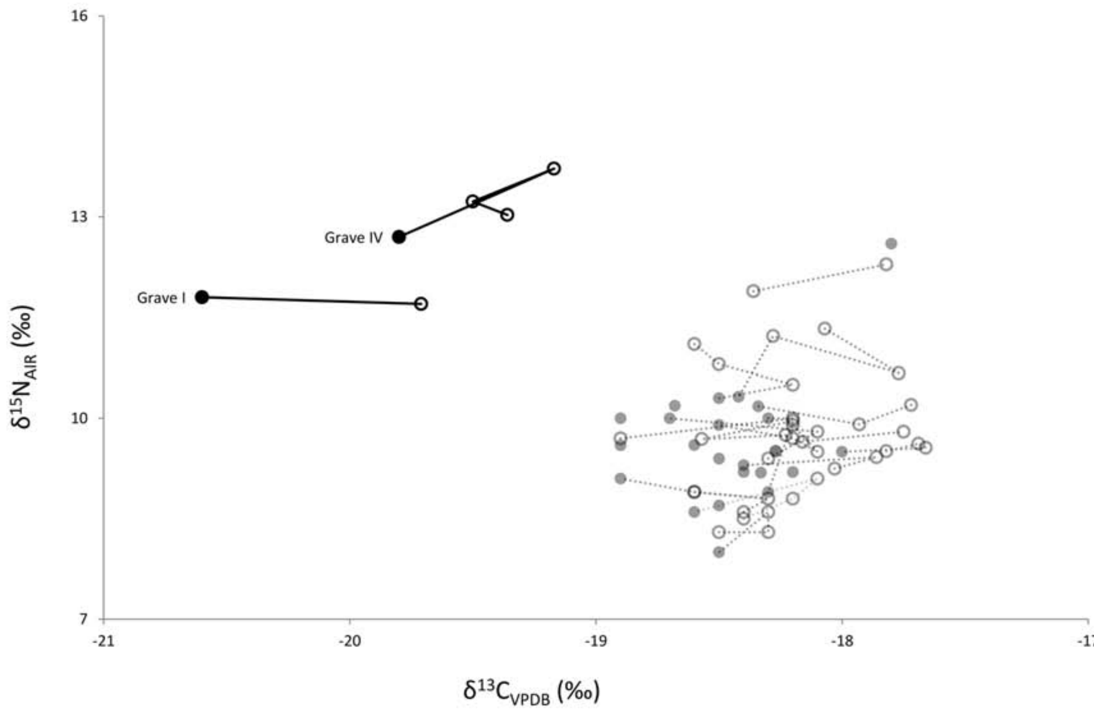

FIG. 5. Intra-individual changes of carbon and nitrogen isotope values for the individuals from graves I and IV highlighted. Filled circles: bone; empty circles: tooth.

