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# XRF analysis of Viking Age silver ingots

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ABSTRACT

*This paper describes results from a programme of metallurgical analysis of Viking Age silver. A large selection of ingots (125) and rod fragments (nine) from five Scottish and four English hoards were analysed by X-ray fluorescence. The results are compared to other analyses of contemporary objects and coins from hoards in Britain, Ireland and Scandinavia. The silver alloy used to form the ingots and rod fragments was broadly similar, but with enough differences to indicate no single silver source, nor in general close correspondence to alloys used in contemporary coinages.*

## INTRODUCTION

Silver ingots are a feature of Viking Age silver hoards in Scandinavia and areas of the British Isles influenced by the Scandinavians. They are common finds in hoards from Ireland and north-western Britain outside of the Anglo-Saxon kingdom proper, and to a lesser degree, in those from Scotland (Kruse 1988). A large selection of ingots (125) and a few hacksilver rod fragments (nine) from Scotland and England have been analysed in this work, with samples from nine of the 14 hoards containing ingots from these regions. The main aim of the work was to add to the corpus of analytical data on Viking Age 'silver' in the hope that more information about the range of compositions would shed light on silver sources and alloying procedures.

Previous programmes of silver analysis have concentrated mainly on numismatic evidence, in particular a large on-going programme by Metcalf & Northover (1985; 1986; 1988; 1989) and a study by Hugh McKerrell & Robert Stevenson of 10th-century coins, primarily Anglo-Saxon issues found in Scottish hoards (McKerrell & Stevenson 1972). Other analyses can augment this picture (see Kruse 1992, App I), but, as will be discussed below, large programmes are preferable, minimizing the problems of comparability between techniques and laboratories.

Far fewer analyses of Viking Age non-numismatic silver have been undertaken, and even fewer in large programmes of analysis (Kruse 1992, App II & III). Three exceptions stand out: analysis of 39 'ring-money' from the Skaill and Burray, Orkney, hoards (White & Tate 1983); 21 ingots and hacksilver fragments from Irish hoards (Ryan *et al* 1984); and 128 samples from ornaments and hacksilver found in Viking Age southern Swedish hoards (Hårdh 1976, 110–27). The analyses discussed in this paper were performed on the same equipment as that of White & Tate, providing a good point of comparison with that study.

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## PROGRAMME OF ANALYSIS

Four museums loaned material for analysis, and the Society of Antiquaries of Scotland generously provided a grant to aid with costs in bringing the ingots to and from the laboratory. The Royal Museum of Scotland lent 29 ingots and one ring fragment from four Viking Age Scottish hoards, and its three ingots from the Cuerdale, Lancashire, hoard; the National Museums & Galleries on Merseyside (Liverpool Museum) lent 24 ingots and four hacksilver fragments from the Cuerdale hoard, and one ingot from the Croydon hoard; the Carlisle Museum & Art Gallery lent the entire non-numismatic part of the Scotby, Cumbria, hoard, comprising six ingots and four rod fragments; and the Grosvenor Museum, Chester, lent 62 ingots from the Castle Esplanade, Chester, hoard.[1] Thus altogether:

| HOARD | DATE | MATERIAL |
|---|---|---|
| Croydon (Surrey) | (c 872) | 1 ingot |
| Cuerdale (Lancs.) | (c 905) | 27 ingots + 4 rod/ring fragments |
| Scotby (Cumbria) | (c 935) | 6 ingots + 4 rod fragments |
| Storr Rock (Skye) | (c 935) | 15 ingots |
| Skaill (Orkney) | (c 950) | 10 ingots + 1 ring fragment |
| Chester (Cheshire) | (c 965) | 62 ingots |
| Iona (Argyll) | (c 986) | 1 ingot |
| Burray (Orkney) | (c 1000) | 2 ingots |
| Bute (Argyll) | (c 1150) | 1 ingot |
| TOTAL | | 125 ingots + 9 rod fragments |

In addition, at the request of one of us (SEK), the Ashmolean Museum undertook XRF analysis of the Viking Age ingots in its holdings, comprising three from the Croydon hoard, 16 from Cuerdale and one from the Co. Dublin hoard (c 935), together with three small ornament fragments from the Cuerdale hoard and two Permian ring fragments from the Dublin hoard.[2] These results are included, by kind permission, in the Appendix.

Consequently, in total, all but one ingot (the Tiree ingot, now in the British Museum) surviving from Viking Age Scottish hoards were analysed, all the ingots from the Croydon hoard, the complete non-numismatic contents of the Scotby hoard, and samples of ingots from the Cuerdale and Chester hoards (8% and 63% of total ingots respectively). The results are presented in Table 1.

## TECHNIQUE

All analyses were undertaken using an energy-dispersive X-ray fluorescence (XRF) system. This system has a Rhodium X-ray tube operated at 46kV and normally 0.5mA. The X-ray beam is collimated to a diameter of 1mm. It is incident on the sample at 45 degrees; thus the analysed area is an ellipse about 1 x 1.5 mm. The exact position to be analysed is determined by shining a light beam down the same collimator.

Fluorescence X-rays are detected in a Si(Li) detector located perpendicular to the sample, the signal being discriminated, shaped and amplified into an 8192 channel analyser (Canberra series 80), 2048 channels being used for each spectrum. Spectra were normally counted for 10 minutes to get adequate statistics, before being stored on disc via a Cromenco microprocessor (now replaced by a HP Vectra PC). The system has an air path between sample and detector, so low atomic number elements cannot be detected.

