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International Trade in Outland Resources: the Mining and Export of Lead in Early Medieval England in Light of New Isotope Data From York

By JANE KERSHAW[1] *and* STEPHEN MERKEL[2]

THE PROCUREMENT AND TRADE OF VALUABLE 'outland' resources was fundamental to the early medieval economy, linking upland, forested and coastal regions with emerging urban markets. Recent research has detailed the increased exploitation and production of raw materials, including tar, soapstone, iron and antler, in the centuries prior to and during the Viking Age, primarily within Scandinavia. Here, it is argued from new isotope data relating to lead from 9th- to 11th-century York that there was an additional, international trade in a valuable but non-precious outland resource. Lead mined from the North Pennines was exported across the North Sea on a significant scale, connecting the remote uplands of northern England with urban nodes including York, Kaupang (Norway) and Hedeby (Germany; historically Denmark). We argue that North Pennines lead was part of a wider early medieval English lead export industry that operated from at least the mid-8th century AD.

Recent research in early medieval archaeology in Scandinavia has drawn attention to the procurement and trade over long distances of valuable, yet non-precious, materials from 'outland' zones including forests, uplands, coastal and Arctic environments. Thanks to new scientific provenancing techniques, materials such as whalebone, fur, antler, tar and iron can be traced to their origin, revealing extensive resource networks connecting outlands with settlement and agrarian regions, including southern Scandinavia emporia (Ashby et al 2015; Hjelle et al 2015; Lindholm and Ljungkvist 2016; Hennius 2018). The timeframe of these developments is variable, with some industries showing intensification in the centuries prior to the Viking Age (eg Hennius et al 2018; Hennius 2020), and others being interpreted as a response to demands initiated by the maritime expansion, increased trade networks and urbanisation of the 8th to 11th centuries (eg Ashby et al 2015; Hennius 2018). The cumulative effect of these studies is to deepen understanding of the hitherto largely overlooked 'utmark' or outfield economy (Øye 2005) as well as the mechanisms of extraction, transport and exchange that connected producers in outland zones with distant, yet closely networked, consumers and craftspeople (Lund and Sindbæk 2022, 191–2). To date, these studies have been

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confined to Scandinavia and Scandinavian regions of exploration. This article expands this scope in discussing the exploitation and trade of lead mined from England.

Lead and lead alloys were fundamental to early medieval craft, industry and the built environment. Lead was used to roof and repair buildings, to make vessels, to create low-cost dress items and to support a range of manufacturing processes, from the cupellation of silver to the production of glass, dyes and pottery glazes. It forms a significant component of many early medieval urban archaeological assemblages in England and Scandinavia, particularly from the later 10th century (eg Lincoln: Bayley 2008, 35; Winchester: Biddle and Petersen 1990, 89; York: Bayley 1992, 810–14; Hedeby: Anspach 2010; Kaupang: Pedersen 2016). Yet, despite the widespread use of lead, this valuable but non-precious base metal has received only limited scholarly attention (Raistrick and Jennings 1983; Pedersen 2016; Bayley 2018). Consequently, little is currently known about the provenance, procurement, transport and trade of lead in the early medieval period.

The lead ore sources of Britain are relatively well characterised (Bayley 2018, 56–62; Ixer and Vaughan 1993). Thanks to surviving documentary accounts, it is widely believed that Derbyshire was Britain's pre-eminent, if not only, early medieval lead-mining region. However, there has as yet been no isotopic work to provenance archaeological lead from early medieval assemblages in Britain, meaning that the relationship between source ores and end products is unknown. We therefore conducted lead-isotope analyses of 26 archaeological lead and lead-alloy objects recovered from excavations at 16–22 Coppergate, York, with the aim of elucidating the production and supply chain linking the source ore to the Anglo-Scandinavian and later town. The results reveal the existence of lead-ore sources not previously thought to have been exploited in the early medieval period.

The data suggest that the lead was sourced not in Derbyshire as might have been predicted, but closer to York, in the North Pennines. Moreover, we discovered through comparison of the York data with existing lead-isotope datasets from Scandinavia that the same northern English lead source also supplied the emporia of Kaupang and Hedeby. This points to the exploitation and trade of North Pennines lead on a significant scale. We found, further, that North Pennines lead was one of several English lead sources mined and traded across the North Sea; other evidence from Scandinavia points to the receipt of lead from Derbyshire and, perhaps, south-western England. To judge from the chronology of the lead artefacts sampled, seaborne trade in English lead dates from at least the mid-8th century, with North Pennines lead in partiuculer being exported from c. 800 AD. The evidence from York indicates the continued exploitation of North Pennines lead into the early 11th century. Below, we present the results of this analysis, following a review of the production and uses of lead. We then discuss the procurement, transport and trade in lead, both in relation to York and in a wider North Sea context.

BACKGROUND: THE PRODUCTION AND USES OF LEAD

Lead was smelted from galena, lead sulphide (PbS), probably fairly near to the site of extraction. The first documentary evidence for medieval lead smelting in England comes from the 12th century, and concerns the use of bole, or bale, furnaces. These were simple, wood-fired hearths surrounded by a small stone wall, which relied on draught provided by wind. Consequently, bole furnaces were located on scarp edges, in locations near the source ore as well as fuel resources (woodland) and water (Murphy and Baldwin 2001). They consisted of layers of brushwood and ore placed over dry chopwood (Murphy and Baldwin 2001, 18). The smelting of the ore followed a two-step, roast-reduction process, resulting in molten slag and lead metal, the latter of which could be collected at the bottom of the furnace or drawn off *via* a tap hole and the slag ('blackwork') discarded (Gill 1992a). Although the process was not efficient, the rate of recovery of lead being as low as 50% (Willies 1991, 93), it was not until the end of the medieval period, and the introduction of high-temperature charcoal-fuelled slag hearths, that lead could be extracted from slag under more reducing conditions (Tylecote 1986, 57). Nonetheless, low-temperature smelting under moderately reducing conditions was ideal for producing soft, pure, and easily worked lead (Craddock 1995, 209).

This soft, pure lead had many uses. It was an essential building material, lead sheets, cast on beds of sand, being used for roofing and guttering, particularly on churches. Writing in the 12th century, William of Malmesbury recounted that, in c 670, the roof of York Minster was repaired with 'lead sheeting' to 'protect it from storm damage' (*GPA* 3: 100). Some 20 years later, Bishop Eadberht replaced the reed thatched roof of Lindisfarne with 'plates of lead' (*EH* 3: 25). Indeed, it is likely that the building of stone churches from the 7th century onwards stimulated an increased demand for lead roofing, as well as items such as coffins, inscribed plaques, chalices and lead cames for window glass (Loveluck 1995; Blair 2005, 137–8; Cramp 2005, 161–2). Lead was also required for vessels, including basins, containers for tools and hoards (Cowgill 2009; Graham-Campbell 2011, 127–31), and vats for domestic, industrial and/or religious use, including as fonts (Blair 2005, 461–2). Two lead vessels containing an iron tool hoard were found near excavations at Flixborough, Lincolnshire (Cowgill 2009). They form part of a growing corpus of large, cylindrical lead vessels from eastern and northern England dating to c 750–950, which also includes a recent detector find from Cottingham, Northamptonshire, with decorative panels in the 9th-century Mercian animal style (Mainman and Rogers 2004, 466; PAS 'Find-ID' WAW-A4D8D4).

There is a perception that, from the late 7th to early 9th century, lead was restricted in use to church settings and to the construction of vessels (Cowgill 2009, 276). Arguably, this view does not take full account of the evidence for the use of lead in early industrial processes (eg for vats used in salt production; see Hurst and Aitken 1997, 17–27) or the evidence for lead working at 8th- and 9th-century settlements such as Flixborough or Lurk Lane, Beverley (Loveluck 1998, 157) and the 8th-century emporia, including York (Bayley 1993, 1238). Nevertheless, there is a marked increase in the supply and availability of lead in the later 10th and 11th centuries, reflecting the growth of urban centres and mass-production processes (Thomas et al 2008, 180). From this period, lead and lead-tin alloys (pewter) were increasingly used to make smaller, decorative dress accessories such as brooches and strap-ends. They could be cast in antler or wooden moulds and satisfied a growing demand for affordable dress items from burgeoning urban populations (Bayley 1992; Weetch 2017).

Lead products also supported the manufacture of other metal items. In the 9th and 10th centuries, lead patrices were used to create moulds for casting dies (Roesdahl 1981, 116, 118, no YMW13) while lead trial pieces represent an early step in the production of metalwork and coinage (Pirie 1986). Lead was an important constituent of copper alloys: from the mid-7th to 10th centuries, cast copper-alloy artefacts usually contain c 3–4% lead (Blades 1995, 220). Lead was also vital in solders (Bayley 1992, 810) and pigments (Gameson et al 2015). Lead was added to silver during the refining process (cupellation), reacting with oxygen to form a litharge (PbO) which would then draw away impurities in the metal to leave behind pure silver: an important process in a controlled monetary currency where the silver fineness of coins had to be guaranteed. From the later 10th century, lead oxide was also used in high-lead glass (containing 70–80% wt lead oxide), for the manufacture of rings and beads (Bayley 2000), while white lead glaze was applied to pottery, particularly Stamford ware (Leahy 2003, 102–4).

LEAD AT COPPERGATE, YORK

Lead, then, had many uses. It is clear that it was worked extensively at 16–22 Coppergate as part of a broader, thriving metalworking industry recorded from the Anglo-Scandinavian period (Period 3) onwards (Tab 1). At Coppergate, excavations in the 1970s and 80s uncovered 400 pieces of lead, tin or lead-tin alloys, totalling c 30 kg (Bayley 1992, 778, 810). Much of the material was scrap metal, indicative of active working, with lead frequently found in the form of sheet, or strips cut from sheet (Bayley 1992, 787–88, 811, tab 49). The assemblage included over 200 spillages (lead droplets spilled during casting), offcuts, a sprue and runners, indicating casting in moulds. Also present at Coppergate were failed or unfinished castings for pendants and 'badges', where the lead had not sufficiently filled the mould or where the items had sprues or casting flashes still attached (Bayley 1992, 779, tab 49, 814). A lead-tin alloy bar may have been used as solder or for tinning iron objects. Tin and lead-tin plating is commonly observed on iron objects form Coppergate, including on strap-ends, buckles, pins and spurs, and would have helped to protect the objects from corrosion (Bayley 1992, 810).