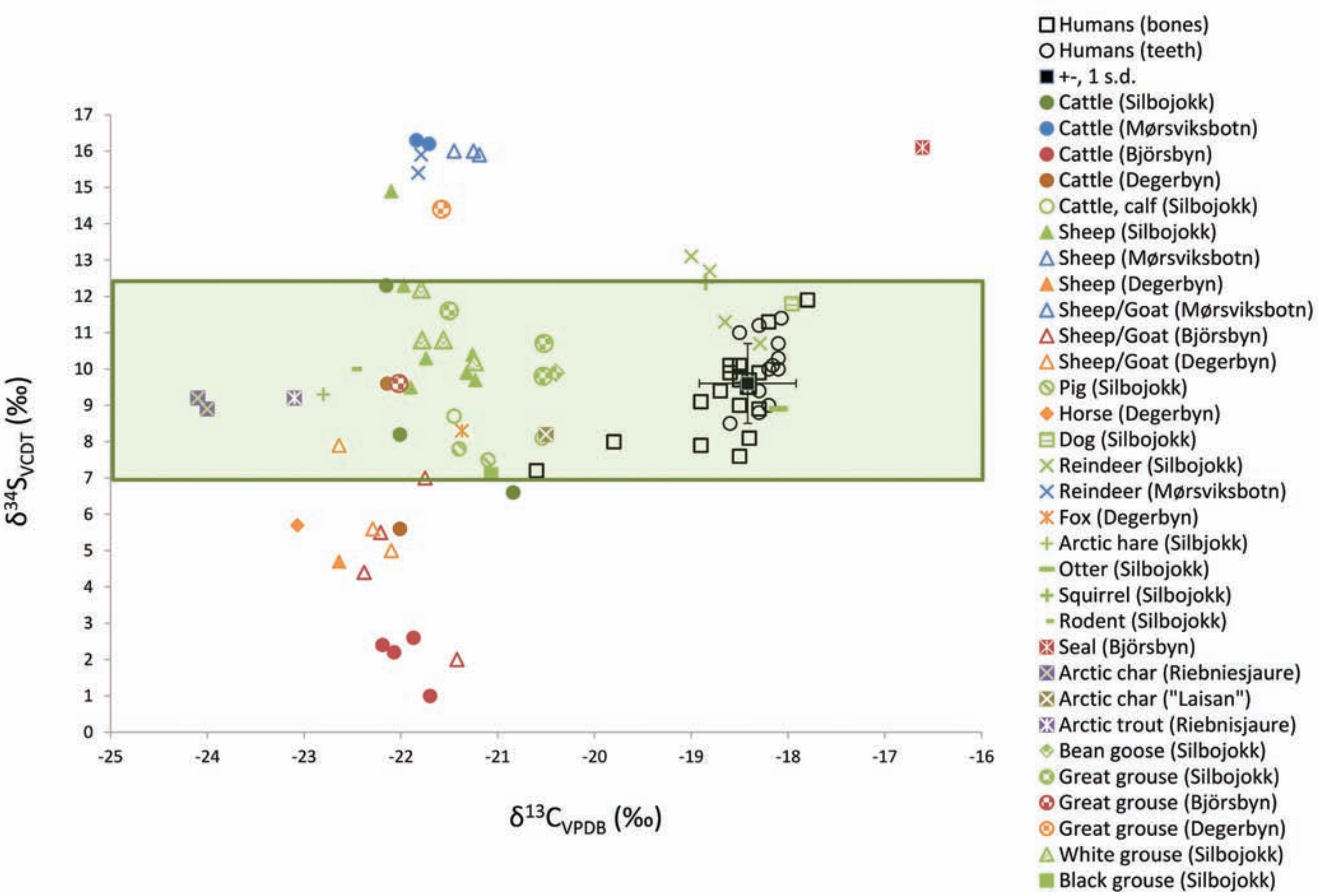

FIG. 6. Stable carbon and sulphur isotope values for human individuals from Silbojokk, faunal samples from Silbojokk, Björsbyn, Degerbyn, and Mørsviksbotn, and additional freshwater fish data on Arctic trout and char from Dury et al. (2018). The local range is marked by a green box.

In the PCA, five components account for 83.8% of the total variance (Table S6). The first component (PC1, 32%) is related to bone post-mortem alteration and is characterized by positive loadings of the bone constituents (Ca, P, Sr, S) and Mg, and negative loadings of an element characteristic of soil particles (Al). Part of the variation of As (37%) and Cu (20%) is also accounted for here (negative loadings). PC2 (16%) is also related to local soil elemental composition with a positive loading for Zr and negative loadings for Cd and Zn. PC3 (15%) is related to elements characterizing the local mineralogy, possibly biotite (Ti, K). A large part of the variation of As and Cu is also accounted for by this component (negative loadings). PC4 (14%) is characterized by redox sensitive elements (Fe and Mn) and possibly related to periodic flooding of the archaeological site. Finally, PC5 (7%) is almost exclusively related to Pb variation (88%).

No differences were found regarding sex, age groups, diet (terrestrial, mixed, freshwater), or burial area. For the one individual (grave XXVII:II) with data from two skeletal elements, there is a discrepancy in Pb concentrations between the mandible (34.6 mg/kg) and the long bone (341.6 mg/kg). The higher value was obtained from a long bone that has a faster bone turnover rate than the mandible. The higher value in the long bone can be interpreted as representing the more recent time of this adult's life, that is, time spent in Silbojokk, whereas the lower value from the mandible, with a slower turnover rate, reflects Pb incorporated from a longer time period including areas outside of Silbojokk. However, intraskeletal differences due to diagenesis cannot be totally ruled out.