The spectra were first processed to recover peak integral for the elements of interest. The background was fitted by a cubic spline for each spectrum and then removed, and the areas for the principal K-peaks of copper and silver, and the L-peaks of gold and lead+bismuth were determined by integration over the appropriate channels. Backgrounds were removed in the same way for pure spectra of copper, lead and silver, the resulting line spectra then being scaled and stripped from the data so that the areas for zinc, bismuth and tin could be recovered. Although present in all spectra, gold is not easy to measure accurately: the first L-peak is unresolved from bismuth and the K-beta of zinc, while the second peak may be affected by bromine (presumably from silver bromide tarnishing in fine cracks). Both gold peaks were therefore measured in this work.

The raw element integrals were used to determine percentage compositions using a version of the fundamental parameters described by Cowell (1977) as previously reported (White & Tate 1983). This procedure sums the calculated compositions to 100% rather than provide independent elemental compositions (as, for example, in analysis by Atomic Absorption).

The analysis was for seven elements: silver, gold, lead, copper, zinc, bismuth and tin. The precision with which each of the elements could be determined depended on several factors, but mainly counting statistics and the size and amount of overlap of the peak in the spectrum. Detection limits were estimated to be below 0.1% for silver, copper, zinc, gold, lead and (rather optimistically) bismuth, although only levels above this have been quantified. Detection of tin was far less satisfactory, owing to the need to strip a huge silver peak first (the silver K-beta peak overlapping the tin K-alpha peak). Thus for tin anything below 0.2% is listed as trace. Accuracy of the results was monitored by the use of copper-silver standards, but no standards were available for all seven elements; hence, as discussed below, some caution has to be exercised in comparing these results with those obtained using other analytical systems.

Most silver of the period was obtained probably by cupellation of lead ores (Hughes & Hall 1979, 323–4). As Metcalf & Northover have pointed out, what the medieval craftsman would have considered silver is, in fact, a combination of the gold, silver, and lead remaining in the alloy (Metcalf & Northover 1986, 36). Following them, we have used the term 'silver' to refer to this combination. However, in some cases lead may also have been added as a debasing element (eg C.61).

Of the elements tested for, gold provides one of the most diagnostic since, as important experiments by McKerrell have shown, when present in the initial ore it survives the cupellation process (McKerrell & Stevenson 1972, 197–8). The ratio of the gold per 100 parts of silver is therefore usually a useful indicator of silver sources (Metcalf & Northover 1985, 166–8; Cowell & Lowick 1988, 70). His experiments also revealed that lead and bismuth are generally not easily removed below 0.5–1%. Concentrations less than this may indicate an unusual alloy or special care in cupellation. Tin, copper and zinc, however, were easily removed to very low levels (McKerrell & Stevenson 1972, 197–8).

In almost all ingots, copper makes up the second largest element of the alloy. As a result, the concentration of copper is less significant than several other elements; the purer the silver, the less copper, and vice versa. Metallic zinc is thought to be unknown in the period, probably appearing in silver alloys due to deliberate debasement with scrap brass, rather than bronze or pure copper. Similarly, although tin might have been added as a raw metal, it is generally assumed to occur from scrap bronze (Metcalf & Northover 1988, 104).

All figures in Table 1 have been quoted to one decimal place, since the technique and subsequent calculations cannot be considered more accurate (Tate nd, 24). However, the gold-in-silver ratios were calculated with results to two places, in order to minimize rounding errors. Although published here to two places, for comparison to other studies, they should be viewed with some caution.

## METHODOLOGICAL PROBLEMS

### SURFACE ENRICHMENT

The effects of silver enrichment, whereby the baser metals such as copper leach out of the surface of the silver object, are well known, and must be accounted for by any analytical technique (Cope 1972, 8–12; White & Tate 1983, 247). In the analyses described here, successive abrasions in the same spot were made, until the results had stabilized. Even on relatively pure objects, the difference could be significant, with purer ingots often measuring 4% less copper on the surface (and correspondingly greater silver), and baser ingots often 10% less.

### ACCURACY OF XRF

Two issues are of relevance here: the errors imposed by the analytical technique, and the accuracy of XRF as compared to other forms of analysis.

The accuracy of measurement for individual elements is an obvious concern, especially when measurements of small amounts are used comparatively. As noted above, the gold-in-silver ratios are a useful indicator of silver sources. However, gold concentrations in silver of this period are usually small, so lack of precision in quantitative measurement, or inaccuracies due to the analytical technique, will lead to large apparent changes in the ratios. Even taking as much care as possible when abrading the ingots, when they appeared to have produced a stable result, measurements of gold could still vary by as much as 0.5%. There are several possible reasons for this, particularly the conflicting needs, on the one hand, to clean a flat surface which could be accurately repositioned in the XRF system, and, on the other hand, the requirement to make minimal damage to a complex-shaped object. Whatever the cause, the outcome is a consequent fluctuation in the gold-in-silver contents, and the modal steps of 0.5 in illus 1 may be more precise than warranted. General trends will be preserved, but fine distinctions are probably inappropriate to draw from these data. The necessity to derive bismuth, zinc and tin figures by stripping away overlapping peaks also renders these results less accurate. In particular, as noted above, accurate measurements for tin are very difficult to obtain with this technique, so little can be concluded from these figures.

Several studies have been undertaken where the same silver object has been tested by different techniques, thereby providing some indication of the comparability of results (eg Oddy & Schweizer 1972; Schweizer 1972, 164–5; Schweizer & Friedman 1972; Gilmore 1987, 167–8). In general, where surface enrichment is taken account of, XRF produces relatively close results to other techniques, but variations of 1–2% are not uncommon. This cautions against absolute comparisons of results by different techniques.

