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Chapter 13

Isotopic analysis of silver from Hedeby and some nearby hoards. Preliminary results

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Abstract

Silver played an important role both as a material of status and as a medium for exchange in the Viking Age. Hedeby was at the frontier between the monetized kingdoms of the West and the hacksilver/bullion economy of Scandinavia and the Baltic. Fueled by the influx of newly mined and recycled silver from the Middle East, Central Asia, and Europe, mints were irregularly maintained at Hedeby and across Denmark in the 9th–11th centuries. A diachronic study was undertaken to examine the flow of silver as a raw material at Hedeby from the 10th–11th centuries with the use of elemental and lead isotope analysis. Sampling of coins was done by Laser Ablation Inductively Coupled Plasma Mass Spectrometry, allowing for precise and accurate analyses with limited damage to the objects. The minting campaigns at Hedeby provide an excellent chronologic mirror to the changing sources of silver.

Introduction

In the Viking Age, silver was one of the most widely used forms of durable, movable wealth and became an important medium of exchange. The need for silver and other valuables can be tied to the development of long-distance trading networks, which not only conveyed material goods from distant lands, but also brought about cultural interaction and the exchange of ideas over large geographic areas (Sindbæk 2011; Skre 2011; Steuer 2004).

Silver, compact and valuable, lends itself well to long-distance travel and is easily recycled, alloyed, and refined. It could remain in circulation for centuries, as in the case of Sassanian Drachmas in the Abbasid Empire (Heidemann 2011: 454), but constant loss and an ever increasing reliance on silver for the currency in many parts of the Medieval world meant that new silver was actively being sought, mined and distributed (Patterson 1972).

The silver used in Viking-age Scandinavia arrived by various means, but most, if not all, came from lands outside Scandinavia. There are a number of famous and prolific mining regions that supplied the Early Medieval world with silver such as Carolingian Melle (Téreygeol 2002), the Ilak of Samanid Transoxania in modern-day Uzbekistan (Buryakov 1974), and the Ottonian/Salian Harz Mountains in Germany (Klappauf 1993). While these are the large-scale mining regions, the 'giants' of silver production, the real picture of medieval silver production is much more complex.

There is a multitude of factors that impact the productivity of mines and the distribution of their products. The rise and fall of mines is not only linked to the availability of ore, but also to the technological capabilities, economic/political stability, and availability of fuel. Our knowledge of mining during the Early Medieval period is not complete, nor will it ever be. With a focus on the large well-published mines we risk the danger of underestimating the role of small or decentralized operations and mines that are unknown or entirely lost to archaeology through more recent workings.

The material science analysis of silver objects can give us a picture that historical and archaeological evidence alone cannot. The field of archaeometry is a sub-discipline of archaeology, and its methods can provide new strands of evidence to support or supplement archaeological/historical interpretations and can be used to find inconsistencies in the record.

Lead isotope analysis is a relatively untapped resource in the study of Viking silver. Due to the lack of comparable studies, this project is exploratory in nature; we aim to find the benefits and limitations of this technique in combination with trace elemental analysis to investigate silver production, trade, and re-use in the Viking Age. Coins, jewelry, and hacksilver found at Hedeby and some nearby hoards from the late 9th–11th centuries were analyzed in order to identify any chronological trends in isotope and elemental composition. The project was designed to examine how silver objects and coins are interconnected by comparing the different types of silver objects available at Hedeby with the Hedeby coins and other Danish coins. These coinages form the backbone of this study; since they are thought to be produced at Hedeby and other Danish mints, they can potentially give information about the silver stock at different points in time.

Minting at Hedeby

Minting at Hedeby in the 9th and 10th centuries is a widely accepted hypothesis and is based on the distribution and concentration of coin finds. The typology is illustrated by Ralf Wiechmann (2007: Abb.1a–b), but a few examples of the Hedeby coinage are presented in Figure 13.1. Brita Malmer (1966, 2002) developed the typology and distribution of the combination group (KG) series coins. The first minting at Hedeby (KG3) is thought to have taken place around the year AD 825 and was stylistically based on Frisian imitations of the Carolingian Dorestad coinage (Malmer 1966: 204–209). Minting resumed in the first decades of the 10th century with the KG7, which is stylistically related to the earlier KG3. The precise dating of the KG7 is not settled, but is thought to be between AD 900 and 920 (Wiechmann 2007). The KG8 and KG9 are further elaborations on the design of KG7 and are attributed to the 950s–980s (Malmer 2002; Wiechmann 2007).