DISCUSSION

Diet

From historical written sources and previous research, we know that people with different ethnic or cultural affiliations were present in Silbojokk. This fact makes it highly likely that they also ate different types of food or preferred different cuisines, at least within the limits that the resources at the site offered. According to the carbon and nitrogen isotope results, most of the analyzed individuals had a mixed diet consisting of, in descending order, aquatic resources, forest birds and domesticated animals (Figs. 3 and 4). The marrow-spliced reindeer bone at the site, found in the waste heap, shows that reindeer was part of the diet (Sten, 1989). However, according to the stable isotope results, reindeer were not consumed to any great extent. This does not, however, by any means indicate that reindeer were unimportant; we know that reindeer were important for transportation (Fjellström et al., 2019:13). The very little intra-individual variation in the analyzed individuals indicates that they had not changed their diet over their life span (Figs. 5 and S1 – S15).

There is little variation in diet between the analysed individuals, although we cannot be certain that they are representative of the total population at Silbojokk. However, two individuals deviate from the rest: graves I and IV. The individual from grave I, a two- to four-year-old child, and the individual from grave IV, a male aged over 20 years old (Fig. 5), had a diet mainly based on freshwater resources. The latter was buried with a strike-a-light, common in Sámi burial traditions.

Mobility and Migration

The δ^{34}S values differ depending on the local geology of the bedrock and between marine and terrestrial environments (Krouse, 1980:436; Richards et al., 2003; Faure and Mensing, 2005). In this study, the range of δ^{34}S values in the wild animals from Silbojokk is used to define the local range. All human sulphur values fall within the local range (Fig. 6). There is little intra-individual variation (Figs. S16 – S21), similar to the δ^{13}C and δ^{15}N values. While the local range both for sulphur and strontium can be used to positively identify non-local individuals, we are aware that it is not possible to positively identify local individuals, although it is often the most parsimonious explanation.

Strontium isotope data from the local fauna, soil, water, and a plant define the bioavailable local range for strontium. The water, plant, and faunal strontium values range between 0.7165 and 0.7232, a considerably smaller range than for the soil samples (0.7297 – 0.7501). The strontium values for the soil samples are much higher, which might reflect erosion processes in Silbojokk. Therefore, the strontium values for the soil samples may not be indicative of the bioavailable strontium in Silbojokk and have not been used to define the local bioavailable strontium.

The strontium isotope ratio (^{87}Sr/^{86}Sr) in the analyzed human enamel is representative of the bioavailable strontium in plants, animals, and water that was ingested at the time of tissue formation. Ingested water from the rivers used for transportation to the coast, the Kåge and Lillpite Rivers, might have contributed to the strontium isotope values in the individuals. Kåge River has an ^{87}Sr/^{86}Sr of 0.7209, whereas we have no data for the Lillpite River (Ericson, 1985; Åberg and Wickman, 1987:36); both discharge into the Gulf of Bothnia. However, riverine systems vary up- and downstream in their ^{87}Sr/^{86}Sr values (Åberg and Wickman, 1987:36).

The strontium isotope ratios of the 11 individuals analyzed for mobility patterns during their childhood indicate that three individuals were non-local (Lösfynd 2014, XII, and XV) and eight were local (Lösfynd, Lösfynd c, Lösfynd 2012, I, IV, XXIII, XXV, and XXX). One of the non-local individuals (Lösfynd 2014) has a value indicating that he or she could have been present in Silbojokk around the age of six. The values of six of the eight local individuals indicate that they moved within the area of Silbojokk (Lösfynd, Lösfynd c, Lösfynd 2012, IV, XXIII, and XXV). The values of the other two individuals (Lösfynd c and

XXIII) indicate that they moved between Silbojokk and other areas (Fig. 7). There were no differences in strontium isotope values between males and females (Fig. 8). Historic sources refer to workers from Sala silver mine taking part in the mining activities in Silbojokk, which is partly supported by the strontium data overlapping between the different sites (Bäckström and Price, 2016) (Fig. 7). The range of $^{87}Sr/^{86}Sr$ values for the individuals buried at Salberget, close to the Sala silver mine, is extremely wide, with values from 0.710 to 0.733 and mainly outside the local range, indicating non-locals. In contrast to the buried at Sala silver mine, the individuals in Silbojokk seem to be mostly local.