Finds of litharge cakes (lead oxide) from 16–22 Coppergate show that lead was also used as a raw material in the cupellation of silver (Bayley 1992, 749), possibly in connection with the site's mint, which is separately attested by the recovery of several lead trial pieces for coin dies (Pirie 1986, 33, 38–41). Lead blocks/ingots quite literally supported the production of other metalwork: some carry cut and punch marks and may have been placed underneath metal sheets while decoration was applied, and thus appear to have functioned as anvils (Bayley 1992, 785–6, fig 346 [4116]). The use of lead in glass-working at Coppergate, as well as 22 Piccadilly and other sites in York, is demonstrated by the presence of over 1,500 crucible sherds containing high-lead, usually opaque green/black, glass. The same sites have yielded high-lead glass spills from crucibles, droplets, other waste material and part-made and malformed glass beads and slickstones, for smoothing and polishing (Bayley and Doonan 2000, 2520–5).

The chronological distribution of lead and tin finds from Coppergate indicates a concentration of lead working from Period 4B (c 930/5– c 975) which is characterised

TABLE 1

Relevant site phases at 16–22 Coppergate, York. *Table after* Hall 2000, *tab* 223.

Period	**Date**
3	Mid-9th–late 9th/early 10th century
4A	Late 9th/early 10th century–c 930–5
4B	c 930/5–c 975
5 A	c 975
5B	c 975–early- to mid-11th century

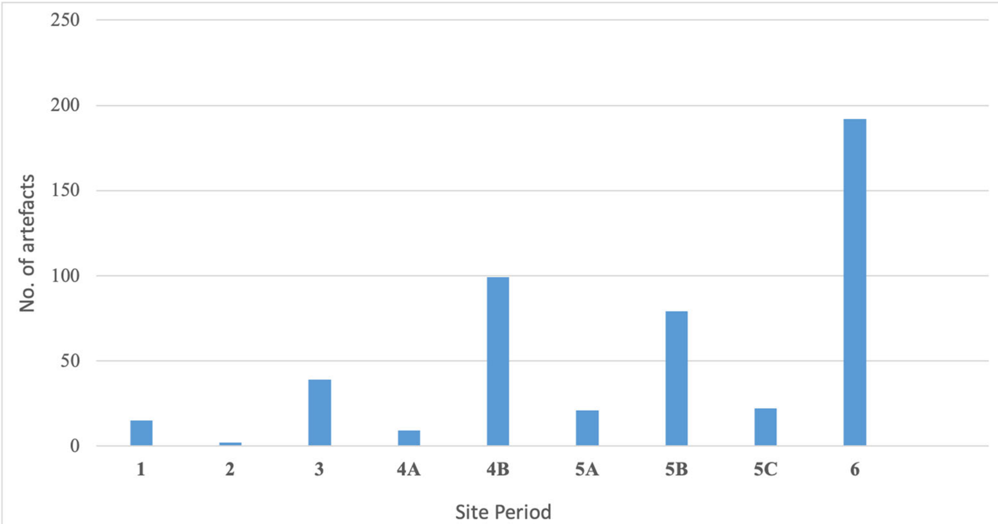

FIG 1
Number of lead and tin scrap artefacts by site period excavated from 16–22 Coppergate. *Data after* Bayley 1992, *tab 49*.

by the laying out of four long, street-fronted tenements, each with post-and-wattle buildings (Fig 1, Tab 1; Hall 2000, 2460). Lead finds remain abundant across Period 5. As might be anticipated due to the long chronology of Period 6 (later 11th to 16th centuries), the number of lead/tin finds from this phase increases significantly again. The production of high-lead glass at Coppergate also dates from the mid-10th century, with a main period of production in the 11th century, 'probably earlier rather than later' (Bayley and Doonan 2000, tab 246, 2528).

POTENTIAL SOURCES OF LEAD

It is commonly believed that the exploitation of fresh lead ore (principally galena) was limited in the early medieval period, with that in circulation mainly constituting recycled Roman lead (Willies 1992). Lead was mined in Roman-period Britain, primarily in Derbyshire and Mendip (Somerset), with smaller production in Flintshire, Shropshire and, potentially, Yorkshire (Tylecote 1986, 61–70). Ronald Tylecote includes Yorkshire among areas of lead mining in Roman Britain, on the basis of the discovery in the region of four lead pigs or ingots (see below for further discussion). Thanks to its low melting point (327 °C), lead is easy to melt and recast. Following the decline and then withdrawal of Roman infrastructure, it seems likely that lead was, for a time, indeed drawn from a recycled stock (for a discussion, see Brooks et al 2004, 136–7; Fleming 2012, 21–2).

However, the establishment of Christian monastic houses from the second half of the 7th century stimulated a great increase in demand for lead, generating a supply that could only have been met by fresh mining (Loveluck 1995, 90). Indeed, it has been suggested that control over lead mines in Britain's best documented lead-producing region, the Derbyshire Peak district, was responsible for the wealth of 7th-century graves in the area (Loveluck 1995, 90–91). The availability of lead from this period onwards is less certain: evidence for lead working is documented at emporia and 8th/9th-century excavated rural sites, and is attested in documentary sources from the 9th century (see below). By the 10th century, the use of lead in personal ornaments, pottery glazes and glass suggests that it was relatively abundant. Rather than deriving from an existing, continually depleting stock, it is likely to have been freshly mined (Biddle and Petersen 1990, 89).

This view is supported by chemical data. Elemental analysis of Roman lead objects, including bars, weights, tokens, and rolled and folded sheet, demonstrates that they are consistently contaminated with tin (up to 1% wt and sometimes higher) (Cochet 2000, 150–1, tabs I–II; Cowgill and Northover 2009; Bode 2016, read together with Mirschenz 2016). This likely reflects the frequent recycling of lead containing tin solder (Wyttenbach and Schubiger 1973; Tylecote 1986, 75). (Lead pigs found in regions of lead ore do not contain tin, supporting the notion that the tin derives from circulation and recycling—Tylecote 1986, 65). However, analysis of three lead vessels dated c AD 650–850 from Lincolnshire demonstrated that they were made of exceptionally pure lead with no detectable tin: they must therefore derive from fresh lead (Cowgill and Northover 2009). XRF analysis of the wider corpus of lead objects from 16–22 Coppergate conducted in the 1980s returned parallel results: c 90% of the manufacturing-related lead objects were found to be pure lead, and most of the finished artefacts either pure lead or pewter, a deliberate alloy of tin and lead (Wilthew 1984; Bayley 1992, 810).

Our pXRF analysis of the 26 Coppergate lead objects under consideration here (see p 13 below) present a similar picture. All objects are composed of >99.7% Pb except for three which contained detectable amounts of tin (Tab 4). (The Pb-Sn alloys are rod 11344 (c 15% Sn), bar 11770 (c 3% Sn) and pendant 8323 (c 35% Sn); Table 2). The levels of tin present in two of the three items indicate deliberate alloying, rather than contamination. The results indicate that the Coppergate lead likely derived from freshly exploited ore and not recycled metal. From which ore sources could it have originated?

Writing c 731 AD, Bede famously declared that Britain was rich in 'veins of metals, as copper, iron, lead (*plumbum*), and silver' (*HE* 1: 1, 17). The lead from Coppergate could have come from one or several of Britain's multiple lead ore fields, or, given York's status as an international entrepot, from abroad. Britain's lead-ore deposits run from the southern uplands of Scotland south along a central spine encompassing the Lake District, the northern Pennines, the Yorkshire Dales and the southern Pennine hills. They pick up again further to the west, in Wales and along the English/Welsh border, the Mendips and Cornwall and Devon (Bayley 2018, fig 1). In a recent review, Justine Bayley considered the documentary and scientific dating evidence for lead mining in the medieval period, concluding that most of Britain's ore fields were likely worked at some point (2018). Nonetheless, the evidence for *early* medieval mining in particular is limited, with the exception of the southern Pennine ore fields in Derbyshire. Below, we outline the contender sources for York's supply of lead before going on to discuss the results of the lead isotope analyses.

Table 2
Detailed list of lead items from York sampled in this study.

Small Find No	Artefact	Material	Context	Cat No	Site Period
11344	Rod	Lead-tin	31383	4126	3
11942	Fragment	Lead	31650	4139	3
15776	Fragment	Lead	30760	4139	3
11332	Bar	Lead	30296	4142	4A
4733	Spillage	Lead	18127	4193	4B
7528	Spillage	Lead	23245	4193	4B
12802	Rod	Lead	32226	4153	4B
8323	Pendant	Lead-tin	24647	4148	4B
4088	Strip	Lead	15173	4199	5A
4973	Run-off	Lead	18458	4214	5A
401	Offcut	Lead	2778	4227	5B
1031	Strip	Lead	7262	4224	5B
1274	Run-off	Lead	8290	4253	5B
1279	Sheet	Lead	7378	4238	5B
2076	Sheet	Lead	5641	4239	5B
2262	Bar	Lead	7669	4218	5B
3837	Rod	Lead	7920	4220	5B
3877	Run-off	Lead	14325	4253	5B
4233	Strip	Lead	15368	4221	5B
4342	Offcut	Lead	15470	4232	5B
4372	Sheet	Lead	15416	4237	5B
4416	Spillage	Lead	15530	4247	5B
5044	Offcut	Lead	14434	4234	5B
6918	Fragment	Lead	19320	4255	5B
11770	Bar	Lead-tin	29465	4219	5B
5897	Ingot	Lead	18962	4216	5B

YORKSHIRE DALES (ASKRIGG BLOCK, NORTH PENNINES)

Geographically, York's closest lead-ore source is the Yorkshire Dales, with mineralisation in Nidderdale, Grassington in Wharfedale and Gunnerside in Swaledale (Ixer and Vaughan 1993, 356, 361–3). Today, the region's landscape carries the visible remains of a lead-mining industry that commenced in the 17th century and reached its peak in the mid-19th century: disused mines, managed water systems, spoil heaps, smelt mills and unvegetated scars. It is unclear, however, when mining here began.

The evidence for Roman mining in the Yorkshire Dales is slim and tentative, resting on antiquarian records of a small number of Roman lead pigs (most now lost) found at Nidderdale and Swaledale (for an overview of the evidence, with references, see White 1988, 204; Bayley 2002). Lead-isotope analyses carried out on Roman lead pigs found in Britain and on the Continent show no link to the distinctive lead-isotope ratios characteristic of the Yorkshire Dales; instead, mines in Derbyshire and/or the Mendip Hills dominate (Hanel et al 2013; Bode 2016; Ponting 2018).

The status of lead mining in Yorkshire in the early medieval period is uncertain. Unlike in the southern Pennines (discussed below), there is no mention of lead production in Yorkshire in Domesday Book. The earliest documentary evidence for lead mining in the region dates to the mid-12th century when Roger de Mowbray gave rights to lead working at Greenhow Hill in Nidderdale to Fountains Abbey (Smith and Murphy 2010; Bayley 2018, 60). At a similar date, in c 1145, Jervaulx Abbey was given the right to dig lead ore in Wensleydale (Gill 1992b, 113). From this point onwards, regional lead mining appears to have been organised by, and largely in the hands of, monastic houses.