### HOMOGENEITY OF THE ALLOY

With two exceptions, each object was analysed as nearly as possible on the same spot. The results therefore assume a homogeneous concentration throughout the entire object. However, previous studies have suggested that this may not be true, especially for baser objects (Gibbons *et al.* 1974; Schweizer 1972, 162–4; Hughes & Hall 1979, 325).

We analysed two objects in different positions. One of the Scotby ingots was in half, broken probably in modern times (Kruse 1986, 81). Analyses on both halves produced very similar results (see Table 1, Scotby B & C). A less satisfactory comparison results from analyses of the Burray ingot/ring fragment (RMS IL 266). This object was also analysed by White & Tate (1983), in a separate place using an earlier version of the same equipment as the present study. The average copper values were 25.8%±3.0% and 23.3%±1.4% respectively. This object, however, was quite base, and with such objects it is particularly difficult to be sure that the surface enriched, or corroded, layer has been removed entirely. There is also a danger of corrosion in cracks into the body of the metal, evident from the bromine peaks seen in some spectra even after abrasion. Little can be done about this other than select another area to analyse if this is possible.

As noted above, bismuth is an important diagnostic element. It generally appears in very small amounts, and is difficult to measure accurately. There is, however, some indication that it may also segregate within the alloy, thereby introducing a potential error (Metcalf & Northover 1986, 47). Further experiments on the behaviour of bismuth would be extremely useful.

### COMPARISON BETWEEN LABORATORIES

The comparability of results between different laboratories is another source of concern when looking at results from different programmes of analysis, even those using similar techniques. Although standards were exchanged between the Ashmolean and Edinburgh laboratories, no objects were tested in both.

The XRF analyses of the Cuerdale ingots undertaken by the Ashmolean Museum show somewhat different gold-in-silver contents (illus 1). This is probably not due to insufficient abrading to overcome silver enrichment, since the silver results are similar for both analyses (illus 2). However, the gold results are notably different (illus 4). It is possible, of course, that the Ashmolean sample contained ingots with slightly different gold concentrations. However, distortion due to different calibration and laboratory techniques may also be a possibility. Other programmes of analysis have also encountered problems when trying to compare results (eg, Metcalf & Northover 1988, 105; 1989, 102).

This uncertainty limits the value of single analyses. At least in large programmes it is possible to compare the results internally with one another. For this reason alone, any programmes of silver analysis should be undertaken on a large scale, with careful choice of objects.

## RESULTS

A general feature of all ingots is that, in the main, they were cast from high-purity silver. Modern sterling silver is defined as 92.5% silver, and of the ingots, 40% are as good or better (illus 2); if one uses the figures for 'silver' (gold, silver and lead), this increases to 60%, with many others only just falling short (illus 3). Nevertheless, the Croydon ingots are slightly less pure than Cuerdale, Scotby, and the Scottish finds, while a cluster of ingots, including three mould duplicates, from the Chester hoard are much baser.

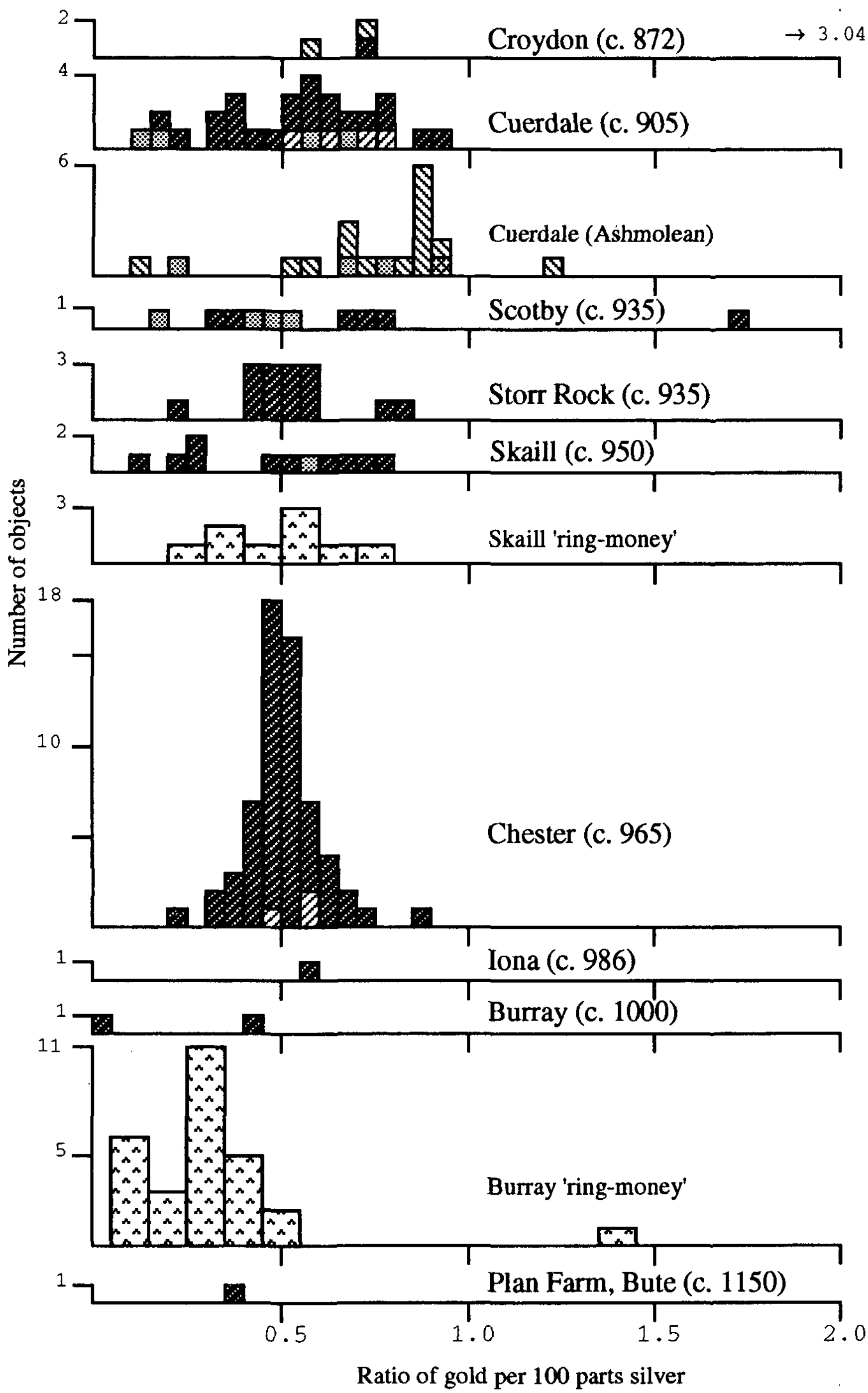
However, even concentrating on the objects of higher purity, quite substantial difference in alloy could be ascertained. If one compares the gold-in-silver contents (illus 1), most hoards display a wide spread. Assuming that this ratio will be fairly consistent for ores from one source, then allowing for experimental uncertainties these results indicate no one source of silver. The exception is provided by the Chester hoard, which has a very clustered distribution, including the very base objects, most closely paralleled by a clustering within the Storr Rock hoard deposited 30 years earlier.