While the strontium isotope values reflect childhood (enamel formation), the sulphur isotope values reflect both childhood (dentine formation) and adulthood (bone remodelling). However, four individuals have a perfect match between the sulphur and strontium isotope values in terms of local vs. non-local values. The only exception is individual Lösfynd 2014, where 10 $^{87}Sr/^{86}Sr$ measurements are outside the local range, and one within the local range, representing ages c. 4 – 6.5 years. In contrast, the two sulphur values (M1 and M2), representing an average of the ages c. 3 – 9, are local. The only local strontium value, representing age 6, lies within the age range for the sulphur values.

Exposure to Lead

Some elements that are vital for humans can be poisonous in high levels (e.g., Cr, Cu, and Se). Other elements such as Pb do not have any function in the human body and are toxic even at low levels. According to the Swedish Food Agency (SFA, 2020), heavy metals such as Cd, Hg, As, and Pb are among the most poisonous. The European Food Safety Authority (EFSA) does not give any recommendation on the maximum intake of Pb, as little is still known about the thresholds of critical effects on health (EFSA, 2012). However, high exposure to Pb can cause disease or even death. Some of the pathological symptoms are loss of appetite, vomiting, severe colic and muscle weakness, or paralysis (Handler et al., 1986:406; EFSA, 2012). Pb accumulates in bone tissue during an individual's lifetime and even though Pb has a turnover, bone tissue is a good indicator of long-term exposure to Pb (Schroeder and Tipton, 1968; Barry, 1975).

The environments in Silbojokk and Nasafjäll were highly polluted; the mining and smelting activity released large quantities of Pb that polluted the air, food, and water (Fahlman, 2012). All these sources contributed to pre-mortem incorporation of Pb, As, and Cu. The fact that both males and females show similar distribution for Pb ($U = 32.0$, $p = 0.31$) indicates that males and females were equally exposed to Pb. Further, there is no significant relationship between Pb content and age ($U = 66.0$, $p = 0.77$), although non-adults and females tend to have lower PC5 scores (Fig. 9). Both facts suggest that the pollution affected all family members. Even though the churchyard was in use long after the smeltery was abandoned, there is a similar distribution of Pb in the people buried in Silbojokk throughout the whole period of use (df. 2, $p = 0.5$), which may relate to the long residence time of this element. As can be observed in Figure 10, the two individuals (IV and VII:I) with positive Pb concentration scores were probably more intensely exposed during life (e.g., mining or metal-working activity). Although diagenetic incorporation of Pb in human bones is also possible, the differences observed between individuals seem to be explained by other factors than diagenetic incorporation; note that the correlation with lithogenic elements and other metal elements is low (e.g., $r = 0.09$ for Pb and U).

Both As and Cu distributions are closely related to soil particles (PC1, negative loadings) and the local mineralogy (PC3), which means that the area where the skeletons were deposited affects bone preservation. Accordingly, the elevated concentrations of As and Cu in the skeletons seem to be caused by post-mortem incorporation and thus related to diagenesis. The fact that Pb has all its variance in one component and that no other element covaries with it, by contrast, suggests a different source than post-mortem incorporation of Pb. Since no lead coffins have been found, environmental pre-mortem incorporation seems the most feasible explanation. Similar results have been found in a previous study of individuals living in Roman Spain (López-Costas et al., 2016, 2020). The Pb values in Silbojokk (max. 827 mg/kg) were, however, much higher than in Spain (max. 20.9 mg/kg) or in a similar study on Danish individuals (max. 184 mg/kg) (Rasmussen et al., 2019). There is no correlation between bone preservation and Pb concentration in the human samples (Fig. 10), again suggesting pre-mortem incorporation of Pb. Further, the Pb concentration in soil samples (Table S5) is generally lower than in the bone samples, also pointing to a pre-mortem source. Compared to previous research (López-Costas et al., 2016; Rasmussen et al., 2019), the concentrations in the Silbojokk population are extremely elevated. The high levels observed in Silbojokk lead us to surmise that they may have had a negative impact on the overall health of the population.