CUMBRIA/CO DURHAM (ALSTON BLOCK, NORTH PENNINES)

Further north within the Pennine hills, where the modern-day counties of Cumbria, County Durham and Northumbria meet, lies the Alston Block, with lead-ore fields in Allendale, Weardale and Teesdale (Ixer and Vaughan 1993, 358–61). The Northumbrian monastic houses of Lindisfarne and Hexham were situated within or close to this region, and it is reasonable to suppose that they were supplied with local lead (Maddicott 2000, 31–2). Admittedly, the evidence for lead working in Teesdale is slim before the 16th century (Pickin 1992). However, argentiferous lead ores from Weardale, notably around Alston, are known to have supplied silver to mints in Carlisle and Newcastle from the 12th century. Debate continues about the scale of their contribution (Allen 2012, 238–71), but documentary records chart a parallel trade in lead (Drury 1992). Whether lead was mined at an earlier date, with or without silver extraction, is currently unknown.

DERBYSHIRE (PEAK DISTRICT OREFIELD, SOUTH PENNINES)

Derbyshire is perhaps the best-known lead-mining area in England and is usually seen as the dominant, if not only, supplier of lead in the early medieval period (Hill 1981, 111; Tylecote 1986, 71; Loyn 1991, 106). Documentary sources indicate that Derbyshire lead mines were actively exploited in this period, as they had been under the Romans (Daniel 1980; Tylecote 1986; Dearne 1993, 158–9). Lead mines were worked at Wirksworth, Derbyshire, an estate under the control of Repton Abbey. In AD 835, Abbess Cynewaru granted land there to earldorman Humberht in return for an annual render of lead worth 300 solidi (Hart 1975, 102). Domesday Book lists several Derbyshire lead works, that is, smelters (*plumbariae*) at royal estates including Ashford, Bakewell, Matlock and Wirksworth, each of which served multiple mines (Bayley 2018, 60). The Derbyshire lead-mining industry was thus well-established by the 11th century.

There is evidence in the Roman and medieval periods that Derbyshire lead was exported along the Trent to the Humber, from where it could have travelled along the coast or across the North Sea. Other routes went *via* the fenland port of Boston, where, in the 13th century, a regular lead market was established (Raistrick and Jennings 1983, 26, n 4, 28). If this route were followed in the early medieval period, Derbyshire lead could be a real contender for the Coppergate lead-alloy objects. Certainly, the 873–4 Scandinavian takeover of Repton, which controlled the Wirksworth mines, provides a plausible historical context for the supply of Derbyshire lead to Scandinavian-controlled York.

MENDIPS (MENDIP OREFIELD)

Although the Mendip orefield south-west of Bristol in modern-day Somerset encompasses 120 square kilometres, fewer than 20% of the region includes significant mineralisation (Ixer and Vaughan 1993, 392). Lead ore is focused on a region incorporating Charterhouse, Green Ore and Priddy (Ixer and Vaughan 1993, fig 7.12). The Romans mined for lead on Mendip, the most significant lead-silver mines being Charterhouse, and Roman lead pigs have been isotopically linked to Mendip sources (Fradley 2009; Hanel et al 2013; Ponting 2018). The discovery of litharge at Green Ore suggests that the Romans also extracted silver from the lead (see discussion in Tylecote 1986, 69).

Whether this lead/silver industry continued into the Anglo-Saxon period is unknown. A letter of AD 852 from a Frankish abbot, Lupus of Ferrières (d c 862) to the Anglo-Saxon king Ethelwulf of Wessex, suggests that the king could find favour with God by sending him (Lupus) lead for the roofing of Ferrières Abbey, which hints at the cross-Channel export of lead from the royal estates at Mendip (Whitelock 1979, no 217, 878–9). These incorporated Priddy and Green Ore at Chewton, and Charterhouse at Cheddar, and it has been suggested that silver from these lead ores fuelled royal minting (Maddicott 1989, 44–6). A concentration of mints in the vicinity of Mendip in the later 10th century may lend support to this claim (Maddicott 1989, 45; Bayley 2018, 62).

AVON (FORMERLY SOMERSET)/BRISTOL

Smaller veins with similar mineralisation, yet distinctive lead-isotope ratios, occur in the regions just outside Mendip, particularly to the north-west, around modern-day Bristol (Ixer and Vaughan 1993, 392 and fig 7.12). This is significant, since a boundary clause for the estate of Stoke Bishop, contained within a charter of AD 883, mentions a 'Leadgedelf' ('lead diggings') on Durdham Downs on the outskirts of Bristol (Everett 1961). Lead mining in the Bristol area can be traced back to the Iron Age (Ponting 2018). Two Roman lead pigs found in Wade Street, Bristol, are assumed to have been cast from Mendip lead (Elkington 1976, 195). However, their lead-isotope ratios indicate a connection with Bristol lead sources, rather than those from Mendip proper, and it seems more likely that they were local products (Bristol HER 2518).

OTHER BRITISH OREFIELDS

It is possible that the Coppergate items were made from lead from one of Britain's other lead fields. Iron-Age lead-tin objects have been identified through isotope analysis as deriving from Devon/Cornwall (Ponting 2018). Argentiferous lead ore was mined in south-western and northern Devon from the late 13th century, reaching a peak in the 16th/17th centuries (Bayley 2018, 62). This industry may have had a deeper history. There is evidence for Roman lead mining in north Wales, which may have continued into the early medieval period (Bayley 2018, 61). A grant of privilege for the lands of the monastery at Hanbury (Worcestershire) in AD 836, lists among its appurtenances, 'salt-pits and lead-furnaces, and villages and all things belonging thereto', raising the possibility of a local lead source along the English/Welsh border (Whitelock 1979, no 85, 518–19). The northern Lake District hosts a number of lead deposits, particularly around Keswick and Caldbeck. A lead-smelting site near Caldbeck at Calebrack has yielded charcoal with a radiocarbon date of AD 1020–1200 cal at 95% confidence (AD 1020-1170 cal at 68% confidence; Lab code: Calebrack A 051) (Smith 2006, 101–2; Tab 1). It may have processed lead ore from veins at Brandy Gill or Driggith, although the earliest documented mining in the area, relating to the mining of silver (from lead ore) at Caldbeck, dates to the early 14th century (Smith 2006, 102). There are also lead-ore fields in the upland area of southern Scotland, in the Lowther Hills and in Dumfries and Galloway. Documentary evidence indicates lead working at Leadhills-Wanlockhead ore fields (Lowther Hills) in the 13th century, but recent radiocarbon dating from slag scatters in the area produced late 10th- and 11th-century dates (Pickin 2010, 83).

CONTINENTAL SOURCES

Alternatively, lead could have been imported to York from overseas.

MELLE AND THE CÉVENNES, FRANCE

Melle in Aquitaine, France, hosted a prominent Merovingian and Carolingian lead/silver mine, which, according to radiocarbon dates, was exploited from the 6th- to late 10th century (Téreygeol 2002, 2007, 2013). Although the scale of its silver production is debated (Bettenay 2022), the intensive mining of Melle ore has been causally tied to the introduction of silver currency in northern Europe (Loveluck et al 2018). Alongside silver, its lead circulated widely, and has been traced isotopically in Viking-Age assemblages in Scandinavia (Téreygeol 2007; Pedersen et al 2016, 11–12). It is thus possible that lead from Melle also reached York in the 9th and 10th centuries.

The Cévennes Mountains of the southern Massif Central were mined for lead and silver in the 11th and 12th centuries, with metal production concentrated on the Mont-Lozère Massif (Baron et al 2006). Since this production overlaps chronologically with the latest (11th-century) lead finds from York, it is considered a possible source for those items.

THE RHENISH MASSIF AND HARZ MOUNTAINS

The Rhenish Massif has multiple lead deposits, and it is possible that lead metal was among the region's many commodities exported to the North Sea region along the Rhine (Merkel 2016, 56). Low silver-bearing galena ores were mined for lead in the north-western Eifel, Aachen and Siegerland during the Roman period and in the High Middle Ages (Bartels and Klappauf 2012, 169–74). Some deposits appear to have been of regional significance. Lead from Brilon, south of Padeborn, supplied the major monastery of Corvey in 1103 (Jülich 2006, 56). However, to date there is no secure evidence of early medieval lead mining in the area (Merkel 2016, 56).

From the 9th century, silver-lead deposits were also worked in the Upper Harz region of the Harz mountains, while silver production became supra-regionally important during the reign of Otto the Great in the second half of the 10th century (Klappauf 2014; Merkel 2016). Silver mining concentrated on silver-rich fahlore minerals and galena enriched in these minerals, but most galena from the Harz was silver poor and uneconomical to process (Bartels 2014). Lead and litharge would have been by-products of silver production and it is possible that lead metal was traded north. At present, the extent of pre-/Ottonian lead production and its role in regional consumption and long-distance export are unexplored questions. We include lead-isotope data from the Rhenish Massif and Harz Mountains within our reference dataset.

LEAD-ISOTOPE ANALYSIS OF LEAD ARTEFACTS FROM COPPERGATE

We sought to evaluate the sources of the Coppergate lead through the application of lead-isotope analysis. The radioactive decay of uranium and thorium and geochemical processes create a natural variation of lead-isotope ratios within metallic ores. Owing to the fact that lead isotopes do not fractionate significantly during production processes, the relative abundance of isotope ratios in artefacts can be compared with those in ores to identify candidate sources of metal, and rule out others. It is widely recognised that the method cannot identity with absolute certainty the source ore: different ores can have overlapping isotope values, while the number of ores that have been analysed is, and always will be, incomplete (Bode et al 2009). In addition, the mixing of two or more different sources of lead will result in isotope values that are likewise a mixture of the different sources.

The application of lead-isotope analyses to determine lead sources in Britain has been viewed as particularly problematic, due to the similar geological age of Britain's orefields and their subsequently similar lead isotope values (Bayley 2018, 63). However, while the issue of ore overlap cannot be avoided for some orefields—such as Derbyshire and Avon/Bristol—overall, we find the available reference data for Britain useful for excluding some sources, and including others (Rohl 1996). Supplemented with more recent isotope studies for both England, Melle, and other mining locations in France and Germany (see list below), it offers a robust dataset for discriminating between potential lead sources.

A number of lead objects were sampled from Coppergate (Tab 2; Fig 2). As noted above, the site has yielded c 400 pieces of lead, tin or lead-tin alloys, primarily in the form of manufacturing debris. Whereas finished artefacts may have been made elsewhere and imported to the site in their final form, manufacturing debris is highly likely to reflect production processes in York. It ought, therefore, to be representative of raw material supplied to the town. We selected 26 artefacts to analyse, choosing a range of different objects types. Twenty-five items relate directly to manufacturing, and include lead bars, sheet, offcuts and spillages. The remaining item, a pendant pierced for suspension and decorated with a pseudo-runic inscription, still has a sprue and casting flash attached (Bayley 1992, fig 340, 4148).