Fig. 13.1. Examples of Hedeby/Danish coins analyzed in this study. From left to right, top to bottom: KG7, KG9, KG10a and penny of Hardeknut. Photo: Stephen Merkel, © Landesmusem Schloss Gottorf.

In the 980s and 990s, the KG10 Cross coinage of Harald Bluetooth replaced the Carolus-Dorestad motif coinage, and recent findings suggest minting occurred at Hedeby (Moesgaard 2012). The distribution and chronology of the Årstad 95/96 coinages also indicate that Hedeby was minting between AD 1015 and 1035 and typologically represent the transition in Denmark between the earlier half-bracteate and the later penny type coinage (Wiechmann 2013). In the 1030s the style of coinage in Denmark radically changed taking a more nationalistic character with mints having individual symbols (Malmer 2002: 129). Under the reigns of Hardeknut (1035–1042), Magnus (1042–1047), and Sven Estridsen (1042–1074) coins were minted at Hedeby and other Danish towns (Gullbekk 2000; Hauberg 1900; Jonsson 1994: 223–227), but minting under Knut the Holy (1075–1086) is more obscure.

Hedeby and the trade of silver

The town of Hedeby developed into a trading and manufacturing center, which was not only a focal point of royal power, but also functioned as a hub for Baltic and North Sea traffic (Hilberg 2009; Kalmring 2010; Steuer 1987). The finding of weights and scales, silver ingots, hacksilver fragments, locally made coins, and foreign coins from as far as Afghanistan attests to the importance of silver as an exchange medium and the complexity of the local and supra-regional transfer of silver.

Although coin-use was widespread in many of the silver-using lands in Europe, North Africa, and Asia, coins are astonishingly rare in southern Scandinavia before the later 9th century. The custom of trading with weight adjusted rings and ingots, known as the Aurar

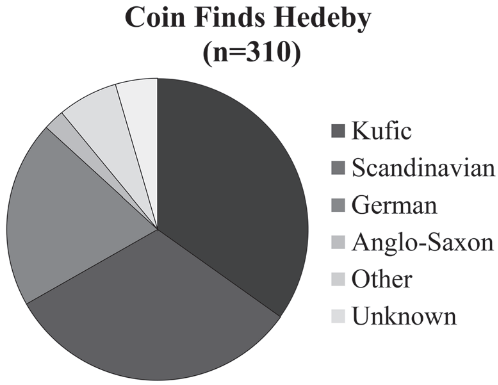

Fig. 13.2. Breakdown of coin finds from Hedeby. Coin counts are based on the work of Wiechmann (2007) and Hilberg (2011).

System, may be partially responsible for this discrepancy (Coupland 2007: 15–20; Kilger 2008a). The Aurar System was used in southern Scandinavia in the early Viking Age, and perhaps earlier, but a drastic change occurred with the introduction of a normalized weight system and the establishment of the hacksilver economy around the turn of the 10th century (Kilger 2008a).

One possible consequence of the collapse of the Aurar System in southern Scandinavia at the end of the 9th century is that coins and coin fragments were no longer being melted down to form ingots and rings in such numbers as before (Kilger 2008a: 324). Archaeologically speaking, coins are invaluable due to their inscriptions and stylistic peculiarities that allow them to be geographically and chronologically placed, and, with the development of the hacksilver economy, coins can be seen in the archaeological record in increasing numbers.