In general, the compositions of the Scottish ingots are very similar to one another, and to the other ingots from English hoards. There are a few exceptions: the Storr Rock hoard includes a few distinctly baser ingots, and the presence of tin in larger concentrations than other contemporary finds. However, the similarities suggest all these objects, with the exception of the Croydon ingots, should be viewed as part of the same silver supplies and circulation. Some distinctive alloys, such as the no-lead one discussed below, can be traced throughout the material. For this reason, the discussion below and the illustrations are divided chronologically rather than regionally.

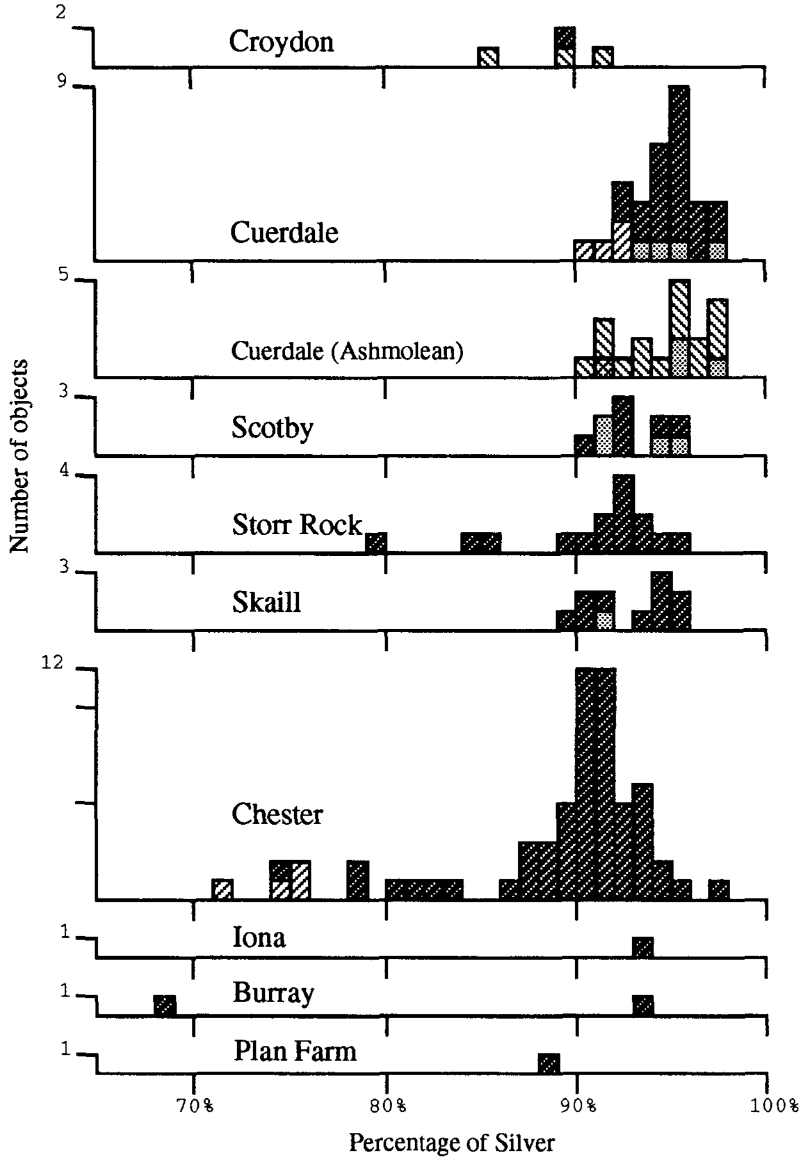
The results for individual elements are presented in illus 1–9. Where distinctive combinations of elements can be identified, these are noted in the discussion below, grouped chronologically by hoard. The largest discussion is devoted to the Cuerdale hoard, in part due to the unusual nature of the find, but also since many of the alloys which appear in later hoards can already be identified here.