Somewhat surprisingly, the child from grave I, who, judging from the $^{87}Sr/^{86}Sr$ data, was not local to Silbojokk, still had moderately high concentrations of Pb. Infant bones are usually less mineralized than adults, which could make them more prone to diagenetic alteration. However, this particular sample seems to be little affected by diagenesis because the concentrations of major bone elements (e.g., Ca or P) are above the average of the analyzed human samples, while soil element (e.g., Al, Ti, U) concentrations are lower than the average. This fact makes us consider a possible pre-mortem incorporation. Pb is transferred from the mother to the foetus, so it is likely that this individual was born with an already high level of Pb. We do not know who the mother was, but we can assume that she did not reside in Silbojokk when giving birth, but was exposed to high levels of Pb during her life. During pregnancy, women have

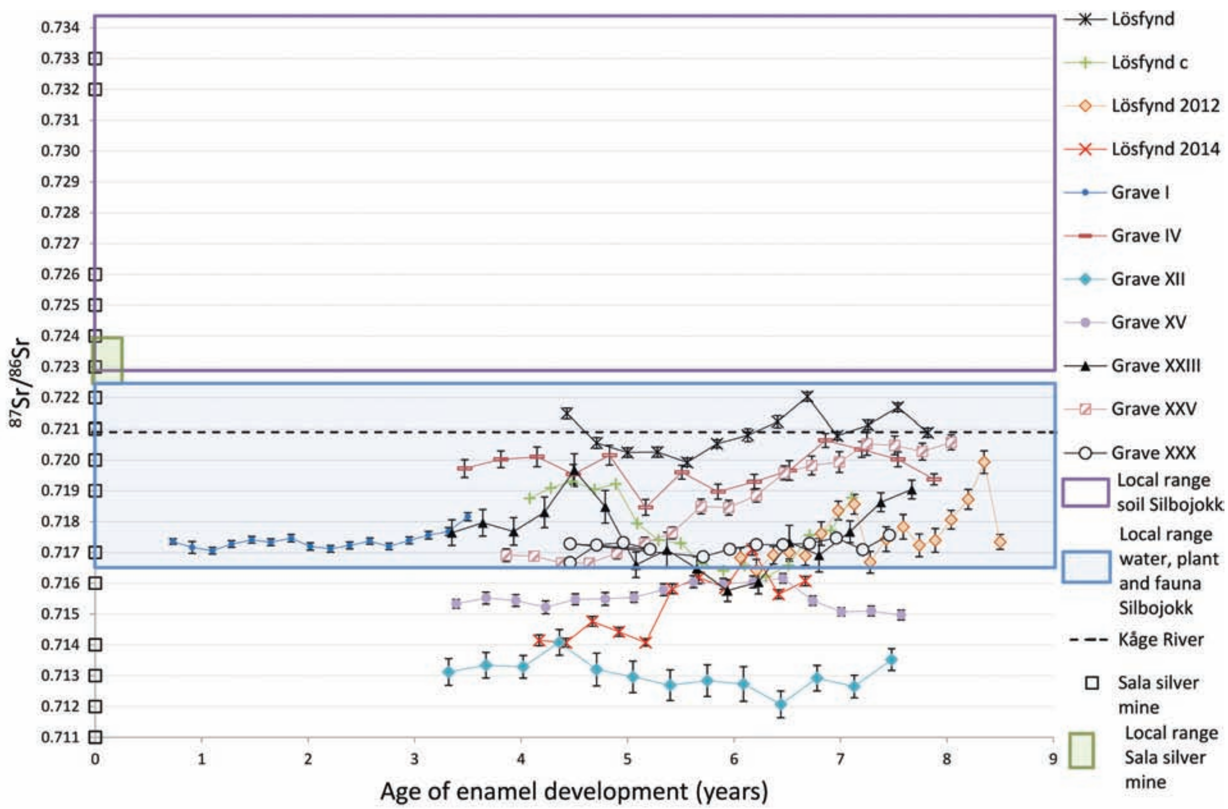

FIG. 7. $^{87}Sr/^{86}Sr$ ratios for human tooth enamel. The x-axis represents years of formation. The error bars are the external precision, 2SD (see Appendix Tables S3–S6). The local range for Silbojokk is marked by a blue box, and the $^{87}Sr/^{86}Sr$ for the Kåge River is marked by a dashed line. The local range for the Sala silver mine is marked by a green box on the y-axis. The human $^{87}Sr/^{86}Sr$ ratios from the Sala silver mine (Bäckström and Price, 2016) are marked on the y-axis (black boxes).