By looking at the breakdown of coin finds from Hedeby, three foci become evident: Kufic, early Scandinavian, and German coins (Fig. 13.2). Viking Age Anglo-Saxon/Hiberno-Norse coins are particularly uncommon in Schleswig-Holstein before the end of the 10th century (Wiechmann 1996: 88). For example, seven coins are known from Hedeby (Hilberg 2011; Wiechmann 2007), and there are three from the overwhelmingly Islamic Giekau Hoard (*terminus post quem* 921, Wiechmann 1996: 240), but the hoards of List and Lübeck of the early 11th century have numerous specimens. Carolingian coins are also rare in southern Scandinavia (Garipzanov 2008; Wiechmann 1996: 80–81), and French coins from middle 10th–11th century are rarer (Wiechmann 1996: 83).

Two broad trends can be seen in the coin finds of Scandinavia: one from the Islamic world in the east from the early 9th to the mid-10th century (Kilger 2008b: 211–212; Metcalf 1997; Noonan 2001) and the second from the Anglo-Saxons and the Ottonians/Salians in the west in the second half of the 10th into the 11th century (Blackburn 1993; Hatz 1974, 1983).

Dirhams coming from the Islamic world are diverse and do not constitute a single movement, but waves from various regions at different times (Kilger 2008b; Metcalf 1997: 310–312; Wiechmann 1996: 77–78). It is clear that the eastern trade routes were the major arteries for the flow of Kufic coins. Abbasid dirhams dominate in the 9th century, but by the late 9th century, Samanid dirhams begin to be minted in Central Asia and Khorasan and have a major presence in the hoards and coin finds of the Baltic in the 10th century. German coins appear in Hedeby starting with the mid-10th century Sachsenpfennig, which is thought to be minted in Magdeburg. The Sachsenpfennig predate, but might overlap with, the minting of the Otto-Adelheid-Pfennig, which is closely tied to silver production in the Harz Mountains (Zwicker *et al.* 1991). Coins from the Cologne region and Frisia produced at the end of the 10th into the 11th century also found their way to Hedeby.

The archaeometry of Viking-age silver

Viking-age silver has been the focus of a number of analytical studies, which form an important basis for further study. The analysis of silver has often been achieved through non-destructive means such as X-ray Fluorescence and Microprobe Analysis (Ilisch *et al.* 2003; Kruse and Tate 1992; Metcalf and Northover 1985), but destructive techniques such as Atomic Absorption Spectrophotometry and analytical cupellation have also been used (McKerrell and Stevenson 1972; Metcalf and Northover 1988: 116). These tools can reveal information not only about silver purity, but also elemental relationships among various types of objects.

The groundbreaking study by Hugh McKerrell and Robert Stevenson (1972) demonstrated that there are several distinguishing characteristics between types of Viking-age silver. These differences in chemistry either relate to the ore minerals used to produce the silver or to technological traditions or practices.

Silver-containing minerals have formed in a number of deposits around the world. Silver can occur in nature as metallic silver, which can be remarkably pure. More often, silver minerals are found mixed with sulphur, gold, antimony, arsenic, copper, bismuth, iron, lead, and many other elements. During the smelting and refining processes most of these elements are separated from the silver; gold, bismuth, and lead are the major exceptions. Cupellation, a high temperature process where noble metals are separated from metallic lead, was used for the production of silver in the medieval world (Meyers 2003). It is not possible to separate gold from silver with this process and bismuth and lead are very difficult to remove completely as has been found through experimental investigations (McKerrell and Stevenson 1972; Pernicka and Bachmann 1983: 595). The use of gold and bismuth contents in distinguishing sources of Early Medieval silver was discussed by several early researchers (Kraume and Hatz 1967: 36; McKerrell and Stevenson 1972: 202–203; Metcalf 1972: 413–416) and has continuously been used since.

Elements such as tin, zinc, and mercury found in silver reflect technological traditions. These elements are typically removed by the cupellation process and thus reflect anthropogenic alteration of the alloy after refining (Pernicka and Bachmann 1983). Their presence indicates intentional processes such as the use of brass or bronze as an alloying agent in silver or application of mercury surface treatments. There are ties between the Carolingian and the Anglo-Saxon silver in that brass was often used in alloying the silver, especially in the debased coinage of the mid-9th century at the time of Charles the Bald

(McKerrell and Stevenson 1972: 205; Metcalf and Northover 1985: 161–162, 1989: 114–115; Sarah 2010: 233).