All objects were retrieved during excavation and can be attributed to site phases, specifically phases 3 to 5B: from the mid-9th to the early-to-mid 11th century (Fig 3; Tab 1). The majority, 15 items, come from period 5B (c 975 to the early-to-mid 11th century). This chronological distribution reflects the high degree of intensity of lead-, and other metal-working observed at Anglo-Scandinavian Coppergate from periods 4B and 5 (Tab 1; Bayley 1992, 816).

METHOD

We took four to 15 mg of material from each of the 26 objects. The micro-samples were acquired by clipping in inconspicuous locations and in two objects (small find nos

FIG 2
Selection of lead and lead-tin artefacts analysed in this study: (a) ingot, 5897; (b) bar, 2262; (c) rod, 3837; (d) bar, 2262; e) sheet, 2076; (f) bar, 1170. *Photographs: York Archaeological Trust.*

11332 and 12802) by micro-drilling with a 0.6 mm drill bit. The solid samples were mechanically cleaned of corrosion and their compositions were checked by semi-quantitative pXRF.

For each item, we digested between one and 13 mg of material for lead-isotope analysis. Samples were digested using dilute nitric acid and diluted to a concentration of 20 ppb Pb. The Pb-solutions were analysed by multi-collector inductively coupled plasma mass spectrometry at the Earth Sciences Department, University of Oxford. Solutions were doped with thallium, which was used in correction, and mercury interference was measured and corrected. Each set of three solutions was bracketed by SRM981, which was then used to normalise the values to those of Todt et al (1996). Each sample solution was measured three times, and the standard deviations represent the variability of the repetitions. The analytical result of the standards can be found in Table 3 and that of the Coppergate lead in Table 4.

The results were interpreted against a large amount of aggregate lead-isotope data (published and unpublished) relating to lead ore (galena), particularly from British and Continental deposits. These include:

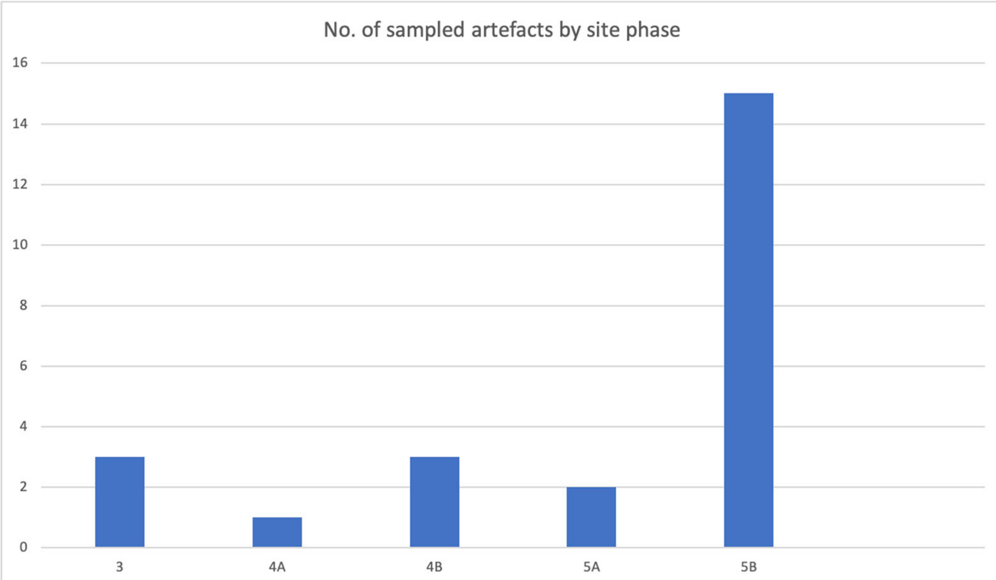

FIG 3
Number of sampled artefacts by site phases.

- Lead ore data from the British Isles (Rohl 1996 [galena only]; Scaife et al 2001). (The Rohl data is supplemented by additional data in the OXALID database (OXADLID database). We exclude marked (*) analyses (median values of repeated analyses), which were frequently outlying points)
- Lead-ore data from the mine of Melle in Aquitaine (Téreygeol et al 2005) and medieval lead slag and vitreous material produced at Melle (Gratuze et al 2018)
- Lead ore and medieval slag from Mont-Lozère, Cévennes-France (Baron et al 2006)
- Lead ore from the Upper Harz (Bad Grund) and Rammelsberg Germany (Lehmann 2011)
- Lead ore from the North Eifel, Germany (Bleialf, Mechernich, Maubach, Rescheid) (Bielicki and Tischendorf 1991; Schneider 1994; Krahn and Baumann 1996; Durali-Müller 2005; Bode 2008)

RESULTS

The overall consistency in the lead-isotope results suggests that lead sources over this period were relatively uniform and stable. Of the 26 items analysed, 25 fall within a single field. The single outlier is discussed below.

On the basis of the lead-isotope results, several sources for the 25 lead items can be excluded immediately. Starting with the geographically most distant sources, it is clear that lead from Melle, France, makes no contribution to the Coppergate lead, nor do documented mines from Mont-Lozère (Fig 4). Ore from the Rammelsberg can be ruled out entirely. Ore from the Upper Harz has a much narrower range of isotope ratios than the York finds, but is consistent with a few York items. Similarly, the North Eifel ore overlaps with a sub-set of the York artefacts (Fig 4). However, while

TABLE 3
Analysis of lead-isotope standards. Pre-normalised SRM981 values and post-normalised SRM982.

Standard	208/206	2σ	207/206	2σ	206/204	2σ	207/204	2σ	208/204	2σ
SRM981	2.1664	0.0002	0.91457	0.00004	16.932	0.002	15.485	0.002	36.681	0.006
SRM982	0.9996	0.0002	0.46694	0.00003	36.724	0.004	17.148	0.002	36.709	0.007

these continental ore deposits could offer a partial explanation for the Pb isotope distribution of the York finds, the York material aligns much more fully with other sources.

Other sources in Britain can also be ruled out (compare Coppergate data with Rohl 1996; Ponting 2018). The southern highlands of Scotland, including Leadhills, and Dumfries and Galloway (Wanlockhead and Woodhead mines), together with sources in Wales, can be ruled out as candidates. So too can sources in the Lake District. There is very slight overlap between the Coppergate values and those from the Mendip ore (distinct from Bristol/Avon ore), which in turn overlap with data from Devon/Cornwall, but these sources are not a close match.

Which sources *are* best aligned with the Coppergate data? With the exception of the outlier, discussed separately below, the Coppergate data align closely with lead-isotope results from galena obtained from the North Pennines, specifically the Yorkshire Dales and the borders of Co Durham, Cumbria and Northumberland, including both the Askrigg and Alston blocks. Specifically, ore data from both the Yorkshire Dales (Nidderdale, Grassington, Gunnerside), and Allendale, Weardale and Teesdale plots with the York lead (Fig 5). The lead-isotope results are consistent across the different site phases. We note that some of the Coppergate items can only be accounted for by a North Pennines source. Since the distribution includes lead-isotope ratios that are geologically younger than the other reference datasets, no combination of mixing could result in matching isotope ratios.

Galena ores from the Askrigg and Alston blocks are the geographically closest lead sources to York, suggesting the local supply of this critical raw material. It is possible that all the York lead came from this local source. However, isotopes of other galena from England overlap in part with the Coppergate values, meaning that they cannot be excluded as potential contributors. This is true of Derbyshire and, to a lesser extent, Avon/Bristol: these values overlap in part with each other, and with a subset of the York objects with lower 208/206 Pb ratios relative to 207/206 (see especially the ^{206}Pb plots in Fig 6). These six items are: rod 11344; fragment 6918; run off 3877; ingot 5897; strip 4233 and spillage 4416. Thus, these ore sources cannot be ruled out as the origin of lead in these items.

Two items, a lead run-off and ingot, both from Period 5B, possess almost identical isotope values (small find nos 3877 and 5897). They likely derive from the same (North Pennines) metal stock. Comparing the Coppergate manufacturing debris against the semi-finished pendant resulted in no discernible difference. The pendant plots with the items that also overlap with Derbyshire.

One item, a cylindrical rod folded in half and then bent into an L-shape with a slight casting flash running along the rod (Fig 2c rod 3837), is a clear outlier: its lead-

TABLE 4
XRF results of lead/tin and lead isotope ratios of the Coppergate lead and lead-tin artefacts.

Small Find No	Artefact	Pb (%)	Sn (%)	208	2σ	207/206	2σ	206/204	2σ	207/204	2σ	208/204	2σ
11344	Rod	85	15	2.0828	0.0001	0.84726	0.00004	18.448	0.003	15.63	0.002	38.422	0.007
11942	Fragment	>99	–	2.0859	0.0001	0.84913	0.00003	18.407	0.003	15.63	0.003	38.395	0.008
15776	Fragment	>99	–	2.0854	0.0001	0.84878	0.00003	18.417	0.002	15.632	0.002	38.407	0.004
11332	Bar	>99	–	2.0791	0.0002	0.84371	0.00004	18.514	0.003	15.62	0.003	38.493	0.007
4733	Spillage	>99	–	2.0795	0.0001	0.84401	0.00004	18.51	0.003	15.623	0.002	38.491	0.006
7528	Spillage	>99	–	2.0729	0.0001	0.84059	0.00003	18.591	0.003	15.628	0.003	38.537	0.009
12802	Rod	>99	–	2.0814	0.0002	0.84503	0.00004	18.484	0.002	15.619	0.002	38.473	0.008
8323	Pendant	62	35	2.0781	0.0001	0.84377	0.00004	18.517	0.002	15.624	0.002	38.479	0.005
4088	Run-off	>99	–	2.0799	0.0001	0.84374	0.00004	18.51	0.002	15.618	0.002	38.499	0.007
4973	Run-off	>99	–	2.0772	0.0002	0.84294	0.00004	18.533	0.003	15.622	0.003	38.497	0.009
401	Offcut	>99	–	2.079	0.0001	0.8454	0.00004	18.491	0.002	15.632	0.002	38.443	0.007
1031	Strip	>99	–	2.0842	0.0001	0.84759	0.00004	18.405	0.002	15.599	0.002	38.359	0.006
1274	Offcut	>99	–	2.0754	0.0002	0.8405	0.00003	18.592	0.001	15.627	0.001	38.587	0.005
1279	Run-off	>99	–	2.0831	0.0001	0.8462	0.00003	18.455	0.002	15.617	0.002	38.443	0.005
2076	Sheet	>99	–	2.0799	0.0002	0.84599	0.00004	18.477	0.003	15.631	0.003	38.429	0.007
2262	Sheet	>99	–	2.0812	0.0001	0.84448	0.00004	18.493	0.003	15.617	0.003	38.487	0.005
3837	Bar	>99	–	2.0619	0.0002	0.83001	0.00003	18.854	0.003	15.649	0.003	38.874	0.006
3877	Rod	>99	–	2.0799	0.0002	0.84402	0.00005	18.506	0.003	15.619	0.003	38.492	0.008
4233	Strip	>99	–	2.0789	0.0002	0.84475	0.00005	18.5	0.004	15.628	0.004	38.46	0.011
4342	Strip	>99	–	2.0761	0.0001	0.84193	0.00003	18.559	0.002	15.625	0.002	38.53	0.006
4372	Sheet	>99	–	2.08	0.0002	0.84396	0.00004	18.505	0.002	15.618	0.002	38.491	0.006
4416	Spillage	>99	–	2.0774	0.0002	0.84476	0.00005	18.498	0.002	15.627	0.002	38.429	0.006
5044	Offcut	>99	–	2.087	0.0001	0.84935	0.00003	18.394	0.002	15.623	0.002	38.388	0.005
6918	Fragment	>99	–	2.0815	0.0001	0.84661	0.00003	18.473	0.002	15.64	0.002	38.453	0.005
11770	Bar	97	3	2.0858	0.0002	0.84923	0.00005	18.408	0.002	15.632	0.002	38.395	0.006
5897	Ingot	>99	–	2.0799	0.0002	0.84403	0.00005	18.508	0.003	15.621	0.003	38.494	0.008