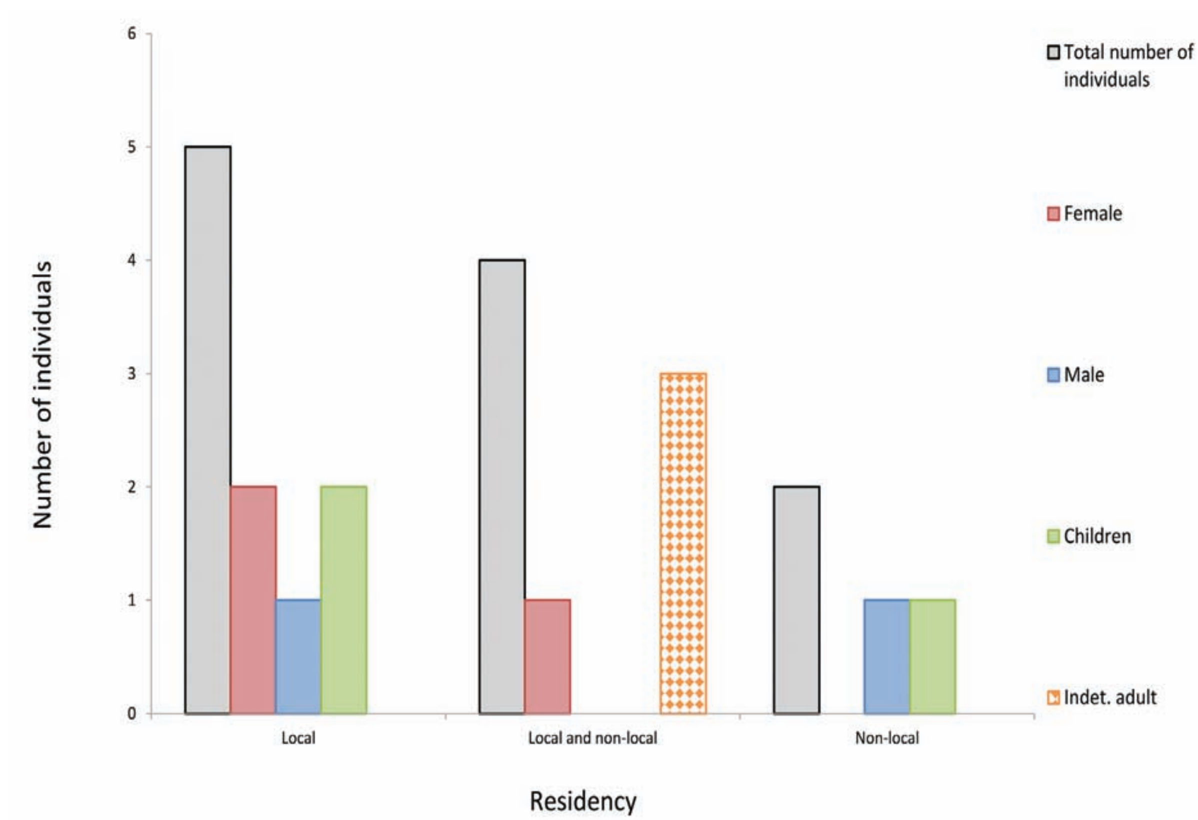

FIG. 8. Number of local and non-local individuals based on $^{87}Sr/^{86}Sr$ ratios.