Bismuth in Samanid silver from mints in Transoxania and Afghanistan has been the topic of a number of studies (Cowell and Lowick 1988; Eniosova and Mitoyan 2008; Ilisch *et al.* 2003; McKerrell and Stevenson 1972). Bismuth, an impurity which considerably increases the hardness and brittleness of silver (Zwicker *et al.* 1991: 72–73), can typically be found in quantities above 0.5% in Samanid silver, and, in some cases where the silver was poorly refined, can be greater than 10% (Ilisch *et al.* 2003). This silver is unusual in comparison to silver produced in Europe and elsewhere in the Islamic world at this time.

A great deal of information can be obtained through the analysis of trace elements. Some characteristics relating to both technological traditions and the geology of silver sources can be defined. When speaking in generalities, the analyses show that differentiation is possible, but due to differences in the various analytical techniques the resolution can be unsatisfactory or incompatible for direct comparison. With advancements in mass spectrometry and laser ablation techniques, particularly in the area of lead isotope analysis, an entirely new dimension can be brought to the discussion.

Lead isotope analysis and its application in archaeology

The use of lead isotope analysis in archaeology is in constant transition, and its success is tied to the adoption of technological innovations as well as an ever-growing awareness of the method's capabilities and limitations (Gale and Stos-Gale 2000; Pollard and Gale 2009). The increasing application of multi-collector ICP-MS in Archaeology (Niederschlag *et al.* 2003), and newly developed laser ablation techniques (Lehmann 2011; Ponting *et al.* 2003), have led to great improvements in the instrumental precision and accuracy, speed of preparation, processing time, and the cost of analysis. A major advantage of laser ablation is that it ablates a microscopic area of an object so that fresh, non-corroded metal can be analyzed with very little visible damage to the original object. Additionally, its semi-non-destructive nature means that the restricted access to sampling precious metal objects is gradually becoming less of an obstacle in archaeometallurgical research.

To briefly go into the chemistry and theory behind lead isotope analysis, there are four stable isotopes of lead, three of which derive from the radioactive decay of uranium and thorium. It has been shown in a number of studies that the ratios between the isotopes of lead are unaffected by metallurgical processes like smelting and cupellation (Gale and Stos-Gale 2000: 525–528). It is therefore clear that a connection can be made from the ore to the finished object via the lead isotope signature. Since the signature of various ore deposits can overlap, the lead can only be confidently used to rule out sources that do not match. In theory, with a combination of analytical methods and archaeological information, lead isotope analysis can produce positive results, but, in practice, it can be quite challenging.

As simple as it may be, the lead isotope ratios in the silver only informs about the lead in the silver. Medieval silver typically has up to one percent of lead, but a distinction needs to be made between the origins of the lead and the silver. Lead metallurgy is intimately intertwined with silver metallurgy: silver and lead ore often occur together geologically. Lead was needed during smelting to act as a silver collector and was used in the refining stage to purify the silver. If old or impure silver was refined, or purified, the isotope ratio reflects the lead used during the cupellation process, effectually breaking the link between the silver origin and the end-product. If silver is recycled, or mixed with other silver, then the isotope ratio reflects this mixture, but there is a relationship to the original composition. When silver from two or more sources are mixed together, the silver becomes homogenized and the isotope ratios are averaged. This means that the new ratio must fall between the two or more original ratios. When the metal is mixed on a large scale, lines will form between the different sources reflecting the various proportions of metal from each source. These lines are called 'mixing lines' (Klein 2007: 144–146; Stos-Gale 2001: 58–60).

While lead isotope analysis is primarily used in archaeology for provenance studies to link metal objects to their prospective ore deposit (Gale and Stos-Gale 2000), this is not the only use. In more complex systems it can be used as a qualitative/quantitative tool to explore interrelationships between metal objects and to explore technological questions regarding the recycling and refining of silver. The technology used in the past impacts the lead isotope signature in important ways, and these principles must be kept in mind while interpreting the lead isotope signatures of silver objects. The goal of this study is not to pin-point the sources of each metal supply, but to look at broader trends and relationships in coinages and silver objects that may have chronological and archaeological significance.