Comparisons will be made in the main to coins, though where available, other analyses of non-numismatic silver will also be noted. The large number of analysed coins allow good provenancing of silver, at least for its remelting, at closely dated periods. Coins are likely candidates for melting into ingots (and other objects), with some obvious possibilities: Anglo-Saxon coins, Viking issues in Britain, Carolingian coins and Arabic coins. However, as more work is undertaken on coinage alloys, these increasingly can be shown to change both over time and region.

The ingots may be much earlier in date than that of the hoard's deposition, and will not




ILLUS 1 Gold per 100 parts of silver: ingots and 'ring-money'




ILLUS 2 Silver contents

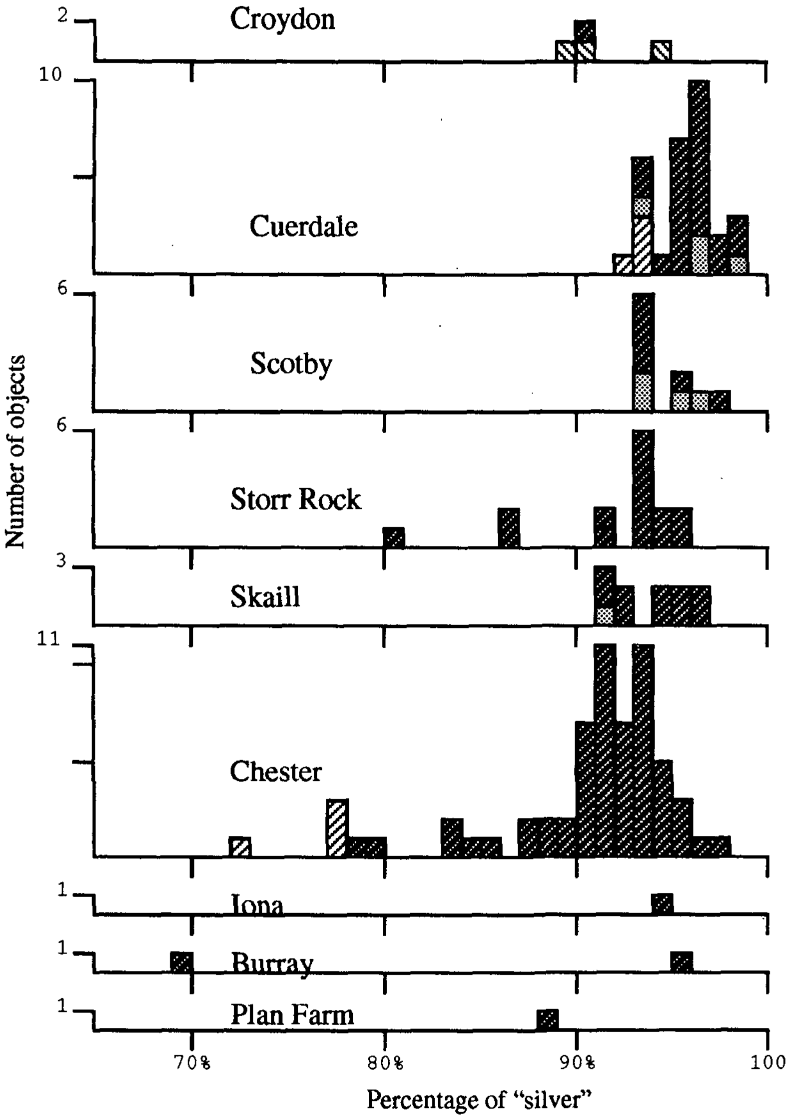
Ingot | Mould duplicate | Hacksilver

Slag | Coin | Ashmolean analysis

'Ring-money' or armring | Permian ring fragment

n.d. not detected | tr trace

Key to the illustrations

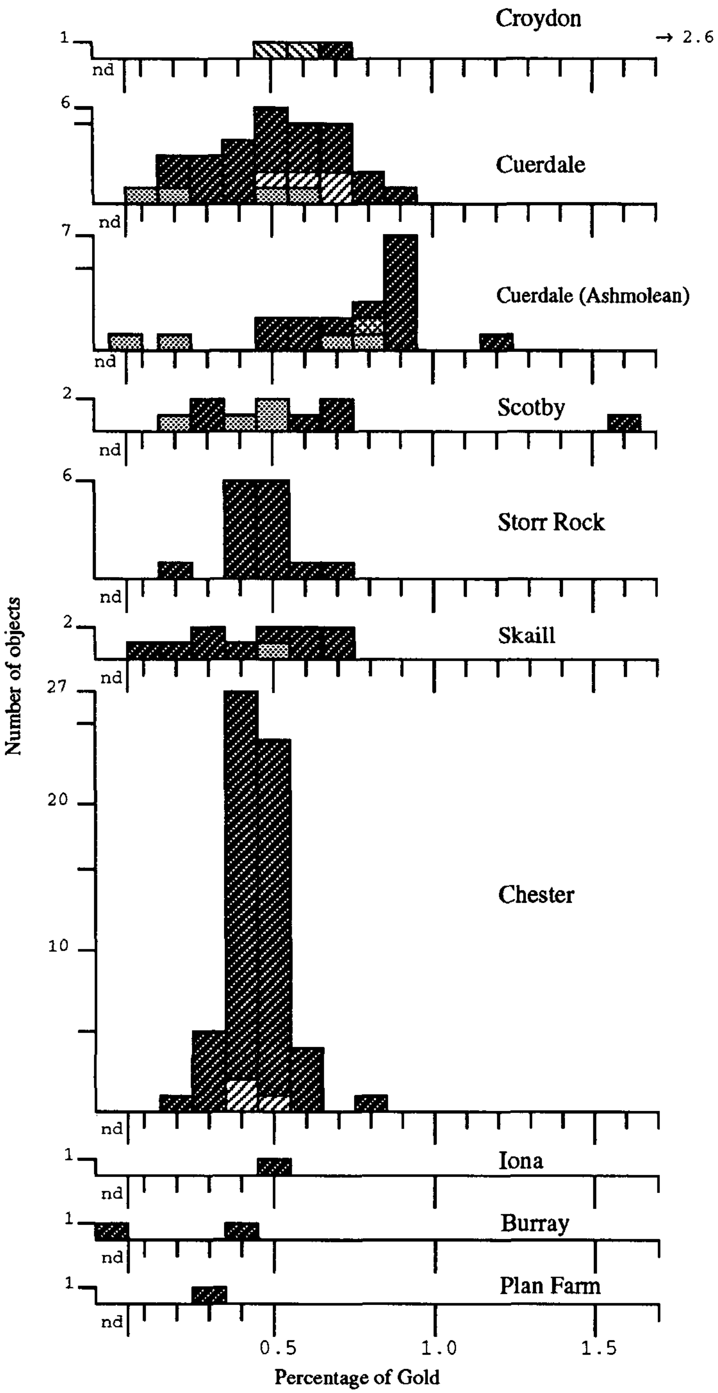



ILLUS 3 'Silver' contents (gold + silver + lead)

necessarily reflect contemporary coins. The same is true for many of the coins, particularly those in hoards outside the Anglo-Saxon kingdom where a metal-weight economy operated. In some cases, the amount of pecking – testing marks made during circulation to gauge silver purity – can provide a rough indication of time in circulation.

CROYDON (c 872)

The earliest ingots examined in this study were the four from the Croydon, Surrey, hoard, deposited c 872. Three were analysed by the Ashmolean Museum, and one by us. All the ingots




ILLUS 4 Gold contents

had a fairly high silver content (85.4–91.8%) but there was little consistency for the other elements: two are high in zinc, one high in gold, and one high in lead. With such a small sample size little can be concluded, although it is reasonable to say that different alloys have been mixed in the ingot production. The ingot with high gold and tin is unusual compared with the whole ingot data set.