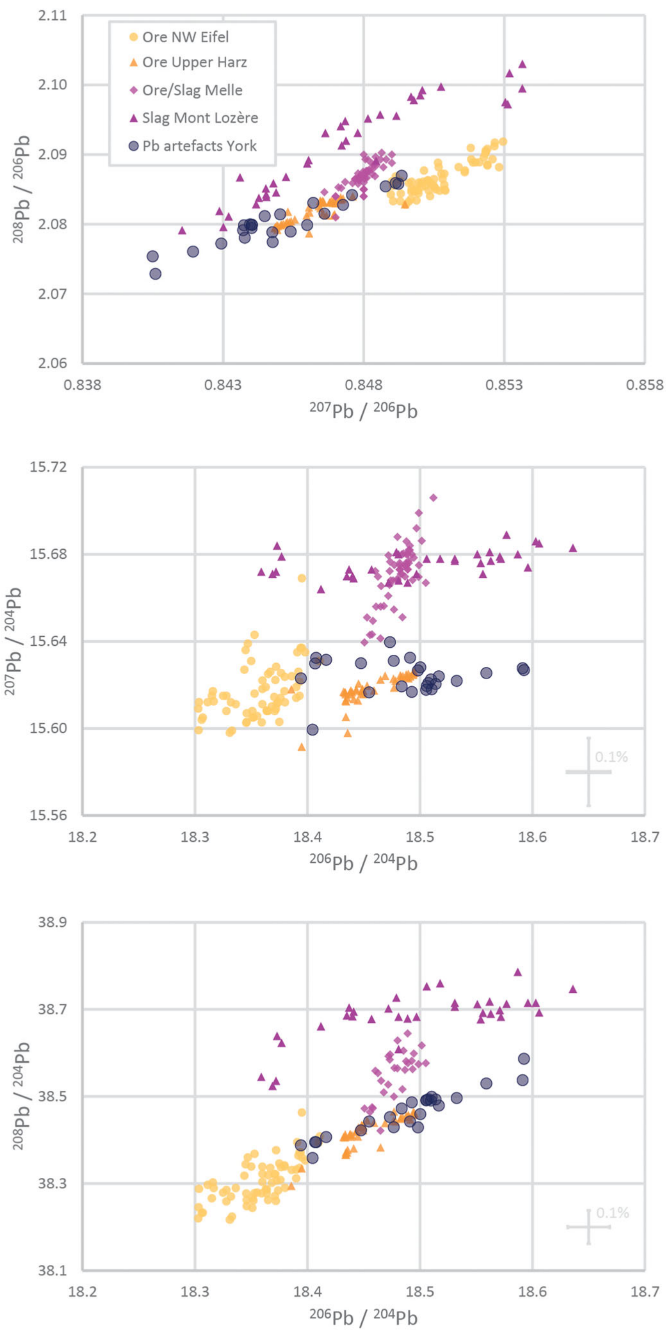

FIG 4
Comparison of the lead isotope ratios of the York lead artefacts from this study with reference data from continental ore deposits in France and Germany. See text for references.

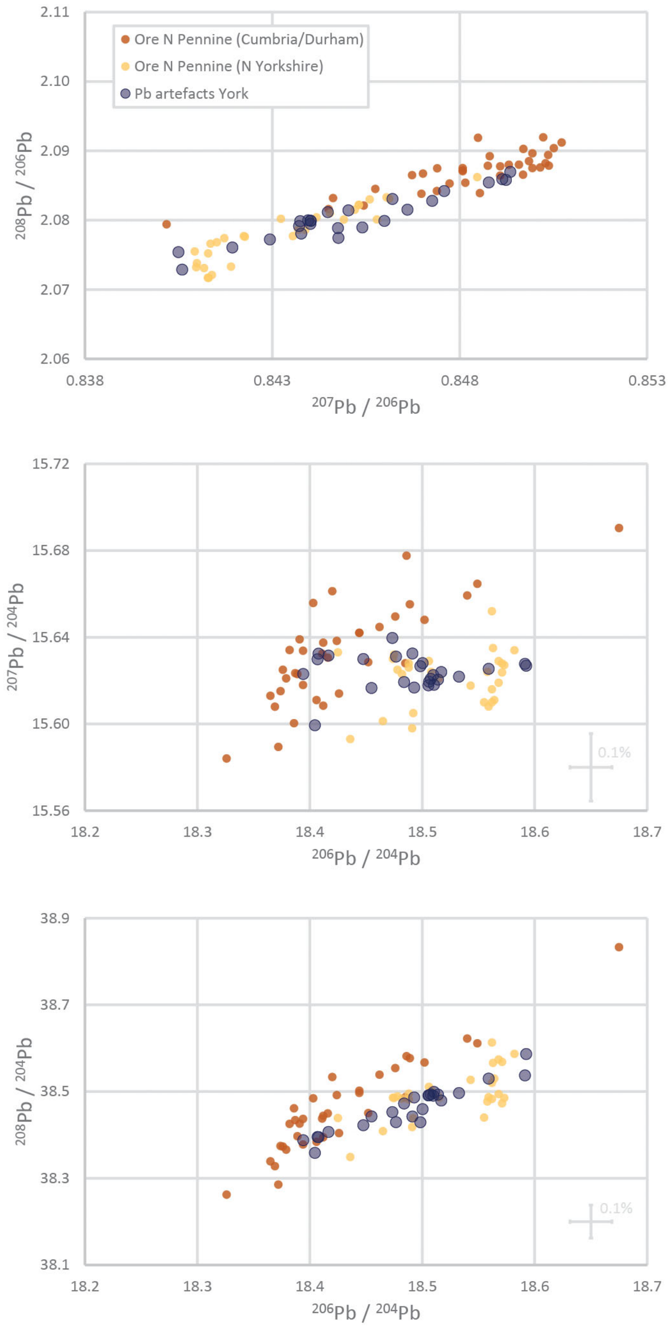

FIG 5
Comparison of the lead isotope ratios of the York lead artefacts from this study with ore from the North Pennines (North Yorkshire and Cumbria/Durham) (Rohl 1996; Scaife et al 2001).

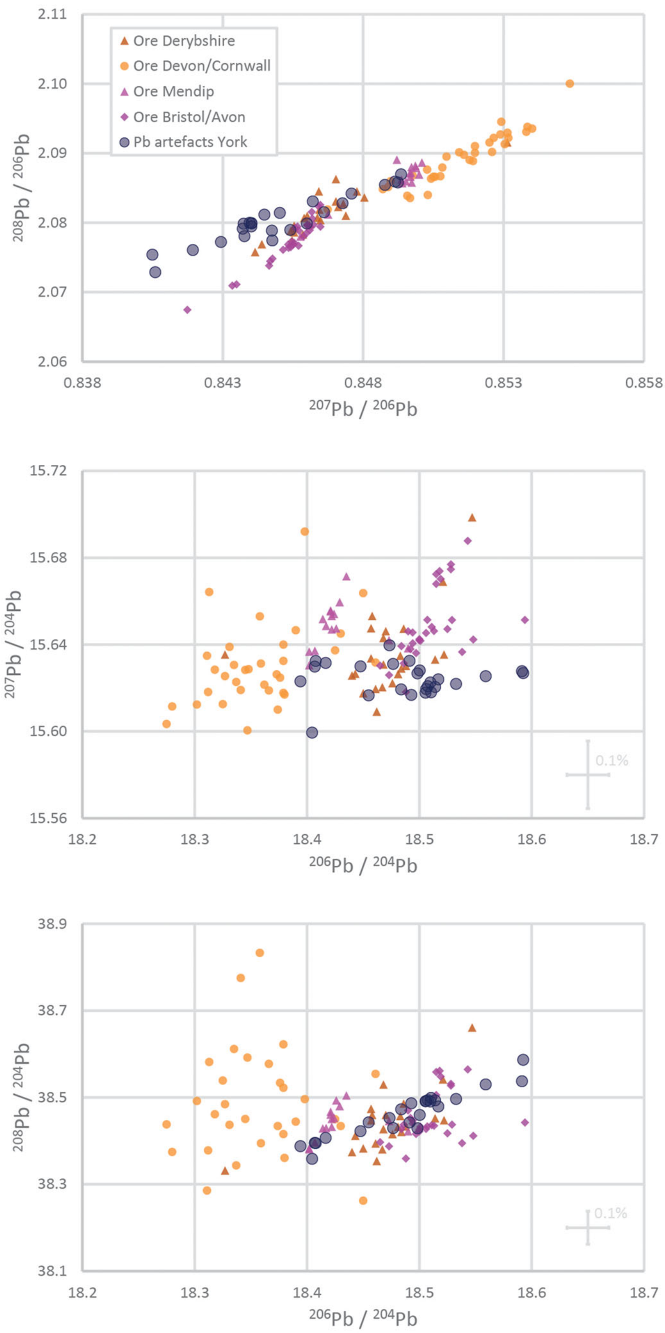

FIG 6
Comparison of the lead isotope ratios of the York lead artefacts from this study with lead ore from Derbyshire, Devon/ Cornwall, Mendip and Bristol/Avon (Rohl 1996).

isotope ratios do not plot with the remaining York items. According to Justine Bayley, the casting flash suggests that the metal was cast in a piece mould and may be a runner for a larger casting, although the lack of specific form means that a date cannot be determined on stylistic grounds. Plotted against a host of different reference data across Europe, and indeed beyond, the only match was with data from mines in Greece, including the famous Lavrion (or 'Laurium') District mines and those on the island of Seriphos (western Cyclades) (compare data in Table 4 with OXALID data for Greece). These are ancient lead mines: both were exploited in Classical Greece (4th and 5th centuries BC) and continued to be worked into the Roman period. Despite coming from a Period 5B deposit, it is perhaps most likely that this item is in fact Roman and is residual in a later context.