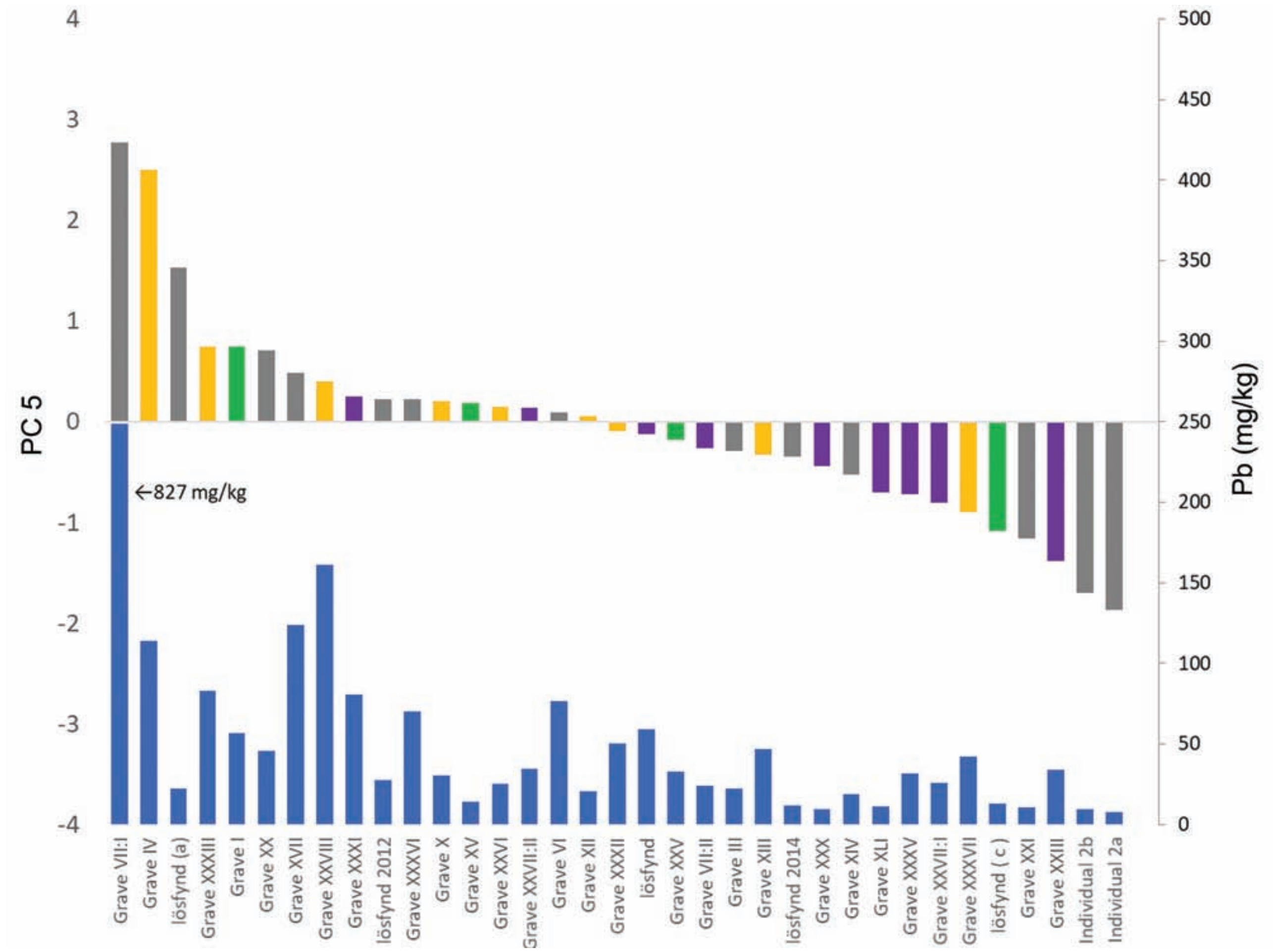

FIG. 9. Lead (Pb) variation in the human Silbojokk population. Top: Scores of PC5 (mainly characterizing the Pb variance); sex and age distribution can be observed in purple (female), orange (males), green (non-adults) and grey (unknown) colours. Bottom: blue bars showing the concentration of Pb (mg/kg) in the samples analyzed. Note that the high Pb value of individual from grave VII:I is outside the range.