Methodology

The sampling strategy reflects the range of object types found at Hedeby, but three areas of focus were selected to reflect the three largest groups of coins: Kufic, German, and Scandinavian coins of the tenth and eleventh centuries (Table 13.1). The objects themselves mostly come from excavation and metal-detecting campaigns at Hedeby, but some supplementary examples were taken from the Schleswig harbor excavations and from hoards in Schleswig-Holstein (Wiechmann 1996), namely the Steinfeld Hoard (*t.p.q*. 920–950), the Giekau Hoard (*t.p.q*. 922), the Waterneverstorf I Hoard (*t.p.q*. 976), the List Hoard (*t.p.q*. 1003), and an unpublished West Slavonic hoard (*terminus ante quem* 985) curated in Tübingen. Coins were selected with a priority for securely attributed types and dates.

A total of 158 coins and 15 jewelry objects were analyzed at the Leibniz Universität Hannover with laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). Nanosecond-LA-ICP-Quadropole-MS was used to characterize the major, minor and trace elements. All silver objects were analyzed by Portable X-ray Fluorescence (pXRF) to compare the elemental results of the LA-ICP-MS. A Neptune Femtosecond-LA-ICP-Multi-Collector-MS was used to obtain lead isotope abundances and to correct the mass bias Neptune Femtosecond-LA-ICP-Multi-Collector-MS was used to obtain lead isotope abundances, and to correct the mass fractionation, a thallium isotope standard (NIST SRM 997) was measured simultaneously following the previously devised methods (Begley and Sharp 1997; Longerich *et al.* 1987; Rehkämper and Halliday 1998; Walder *et al*. 1993).

Silver coins	**Date range**	**No.**
Abbasid Dirhams	776–872	11
Saffarid Dirhams	878–884	1
Samanid Dirhams	892–990	37
Unknown Dirhams	?	1
Khazar/Volga Dirham imitations	870–941	10
Byzantine Miliaresia	963–989	3
Saxon/Cologne/Frisian Denars	950–1040	40
Anglo-Saxon Pennies	942–1025	5
Hiberno-Norse Pennies	997–1003	5
Hedeby/Danish Half Bracteates & Denars	900–1086	41
Non-minted Objects		
Silver ingots/frag.	9th–10th century	6
Hacksilver	9th–10th century	12
Silver jewelry	800–1100	15
Lead	800–1100	6
Cupellation waste	850–1100	4
Pewter coins	9th–10th century	4

Table 13.1. List of objects analyzed in this study and approximate date ranges of production

The interference of ^{204}Hg with ^{204}Pb was corrected through the measurement of ^{202}Hg. For further information concerning the analytical methodology refer to Lehmann (2011).

Further ingots, hacksilver, lead, and cupellation waste were destructively sampled and analyzed at the Goethe Universität Frankfurt am Main with a Neptune ICP-Multi-Collector-MS for lead isotope analysis and elemental analysis was performed at the Deutsches Bergbau-Museum, Bochum, with an ICP-MS Thermo Scientific Element XR. Silver samples were dissolved in nitric acid for major, minor, and trace elemental analysis. Gold content was measured separately using Aqua Regia as a solvent. For the lead isotope analysis an internal thallium standard (NIST SRM 997) was used to correct for mass fractionation, and ^{202}Hg was measured to correct mercury interference. For sample processing and instrumental set-up in Frankfurt refer to Klein *et al.* (2009). In order to insure the data compatibility between the laboratories the same lead isotope standards were used (NIST981), and both data sets were rectified to the values obtained by Todt *et al.* (1996). Additionally, as a control, two hacksilver objects were analyzed in three labs with all instruments.

Preliminary results and discussion

The isotope ratios in addition to the elements gold, bismuth, zinc, tin, lead, and copper were used to compare the objects to one another and to analyses published. The main focus of this study is to observe the changes in the silver stock used in the Hedeby/Danish coins of the 10th and 11th centuries; therefore the discussion of the results will follow chronologically.

Hedeby KG7 (AD 900–920)

The Malmer KG7s are the earliest Scandinavian coins involved in this study. Ten specimens were analyzed which form a relatively homogeneous group elementally and isotopically.