Taking all the ore data together, it is clear that while Derbyshire and Avon/Bristol and/or German (Upper Harz) lead cannot be excluded as a source for a small number of the Coppergate items, the majority of the York artefacts are best accounted for by a North Pennines ore source. It is likely that the largest lead supplier for York was indeed the North Pennines, and remained so across the later 9th, 10th and 11th centuries. Despite the proximity of the North Pennines to York, this result is surprising given both the scarcity of evidence for Roman and early medieval lead mining in the region as well as the prominence of Derbyshire as a lead-producer. The importance of Derbyshire as a lead mining region may have been overstated, an effect, as Bayley has suggested, of the survival of documentation relating to it (2018, 60). The new data gleaned from lead-isotope analyses reveals the existence of a thriving North Pennines lead mining industry, with origins in at least the mid-9th century.

LEAD MINING IN THE NORTH PENNINES: PRODUCTION, TRANSPORT AND TRADE

AN EARLY MEDIEVAL LEAD MINING INDUSTRY? THE IDENTIFICATION AND DATING OF BALE SITES

Despite the absence of documentary evidence for early medieval lead mining in the North Pennines, support for the existence of such an industry can be found in an altogether different source: lead bale sites, where lead was smelted from the ore. Such sites are difficult to identify archaeologically (Fig 7). Their recognition rests on locating bare ground, slags, fire set stones and pieces of metallic lead, tasks complicated by the removal of slags for reworking—bale slags, which can contain up to 50% lead, were re-smelted in blast furnaces, particularly in the 19th century (Willies 1993)—and the deliberate dismantling of bole structures (Claughton 1992, 13; Murphy and Baldwin 2001, 4). Nevertheless, over 70 potential lead-smelting bole/bale sites have been identified through fieldwalking in Swaledale and northern Wensleydale (Barker 1978; Barker and White 1992; Murphy and Baldwin 2001). A further five have been located in Nidderdale, the comparative infrequency of such sites in this region being attributed to the mineralogy of the Nidderdale ores, resulting in sparse residues, along with agricultural improvements to land in Nidderdale, which obscures bale sites (Smith and Murphy 2010). In Nidderdale, Allendale and Weardale, researchers have also identified possible bale sites from place-name evidence (Fairburn 1994, 2007; Smith and Murphy 2010, fig 1).

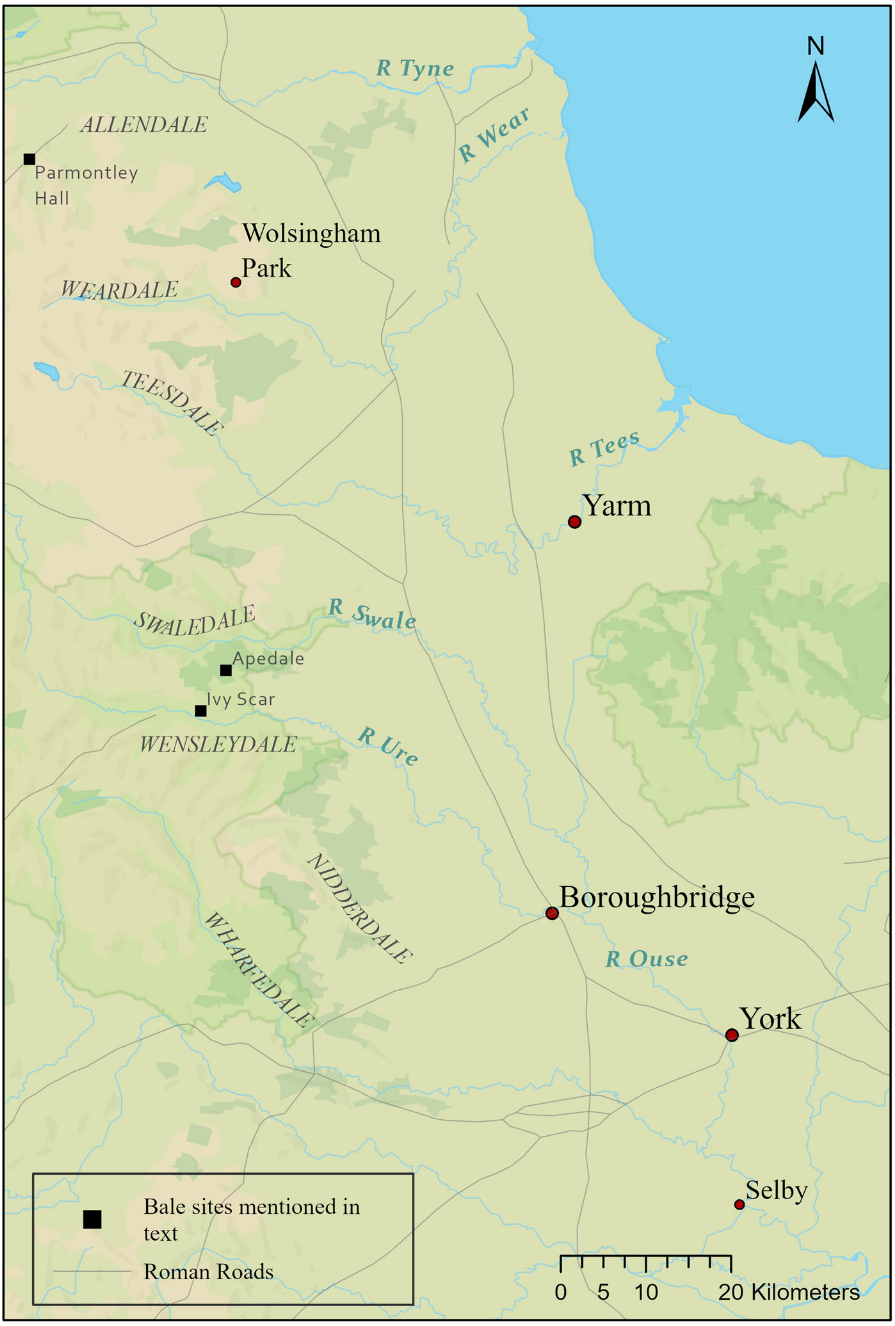

FIG 7
Map showing York in relation to the North Pennines, with places mentioned in the text shown.
Drawing by J Kershaw.

Admittedly, the dating of these sites is difficult. Bole technology continued until the 16th century, when it was replaced by smelt-mills, and it is likely that most of the identified bale sites date towards the later end of this period. Indeed, a series of radiocarbon dates obtained from a selection of bale sites indicates that the majority post-date the mid-13th century (Smith 2006, tab 1; Bayley 2018, 60). However, a small number have yielded charcoal with radiocarbon dates pointing to earlier use. Surface deposits of charcoal at two locations in Wensleydale: Apedale and Ivy Scar, returned radiocarbon dates of AD 900–1030 cal and AD 1010–1180 cal respectively, at 95% confidence (Smith 2006, tab 1; Lab codes: Apedale 480 and Ivy Scar 338). A lead-smelting site at Parmontley Hall, Allendale, yielded charcoal with radiocarbon dates suggesting pre-Norman activity (AD 880–1020 cal, at 95% confidence) although the association with the identified slag is not secure (Fairburn 2007, 48; Fig 7). These dates fit a wider pattern, with similarly early dates recorded from bale sites and/or hearths associated with lead working in Derbyshire, the Lake District and southern Scotland (Smith 2006; Garton and Guilbert 2009, 40–1; Pickin 2010).

The source of the charcoal (ie wood species/size) from the North Pennine sites is not known, and, given uncertainties surrounding the age of the wood when used as fuel (as opposed to when it grew), Bayley warns that these dates can only be considered a terminus post quem (2018, 64). However, bale technology required the use of large amounts of brushwood, layered on top of small logs (shankards) and bigger logs (blocks) where available. It is the brushwood that is typically mixed with the ore/slag and, assuming the charcoal was used as fuel, it is arguably more likely to derive from (young) brushwood than (older) blocks or shankards. In Scotland and Derbyshire, where the charcoal species has been identified, it is birch or alder, both relatively short-lived species (Garton and Guilbert 2009, tab 5.3; Pickin 2010, 83; Bayley 2018, tab 1). In addition, the proximity of the bale sites to woodland means there is unlikely to have been a significant chronological gap between the felling of wood and its use as fuel. We therefore propose that while radiocarbon dates must be treated carefully, collectively, they can be judged to offer sound evidence for early medieval activity at these bale sites. Coupled with the lead isotope data presented in this paper, the bale site evidence helps to strengthen the argument that the North Pennines was home to an early medieval lead industry.

THE TRANSPORT OF LEAD TO YORK

Given the argument advanced here that North Pennines lead was used in York, it is worth considering in what form, and by which routes, lead was transported from bale sites to the town, even if much of the evidence derives from later, medieval sources. The distribution of bale sites in the North Pennines reflects a desire to balance proximity to lead mines with ease of access to woodland (fuel) and transport routes. Owing to its low bulk density, wood, particularly brushwood, was more difficult to transport by packhorse than ore (Fairburn 1994, 93–4). Thus, although needing to be at some elevation in order to capture the wind, most bale sites prioritise proximity to woodland and are positioned with ready access to the valley floor, connecting with overland or riverine communication routes (Gledhill 1992; Murphy and Baldwin 2001, 16–17; Smith and Murphy 2010, 78).

Whether lead was cast in ingot or sheet form near the bole, or close to shipment points is not known. Lead sheets are lighter to transport than ingots, and might have been preferred (Cowgill 2009, 274). After spillages, sheet is the most common form of lead recorded at Coppergate (Bayley 1992, tab 49). However, 15th-century documentary sources describe the transport of lead pigs specifically (see below). Remarkably, finds of galena lead ore in Coppergate indicate that lead ore was also brought into the town. It is difficult to account for this phenomenon, and it was presumably rare—lead could have been smelted within York, but galena is much bulkier than lead metal, while the requirements for fuel and wind made it much easier to smelt lead in rural environments (Bayley 1992, 814).

The question of how lead metal was transported to York may be elucidated through later medieval accounts, which emphasise the transport of lead from upland regions to transhipment points (Raistrick and Jennings 1983, 23–45). The frequent measurement of lead in *caratates* (cart-loads) reveals that the initial journey from the bale sites was often made by cart, although pack-horses may have been used in more remote areas (Raistrick and Jennings 1983, 27). An account of 1365 describes two ox-drawn carts hired to transport 24 *fothers,* of lead from Coldstones in Nidderdale, 'by high and rocky mountains and by miry roads' to Boroughbridge, where the Great North Road crossed the River Ure. (A *fother,* or *foder*, is just over a ton: Raistrick and Jennings 1983, 26, 42–3). From here, it travelled 'both by land and water' to York, and then south onto Windsor (Raistrick and Jennings 1983, 27).