The general high levels of silver in the Croydon ingots make these alloys distinct from contemporary Anglo-Saxon coins. Analysis of a large number of Anglo-Saxon coins dating to the third quarter of the ninth century has shown that the coinage was very debased in this period (Metcalf & Northover 1985). The gold-in-silver contents lie within the range for the coins, with the exception of the one tin-rich ingot, so the coins could be derived from ingot-type alloys which have been debased with bronze or brass.

If the Croydon ingots are from English silver, they perhaps derive from older artefacts. However, analyses of Anglo-Saxon coins from the middle three decades of the ninth century show silver between 61% and 90%, with gold-in-silver contents generally 0.3–0.4 (Metcalf & Northover 1989, 118–19), a concentration generally lower than the Croydon finds. Only two analyses of ninth-century Anglo-Saxon metalwork from hoards dating before 875, two mounts from Scottish hoards, allow comparisons to non-numismatic silver. Both were of silver greater than 95%, substantially purer than the Croydon ingots. Unfortunately no gold figures were published for these objects (Graham-Campbell 1973, 46). The high gold alloy of one ingot suggests a gilt object was melted down as part of the silver.

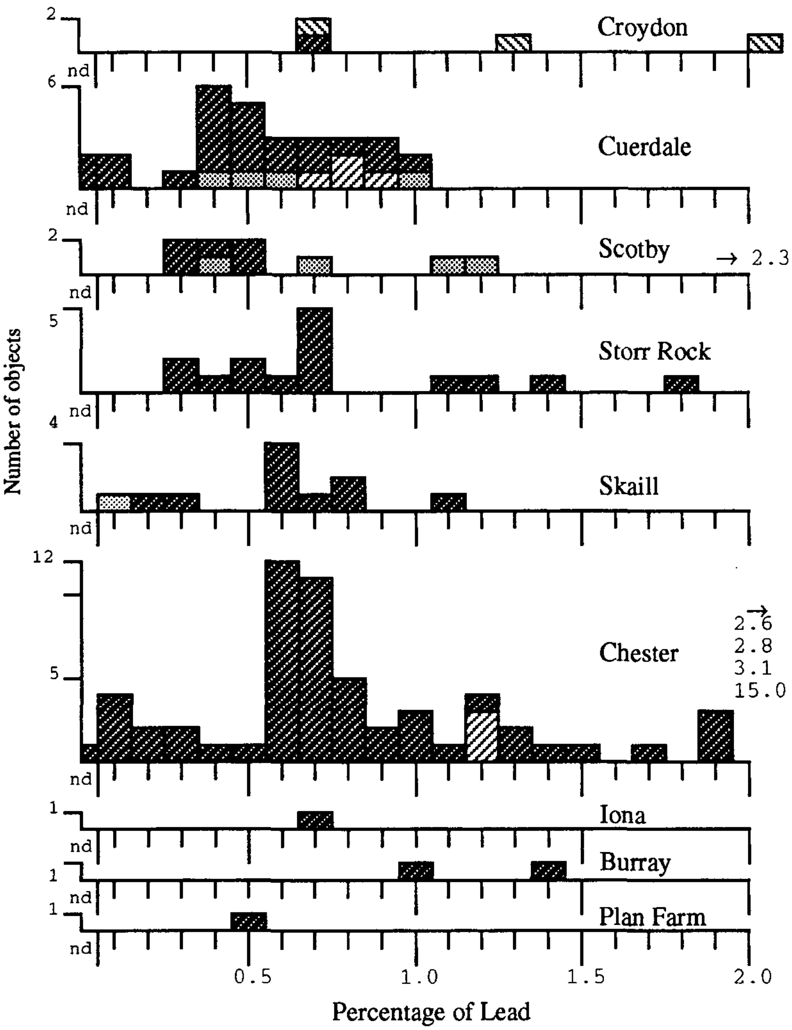
A recent interpretation of the Croydon hoard has suggested that the find was assembled probably by a Danish member of the Great Army which was based in London in 871–2. The Mercian and Wessex coins within the hoard suggest a portion of the money paid by Burgred and Alfred to the invaders. However, the hacksilver within the hoard, an armring and spiral ring fragment, together with the Frankish and Kufic coins, which have been pecked, suggest silver brought from Denmark (Brooks & Graham-Campbell 1986, 97–9). As a result, the ingots are as likely to represent wealth brought from Denmark as they are melted plunder obtained in England. Unfortunately, no contemporary objects or ingots from Danish finds have been analysed which would allow some comparisons.