Their purity is high, above 90% silver, and the coins contain traces of zinc and tin. The gold contents are between 0.2% and 0.4% and the bismuth contents are below 0.2%. The most closely related silver to the KG7 is found in the bar ingots and many hacksilver objects (wires, bars, arm and neck ring fragments) also have a nearly identical range of isotope ratios and elemental compositions. A large Permian spiral ring terminal (Spiral ring Type Sa I after Stenberger 1958:125) is also in this group which itself weighing 50 g likely belonged to a larger type ring weighing 200–400 g.

Besides the hacksilver and ingots, the next nearest group to the KG7 is a portion of the Khazar and Volga-Bulgharian dirham imitations and two dirhams from Iran. These dirhams and dirham imitations date from the late 9th century and early 10th centuries and match isotopically, but have a wider spread of gold and bismuth contents. The silver of the KG7 is distinctly different from the contemporary Samanid dirhams in gold and bismuth contents.

Western sources for the silver may be possible because one Carolingian silver fitting of the first half of the 9th century matches the KG7 silver group. However, the contemporary Carolingian and Anglo-Saxon coins of the late 9th century from the Cuerdale Hoard, in which a KG7 coin was also found, do not match with the KG7 silver group because of their higher gold contents (Metcalf and Northover 1988).

The isotope ratios from several ore deposits in Iran, Anatolia, and Bulgaria (Berthoud 1979; Chegini *et al.* 2000: 309; Stos-Gale 2004) overlap with the KG7 group and overlap slightly with ore from the Carolingian mine of Melle (Téreygeol *et al*. 2005) and other deposits in southern France (Baron *et al.* 2006; Bode *et al*. 2007). Although Melle was ravaged by the Vikings in 848 and thought not to have recovered (Blanchard 2001: 513–514), the evidence based on the mining archaeology and charcoal presented by Téreygeol (2013) indicates that mining industry was resilient and remained strong until the 10th century.

Based on the evidence at hand, an eastern source of the KG7 and related ingots and hacksilver is possible. It is clear that the KG7 silver group is a mixture of high quality silver that predates the widespread recycling of Samanid silver. On the basis of this new information it can be suggested that the KG7 could be dated earlier, or that it may have taken a decade or more for the newly arriving silver from Central Asia to be melted down and to become fully incorporated into the silver stock.

Hedeby/Danish KG8-10 (AD 950–985)

A group of ten Hedeby/Danish coins of the KG8-10 type were analyzed. A lapse of around 30 years occurred between the minting of the KG7 and the KG8 (Wiechmann 2007: 185–187). During this time, Samanid silver dirhams from the mints of As-Shash, Samarkand and Balkh flowed into the Baltic via eastern trade routes, an importation of silver that must have been immense (Noonan 2001). There is a gradual switch from hoards being dominated by Abbasid dirhams to Samanid dirhams in the first quarter of the 10th century (Noonan 2001: 147–158). While it is believed that the flow of Samanid silver into the Northern Lands happened very quickly, within a decade of minting, it is evident that

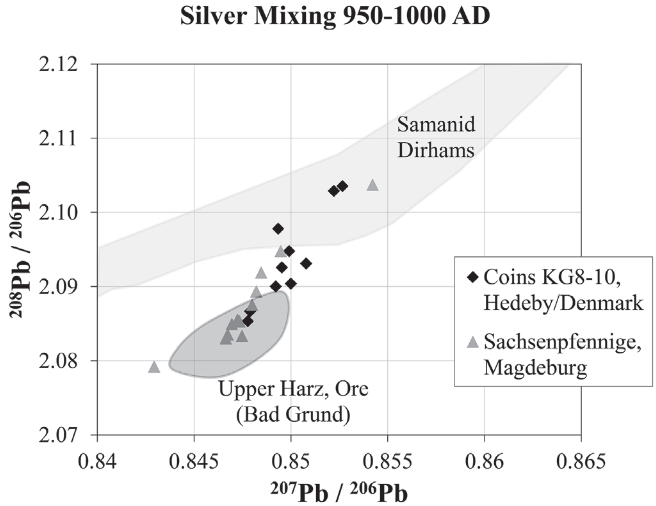

Fig. 13.3. The isotopic relationship of the KG8-10 coins to the Sachsenpfennige compared to Bad Grund ore deposit in the Upper Harz (Purple field, after Lehmann 2011) and Samanid dirhams (Green Field). Some coins have isotopic ratios more similar to Samanid dirhams or Harz ore, while others may be a mixture of both. The analytical error (2σ) is smaller than the symbol.