Boroughbridge was a key conduit for the transport of lead from the North Pennines, and could have received shipments along the Rivers Ure and Swale, or southern-bound cartloads from along the Great North Road. After leaving Boroughbridge, lead could have continued along the Roman road network 18 miles to York, or have reached the same destination *via* shipment along the River Ouse (Raistrick and Jennings 1983, 27, 37). Accounts from the 12th century make it clear that lead was also shipped directly from Boroughbridge to Selby, a gateway for coastwise traffic *via* the Humber estuary (Raistrick and Jennings 1983, 28). Destinations included London and Clairvaux Abbey, France (Raistrick and Jennings 1983, 26).

Further north, Yarm on the River Tees may have served a similar role (Fig 7). Although its early medieval archaeology is limited, Yarm lies in a horseshoe bend of the Tees, and has been proposed as a 9th- or 10th-century market (Caple 2020, 34–5). Lead from Weardale/Allendale may have travelled from the Tyne to York by coastal routes. Early 15th-century documents relating to lead mining in Weardale record the transport of lead pigs 20 miles by ox-drawn wagon, from Wolsingham Park to the River Tyne. Some of the pigs were distributed locally, while others were shipped to London and Kent (Drury 1992, 23–4).

Both secular landowners and monastic houses granted rights to mine lead, but little is known of the organisation of labour or the identity of the population behind the extraction, processing and marketing of lead in the early medieval period. The mines were often located in remote and inhospitable locations; the mining itself may have been carried out by small groups or individuals—tenants on the land—to supplement incomes otherwise generated through agriculture. Nonetheless, as Raistrick and Jennings note, the procurement process as a whole involved, 'miners, ore washers, smelters, charcoal burners and the carriers for ore, charcoal, lead and stores'. There must therefore 'have been a very large number of persons employed in and about the mines' (1983, 34). It has been suggested that lead merchants in Yorkshire in the early 14th century were also miners, selling lead for themselves, but whether miners operated outside of estate structures at an earlier date is unknown (Raistrick and Jennings 1983, 30).

FIG 8
Sites in Scandinavia mentioned in the text.
Drawing by J Kershaw.

NORTH PENNINES LEAD ACROSS THE NORTH SEA

The later international scope of York's lead trade raises questions about when lead began exportation as a commodity. To investigate, the Coppergate lead data were compared against that of early medieval archaeological lead and lead-alloys subject to lead-isotope analyses, all of which relate to material from Viking-Age Scandinavia (Stos-Gale 2004; Pedersen 2010; Merkel 2016; Pedersen et al 2016). Coppergate lead-isotope ratios are consistent with the majority of analysed Scandinavian artefacts, with dates ranging from the early 9th into the 10th century. We propose a shared, North Pennines lead source for several of the pewter mounts from the famous ship burial at Gokstad, Norway, and lead artefacts and manufacturing debris from the urban centres of Kaupang, Norway and Hedeby, Schleswig, Germany (Fig 8; Pedersen 2010, 272–84; Merkel 2016, 229; Pedersen et al 2016, 158). We suggest, further, that North Pennines lead dominated a larger English lead trade across the North Sea, which also included lead sourced from Derbyshire and potentially south-west England.

Gokstad

Pedersen et al's (2016) lead-isotope analyses of 37 stylistically-related pewter mounts from the early 10th-century ship burial at Gokstad, identified four distinct lead sources. The authors identified lead from group a (15 mounts), as likely deriving from a source in northern England, either Yorkshire or Alderley Edge near Manchester (a small copper mine, which the authors propose, and we would also argue, is an unlikely supplier of lead ore: Timberlake and Kidd 2005). Conversely, lead from groups b and c

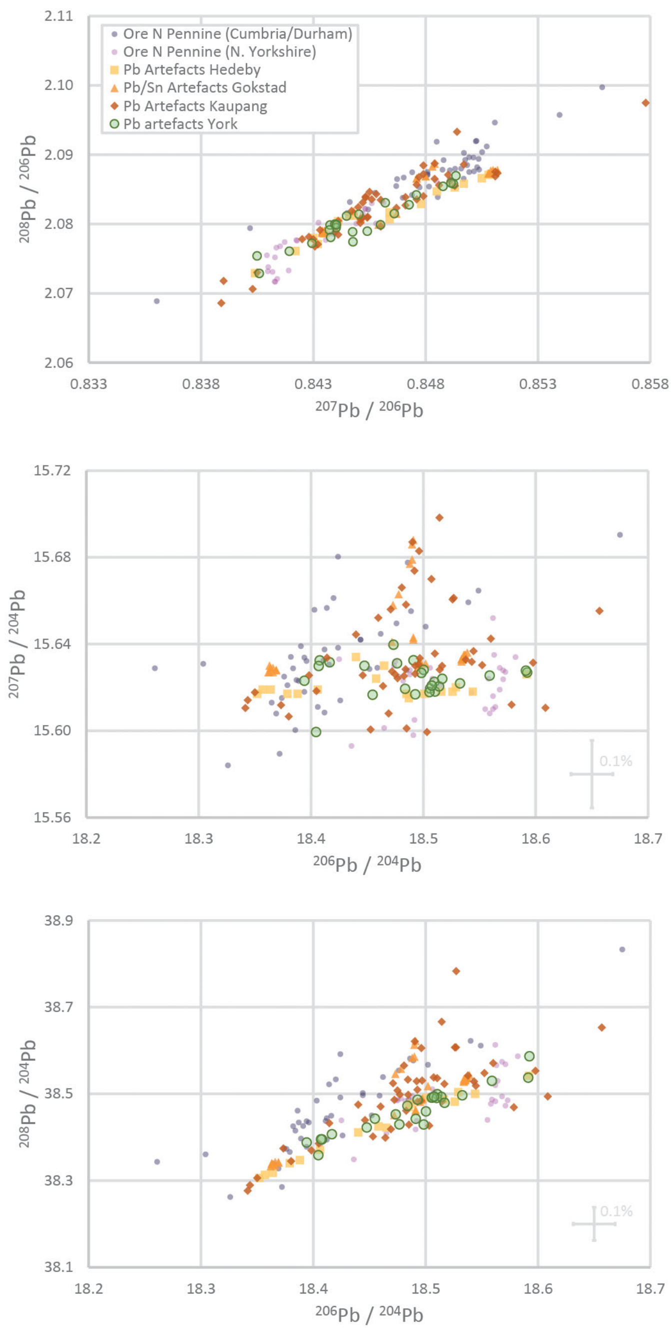

FIG 9
Comparison of lead isotope ratios of the York lead artefacts from this study with lead artefacts found in Scandinavia (Gokstad, Kaupang and Hedeby) (see text for references) and North Pennines ore (Rohl 1996; Scaife et al. 2001).

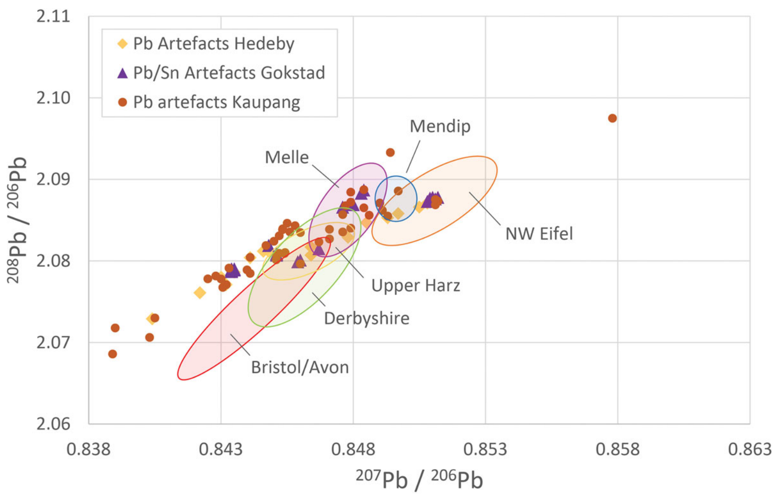

FIG 10
Comparison of the lead isotope ratios of the Hedeby, Gokstad and Kaupang artefacts with a selection of lead ore sources (see text for references). Due to large errors on the 204Pb isotope ratios from older reference data, only the 206Pb normalised ratios are given. A significant number of artefacts fall outside the ore sources shown.

were attributed to Devon/Cornwall and Bristol/Avon or Derbyshire respectively, while group d items were attributed to Melle (Pedersen et al 2016, 157–8).

The discrete grouping of the Gokstad mounts is different to the more dispersed isotope data seen at Kaupang and Hedeby (see below), and points to the presence of closely related items, possibly made simultaneously or in short succession, from single batches of metal (Pedersen et al 2016, 154). Plotting the Gokstad mounts against the new data from York reveals that there is a strong correlation, particularly with group a artefacts, but also with group c items (Fig 9, compare Pedersen et al 2016). Not all the Gokstad data plot with those from Coppergate/North Pennines: it is clear that other sources of lead were also available, and we agree with the authors that the distinctive isotope ratios of Melle are also represented at Gokstad (Fig 10) (Pedersen et al 2016, 158–9). Nonetheless, northern English lead appears the dominant source used for the sampled material at Gokstad. It is plausible that the lead for the mounts arrived *via* the adjacent trading site of Heimdalsjordet (Bill and Rødsrud 2017).

Kaupang

At Kaupang, lead was abundant and was used extensively for creating models for the serial production of dress accessories, as well as for casting jewellery (Pedersen 2010). Unn Pedersen obtained lead-isotope data for 49 lead objects, including ingots, casting waste, and models for moulds (2010, 275–6). She identified 18 objects as deriving from lead from 'middle England' (Group 1), interpreting the likely sources as Mendip/Bristol, the Pennines, Northumberland and Alderley Edge, while Cevennes in southeastern France could not be ruled out. Further analysed items were attributed to other British sources (Scotland, Cumbria, Derbyshire, Cornwall/Devon), as well as, potentially, Cyprus/Anatolia, Siegerland/Eifel and Bohemia/the Erzgebirge (Pedersen 2010, 276–9). These results encouraged the view that Kaupang received lead imported

FIG 11
Large lead bar ingot from Hedeby, weighing c 4 kg, made with North Pennines lead. Photograph: Schloss Gotorff.

from multiple locations: Francia, the Irish Sea region—including the coasts of Scotland—and from the eastern coast of England (Skre 2011b, 427–8).

In light of the new data reported here, we propose that these interpretations be reconsidered. We find that the majority of the analysed Kaupang objects plot with the Coppergate material and, by extension, the North Pennines galena (Fig 9). As with the Coppergate material, Derbyshire and/or Avon/Bristol cannot be ruled out entirely for a subset of the artefacts. We also recognise other potential lead sources, present in a smaller number of items, which we propose are Melle and North Eifel (Fig 10). We therefore suggest that Kaupang's lead supply was not as varied as earlier supposed, but that it received lead chiefly from northern England.