### CUERDALE (c 905)

The Cuerdale hoard is an exceptional find in all respects: the largest hoard from western Europe, with an interesting range of coins and non-numismatic silver (Graham-Campbell 1987; forthcoming). Over 350 ingots and fragments are known from the hoard, probably an underestimate since many were dispersed before recording. The contents of the hoard were accumulated over a long period, with the result that the ingots are unlikely all to date from the same period. Some are fresh in appearance, without the pecking which indicates silver testing during circulation. Others, however, are worn and heavily pecked.

Most ingots tested were of high-purity silver, all greater than 90% (illus 2). The gold-in-silver contents are widespread, from 0.1 to 0.9 (with one Ashmolean analysis even larger), again suggesting no single source for the silver (illus 1). A similarly wide spread in lead concentrations reflects this diversity (illus 5). Few ingots contain zinc or tin, and for the majority, no bismuth could be detected (illus 7–9).

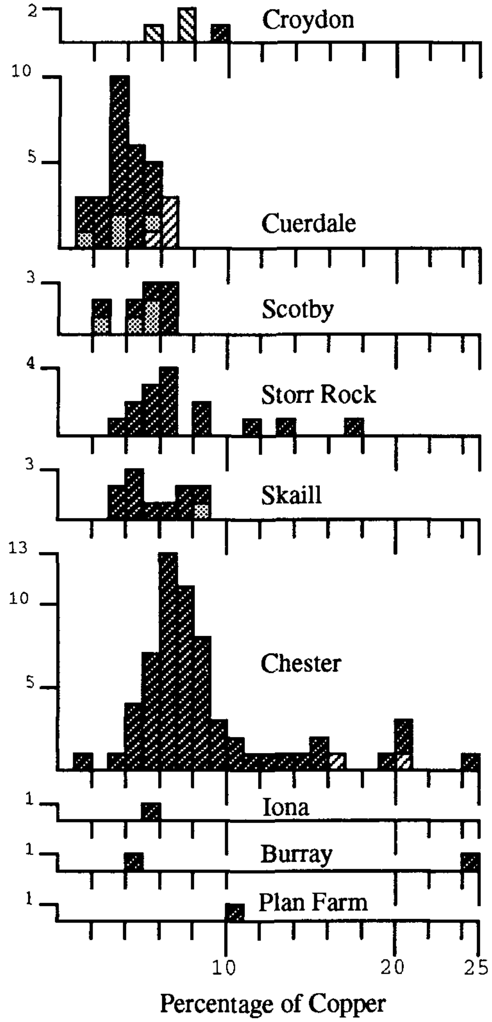
The Ashmolean analyses of two ingots (Am 533; Am 536) had large amounts of zinc (over 0.6%), and two ingots (Am 535; Am 536) and a piece of slag (Am 551) had large amounts of tin (over 0.5%), much greater than found in our analyses. No coinages match these figures exactly.




ILLUS 5 *Lead contents*

Some mid-ninth-century Mercian coins had high zinc and tin (Metcalf & Northover 1985), though rarely silver purity as high as the Ashmolean objects. Similarly, isolated analyses of Viking Northumbrian and Carolingian coins from the third quarter of the ninth century had zinc over 0.6% (though no tin), and high silver (Metcalf & Northover 1988).