there was large variation of how they circulated in Scandinavia. Many coins circulated for decades before being deposited in hoards (Noonan 2001: 212–213). This must also be true for the recycling of imported silver.

The KG8-10 group has a wide variation of compositions and seems to reflect a transition period, but, with such a small sample size, no chronologic differences could be noticed within the group itself. This group is certainly a mixture of silver from two or more sources because a faint mixing line forms between the compositions more typical of Samanid dirhams and another source, possibly reflecting newly mined silver from the Harz Mountains (Fig. 13.3). The KG8-10 group mirrors the range of contemporary Sachsenpfennige in both composition and isotope ratio, though the Sachsenpfennige – some probably also a mixture of eastern and Harz silver – lean towards more local (Harz) silver resources. The Sachsenpfennige were probably minted in Magdeburg, an important town on the Ottonian Empire's eastern border. It is thought that imported eastern silver was re-coined at Magdeburg (Spurrford 1988: 68; Steuer 2004: 125; Zwicker *et al.* 1991: 76), and this could explain why so few dirhams are found west of the border (Steuer 1987: 129–131).

The year of 968 is often associated with the 'discovery' of the silver deposits in the Harz Mountains (Steuer 2004: 133–134), but archaeological evidence indicates that copper, lead, and silver were being produced already in the ninth century (Alper 2003: 19–25, 353). The growth and development of mining is attributed to the organization brought by royal control of the resources first with the Carolingians and then following with Saxonian emperors. Between 965 and 968 the Archbishop of Magdeburg, in addition to having minting privileges, gained control of the mint of Gittelde in the western Harz (Alper 2003: 22–23; Mehl 2011: 30), reflecting a close relationship between Magdeburg and the Harz.

Not only do the coins from Samanid Central Asia have distinctively high bismuth and low gold contents, but they also have a range of isotope compositions characterized by high $^{208}Pb/^{206}Pb$ in relation to $^{207}Pb/^{206}Pb$ and are quite different from deposits in western and central Europe except for the Cevenne in southern France (Baron *et al.* 2006; Bode 2008; Bode *et al.* 2007; Lehmann 2011; Rohl 1996; Téreygeol *et al.* 2005). There is a positive correlation between the high $^{208}Pb/^{206}Pb$ isotope ratios and higher bismuth contents of the KG8-10 group as well as hacksilver fragments and Volga Bulghar dirham imitations, re-enforcing the observation that silver, which is isotopically more similar to Samanid silver, also has higher bismuth contents like Samanid silver.

The KG8-10 and Sachsenpfennige on the other end of the spectrum matches isotope ratios of the vein deposits from the Upper Harz such as near Gittelde, where there are extensive Early Medieval workings and smelting remains (Klappauf 1993: 254). The evidence for newly-mined Harz silver is not only due to the isotope ratios, but also due to the trace elements that show both low gold and bismuth contents. Not all of the coins of the KG8-10 group comply with this interpretation. One KG10 coin has a composition more in line with what is known about Anglo-Saxon silver due to the high gold and zinc content (Ilisch *et al.* 2003; Kruse *et al.* 1992; McKerrell and Stevenson 1972; Metcalf and Northover 1986, 2002). The majority, however, conform to the interpretation that Harz silver, Samanid silver, and perhaps the earlier silver stock were mixed, but more work is necessary to look at this issue in detail, particularly the chronology.