Hedeby

The same appears to be true of 18 analysed lead finds from Viking-Age Hedeby, including scrap metal, ingots and weights (Merkel 2016, 224–5). They are a close match for the Coppergate and Kaupang items, and likely derive in the main from North Pennines lead (Figs 9 and 10). It may be relevant to note here that three of the four ingot forms documented at Hedeby and Kaupang, namely bar, oblong and plano-convex types, are paralleled by lead ingot forms from York (Bayley 1992, 785–6; Merkel 2016, 224–5, pls 12–13; Pedersen 2016, 153). Lead was probably traded in large bar ingot form in both locations. One example from Hedeby (Fig 11) appears to be a slice of a much larger lead cake, potentially representing the tapped contents of a bole furnace. Smaller trapezoidal 'ingots' with a convex underside and cut edges are frequent at the site, and may be cut from larger ingots of similar type. Two of these trapezoidal ingots are isotopically consistent with North Pennine ore and do not overlap with ore from other British sources (Merkel 2016, cat. nos. 200 and 209). Evidence for the fragmentation of massive ingots/boles, combined with the general disregard given to lead metal waste at settlement workshops (eg Pedersen 2016), suggests that lead was abundantly available *via* direct channels and recycling of scrap was not standard practice.

A WIDER ENGLISH LEAD EXPORT INDUSTRY

Further evidence suggests that North Pennines lead formed part of a wider international lead export trade that also included lead from Derbyshire and south-western England. Analysed lead weights from Birka, Sweden, do not match the Coppergate material but appear to be of lead from Derbyshire (Stos-Gale 2004). The weights occur early on in the site's history, from the onset of settlement in the mid-8th century to c 840–860 (Gustin 2011, tab 11.6). The Birka data, then, provides the earliest chronological evidence for the use of English lead in Scandinavia and may imply the earlier prevalence of Derbyshire lead before an intensification of mining and/or export of North Pennines lead in the 9th century. It is possible the lead from south-west England also reached Scandinavia. Pedersen et al (2016) attributed further pewter mount groups from the Gokstad burial to a potential ore source in Cornwall/Devon (group b), while lead from Mendip and Avon/Bristol remains a contender source for a small number of items discussed above (Fig 10).

THE CHRONOLOGY OF THE LEAD TRADE

The Coppergate data presented here derive from mid-9th- to early/mid-11th-century contexts, but the analysed lead objects from Kaupang provide dates which reveal the deeper history of the North Pennines lead trade. Twelve of the 49 Kaupang lead objects reported by Pedersen, including seven from Group 1, come from the earliest stratigraphic layers of the site: Site Periods I and II (AD 800–810 and 810–850 respectively) (Pedersen 2010, 273, tab 4.28). Further items are assigned to a date in the first half of the 9th century on typological grounds (Pedersen 2010, tab 275). A smaller number of items, including two from Group 1, date to the very late 9th century to the first half of the 10th century, indicating the long use of lead from this source (Pedersen 2010, tab 4.29 and 4.31). If our re-identification of Kaupang lead as deriving predominantly from the North Pennines is accepted, this indicates that northern-English lead reached southern Norway as early as the first decades of the 9th century, at broadly the same time as the earliest Viking raids on Britain, and continued in use for over a century.

DISCUSSION AND CONCLUSION

North Pennines lead likely reached Scandinavia initially as a sea-borne trade item within a thriving 8th- and early 9th-century Frisian-dominated North Sea trade network (Skre 2011b, 426). However, the Coppergate material analysed here derives from contexts dating from the mid-9th century onwards, meaning that there is a gap in the data between the identification of North Pennines lead at York and its earliest presence in Scandinavia (at Kaupang, from c 800). We note that late 7th- to mid-9th-century settlement and crafting activity in York has been documented at 46–54 Fishergate. Here, there is robust evidence for lead working, alongside that of other metals (Bayley 1993, 1238). No lead-isotope analysis has been undertaken on lead from this site, but it is reasonable to propose that Fishergate, at the confluence of the Rivers Ouse and Foss, was the point of departure for North Pennines lead destined for Scandinavia.

While the precise mechanisms by which English lead reached Scandinavia are unclear, it seems that lead was traded through, and, at least in some cases, consumed by, emporia. English lead may have been traded directly, *via* the Humber estuary, to sites such as Kaupang or Heimdalsjordet (for Gokstad). Alternatively, it could have travelled *via* an intermediary market such as Dorestad, Ribe, or, following Ribe's demise during the 9th century, Hedeby; which may have served as both a destination and exchange hub (Fig 8) (Hilberg 2009, 83). The material from Gokstad and Kaupang indicates that English lead was not the sole source of lead in circulation; it may be that English lead was received at, for instance, Dorestad, alongside lead from Melle, with both sources then re-exported to southern Scandinavia. Certainly, the Viking attacks on England from the late 8th century would provide a curious backdrop to ongoing direct trade relations between England and Scandinavia. Nevertheless, Kaupang in particular had a close trading relationship with York. Apart from lead, jet and jet-like material from Kaupang ultimately derives from Britain, including the Yorkshire coast, and the Kaupang material has analogies in the jet assemblage from York (Resi 2011; Skre 2011b, 428). However the lead trade was mediated, the vitality of lead craftworking within Scandinavian emporia relied, in large part, on lead from England. This broadens our view of urban networks and connections across regional economies during the Viking Age.

While the mid-8th-century evidence for Derbyshire lead at Birka provides the earliest indication of English lead in Scandinavia, the new lead-isotope data presented here enable us to trace the presence of North Pennines lead in York from the mid-9th century, with the evidence from Kaupang suggesting even earlier origins for North Pennines lead mining, from c 800. The consistency of the isotope data across the Coppergate site phases points to the steady supply of this regional ore source across two centuries. The mining, smelting, transport and supply of lead must have been stable and well organised. It was also large-scale: the evidence from Scandinavia presented above shows that North Pennines lead was the major supplier to southern Scandinavia emporia. Trade in this valuable resource linked the remote uplands of northern England with emerging nodal markets. There must have been a buoyant, if hitherto undocumented, lead industry operating in the Yorkshire Dales and Cumbria/County Durham, with York acting as both a consumer and conduit for international trade.

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Abbreviations

HE	Historia Ecclesiastica
GPA	Gesta pontificum Anglorum

Résumé

Commerce international de ressources éloignées : extraction et exportation de plomb au début du Moyen-Âge en Angleterre, à la lumière de nouvelles données isotopiques provenant de York *par* Jane Kershaw *et* Stephen Merkel

L'approvisionnement en ressources « éloignées » appréciables et leur commerce étaient d'importance fondamentale pour l'économie du début de la période médiévale, puisqu'ils reliaient les territoires de montagnes, les régions forestières et côtières aux marchés urbains émergents.

Des études récentes ont détaillé l'exploitation et la production croissantes de matières premières, dont le goudron, la stéatite, le fer et le bois de cervidés, au cours des siècles précédant et durant l'âge Viking, principalement en Scandinavie. Ici, nous avançons, à partir de nouvelles données isotopiques concernant le plomb à York aux 9e-11e siècles, qu'il existait un commerce international d'une autre ressource éloignée appréciable, mais non précieuse. Le minerai de plomb extrait des North Pennines était exporté à grande échelle via la mer du Nord, reliant ainsi les territoires lointains de montagnes du nord de l'Angleterre et les nœuds urbains tels que York, Kaupang (Norvège) et Hedeby (Allemagne ; historiquement, le Danemark). Nous faisons valoir que le plomb des North Pennines faisait partie d'une industrie plus large d'exportation de ce minerai au début du Moyen-Âge, qui existait au moins à partir du milieu du huitième siècle.

Zussamenfassung

Internationaler Handel mit Ressourcen aus dem Hinterland: Der Abbau und Export von Blei im frühmittelalterlichen England im Lichte neuer Isotopendaten aus York *von* Jane Kershaw *und* Stephen Merkel

Die Beschaffung wertvoller Ressourcen aus dem Hinterland und der Handel damit waren für die frühmittelalterliche Wirtschaft von grundlegender Bedeutung, da sie die Hochland-, Wald- und Küstenregionen mit den entstehenden städtischen Märkten verbanden. Jüngste Forschungen beschreiben detailliert die verstärkte Nutzung und Gewinnung von Rohstoffen wie Teer, Speckstein, Eisen und Geweih in den Jahrhunderten vor und während der Wikingerzeit, vor allem in Skandinavien. Hier wird anhand neuer Isotopendaten für Blei aus dem York des 9. bis 11. Jahrhunderts argumentiert, dass es einen zusätzlichen, internationalen Handel mit einer wertvollen, aber unedlen Ressource aus dem Hinterland gab. Das in den North Pennines abgebaute Blei wurde in großem Umfang über die Nordsee exportiert und verband das abgelegene Hochland Nordenglands mit städtischen Knotenpunkten wie York, Kaupang (Norwegen) und Hedeby (Deutschland; historisch gesehen Dänemark). Wir argumentieren, dass das Blei aus den North Pennines Teil einer breiteren frühmittelalterlichen britischen Bleiexportindustrie war, die mindestens ab der Mitte des achten Jahrhunderts n. Chr. existierte.

Riassunto

Commercio internazionale di risorse oltreconfine: l'estrazione e l'esportazione del piombo nell'Inghilterra altomedievale alla luce di nuovi dati isotopici provenienti da York *di* Jane Kershaw *e* Stephen Merkel

L'approvvigionamento e il commercio di risorse pregiate da zone oltreconfine sono stati fondamentali per l'economia dell'Alto Medioevo, collegando regioni montuose, forestali e costiere con i mercati urbani emergenti.

La ricerca recente ha circostanziato l'aumento dello sfruttamento e della produzione di materie grezze, tra cui catrame, steatite, ferro e corno, avvenuto nei secoli precedenti l'epoca vichinga e durante l'epoca stessa, principalmente nell'ambito della Scandinavia. In base ai nuovi dati isotopici relativi al piombo di York che lo collocano tra il IX e l'XI secolo, qui si sostiene l'esistenza di un ulteriore commercio internazionale relativo a una risorsa non preziosa, ma di grande valore, proveniente da una zona oltreconfine. Il piombo estratto dai monti Pennini settentrionali veniva esportato attraverso il Mare del Nord in quantità significative, collegando remote zone montuose dell'Inghilterra settentrionale con centri urbani quali York, Kaupang (Norvegia) e Hedeby (Germania; storicamente Danimarca). Sosteniamo che il piombo dei monti Pennini settentrionali faceva parte di una più ampia industria altomedievale britannica per l'esportazione del piombo, attiva almeno dalla metà dell'VIII secolo d.C.