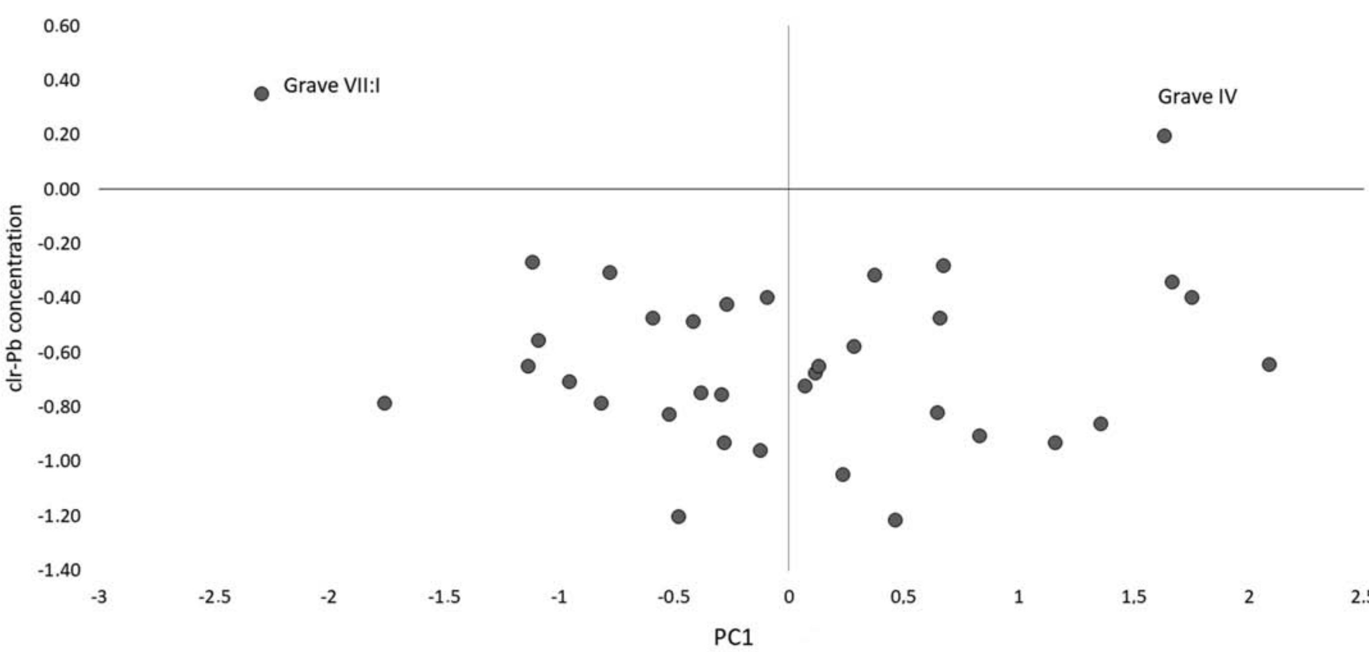

FIG. 10. Pb concentration (clr-transform) vs. the degree of bone alteration (PC1). The more positive PC1, the better bone preservation.

an active bone resorption to transfer calcium to the foetus (whose skeleton is growing), and Pb follows the same route as calcium (Gulson et al., 2003). This means that a mother who lived part of her life in Silbojokk or another mining area (e.g., Lövåsen or Kvikkjokk, albeit not Sala; Figs. 1 and 8), could have transferred Pb to the baby even if she was not living in a polluted environment during pregnancy because Pb was already stored in her bones. More studies considering double burials of mother and child will help us to better understand this process.

CONCLUSIONS

In this study, we have studied diet, mobility, and exposure to Pb in an Arctic mining population from the 17th and 18th centuries. The individuals buried in Silbojokk had a diet based on mixed resources. This mix seems to have been similar within the whole population, with two notable exceptions. Two individuals had a diet mainly based on freshwater fish. The sulphur isotope values for 21 individuals indicate that they most likely were from the region. However, the strontium isotope analysis indicates that three out of 11 individuals were non-local during their childhood. This result also agrees with the written sources on Silbojokk and Nasafjäll, which describe the presence of both local and recruited labour.

It is quite obvious that the mining and smelting activity had a negative impact on this population in terms of Pb exposure. Although diagenesis cannot be completely ruled out, our results suggest that Pb was incorporated during life, while copper and arsenic seem to have been absorbed mainly post-mortem. According to the World Health Organization (WHO, 2019), Pb exposure even at low doses causes a significant burden of disease. Therefore, living in Silbojokk could have had negative consequences on their health and affected multiple body systems.

The establishment of the mine in Nasafjäll and the smeltery site in Silbojokk had an immense and negative impact on the environment and on people living and working there. Nature, humans, and animals were severely affected by the mining activities and still are. These effects can be seen as a colonial infraction on nature and people in Sápmi.

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