Danish coins of the 11th century (AD 1000–1086)

Although the mining in the Harz gained momentum in the years around 970, the great influx of German silver into the North occurred in the last decade of the 10th century. At the same time coins from Anglo-Saxon England began to flow eastward into Scandinavia (Ilisch 1981: 135). The Otto-Adelheid-Pfennig (OAP) is one of the most common coin types found in Scandinavia and was exported in large numbers (Hatz 1974: 41–47; Hatz 1991). All but one OAP match the isotope ratios of the Upper Harz, but the elemental analysis indicates that at least two distinct silver sources were used, both possibly originating in the Harz Mountains, *i.e.* Upper Harz and Rammelsberg (Zwicker *et al.* 1991: 75).

To represent 11th century Danish minting, coins of the Årstad 95/96 types, Hardeknut, Sven Estridsen, and Knut the Holy were analyzed. No longer are any traces of Samanid silver seen in the elemental composition or the isotope ratios. These coins are all relatively low in gold and bismuth. There is a divide between the coins of the Årstad/Hardeknut, which are high quality silver, and those of Sven Estridsen and Knut the Holy that are nearly all debased with brass. The debasement of the coins of Sven Estridsen and Knut the Holy has been noted previously by Gullbekk (2000).

The coins of the early group (Årstad/Hardeknut) fit isotopically with the Otto-Adelheid-Pfennige, the Upper Harz ore and some of the Anglo-Saxon and Hiberno-Norse pennies, but there is a shift in isotope signatures in the debased second group (Estridsen/Knut the Holy). The addition of up to 40% brass may certainly have an effect on the isotope ratios. Interestingly, the isotope signatures of brass-making crucible slag from Medieval production centers of Dortmund and Soest (Krabath *et al.* 1999: 436) as well as lead-zinc ore from the Aachen-Stolberg and Sauerland regions (Bode 2008; Krahn and Braumann 1996) match the ratios of the debased coins of Sven Estridsen and Knut the Holy. The brass used in the coinage may have come from Lotharingia and Westphalia, regions thought to be producing brass in the Early Middle Ages.

Conclusions

In the void of comparable studies, care must be taken not to over-interpret the findings, and a number of blind spots exist to be explored further. It must be re-emphasized that the use of lead isotope analysis in archaeology can only be reliably interpreted in a negative sense. A match in isotope data does not prove that the correlation is meaningful, but with a combination of elemental data and archaeological/historical evidence, interpretations can be made more confident.

This study touches upon several themes in Viking-age silver research: changing silver sources, time of circulation, and recycling practices. Based on the analysis of Hedeby/Danish coins there are four phases over the course of the 10th into the 11th century. The Hedeby KG7 of the early tenth century is the earliest coin type analyzed and is closely related to hacksilver, ring fragments, ingots, and Khazar/Volga-Bulgharian dirham imitations. Although it is thought that Samanid silver flowed into the Baltic shortly after it was minted in Central Asia and Afghanistan, traces of this silver in the coins from Hedeby only become apparent after the minting of the KG7. In the second half of the 10th century the Hedeby coinage seems to be a mixture of Samanid silver and newly mined silver from the Harz Mountains via the Sachsenpfennig, Otto-Adelheid-Pfennig, or other forms. In the 11th century no trace of Samanid silver could be found in the Danish coins analyzed. Danish coinage of the second half of the 11th century reflects adulteration with brass that may be of continental origin.

One important absence is that of Anglo-Saxon England, both in the coin finds from Hedeby and in the elemental signatures of the Hedeby and later Danish coins. The few Anglo-Saxon and Hiberno-Norse coins of the 10th and 11th century and Anglo-Saxon style silver objects analyzed in this study all have a notable gold content, typically between 0.2% and 0.6%, high zinc content, and almost always a low bismuth content which complies well with the published literature. Isotopically, they are often indistinguishable from the Otto-Adelheid-Pfennige. The gold and zinc contents of the Anglo-Saxon coins in the tenth as in the eleventh century seem to indicate that different silver sources and technical traditions were in use.

The lead isotope analysis of Viking-age silver is in an early stage with ample opportunity for further research. The analyses, although relatively small in number, show that there are chronological differences in elemental and isotopic composition of silver. As more is studied, the interpretation of analytical data will improve and enrich our understanding of mining, trade and manufacturing in the Early Medieval period.

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