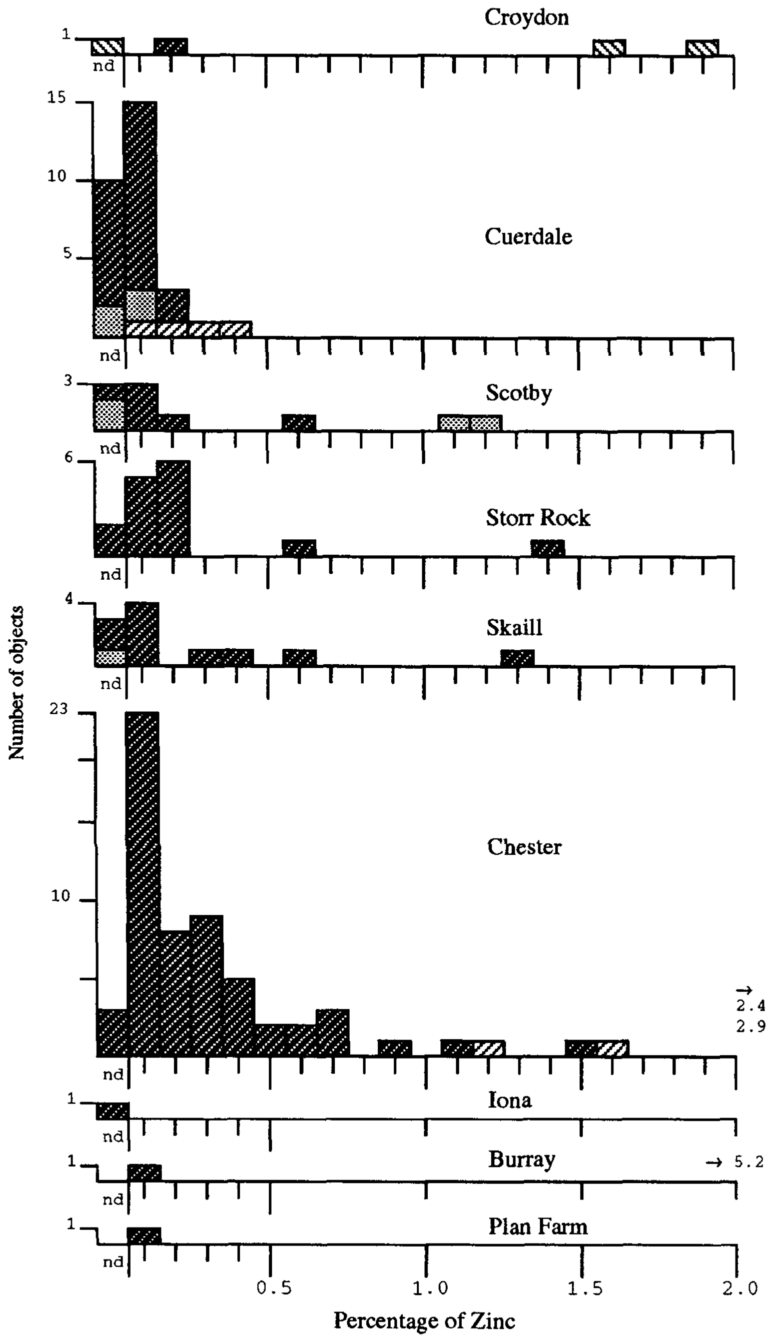
None of the Cuerdale ingots analysed was composed entirely of the debased silver used in Anglo-Saxon coinage from the third quarter of the ninth century. Analyses of coins from the reign of Alfred have shown a dramatic change of alloy from coins in the late 870s, where purity greater than 90% was achieved (Metcalf & Northover 1985; 1988). Although it is dangerous to generalize on the basis of six coins, the alloy no longer includes bismuth, in four of six cases no zinc, and in four of six cases gold content over 0.8% (Metcalf & Northover 1985; Harris 1962). For the



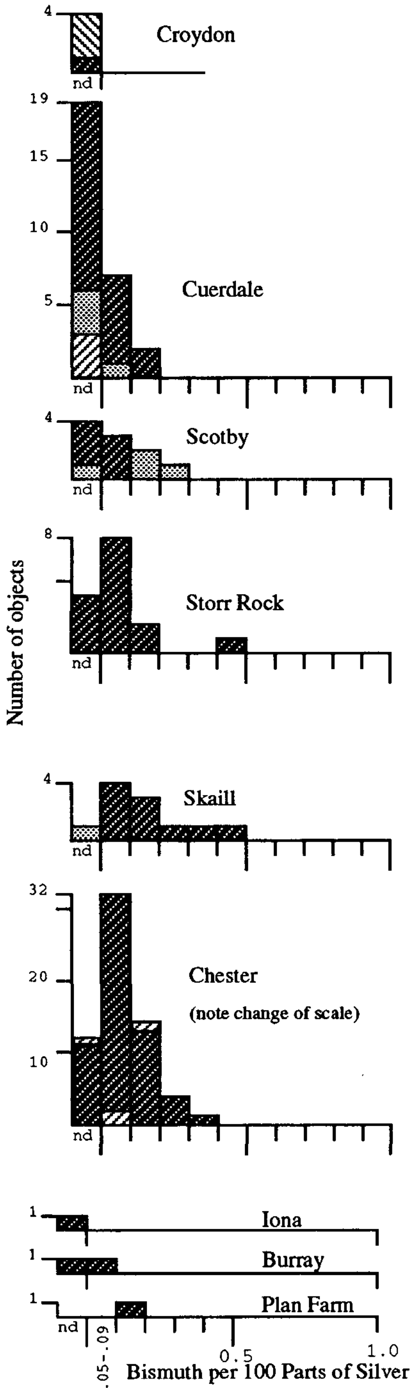

ILLUS 6 Copper contents

diagnostic gold-in-silver ratio, four of the six coins are greater than all but two of the Cuerdale ingots tested by us. Ten of the Ashmolean gold-in-silver contents are greater than 0.8%, but these figures may be slightly high; see the comments above in Methodological Discussion. High-purity silver was maintained in the coins of the succeeding reign of Edward the Elder, the first issues of which would have been available for melting into Cuerdale ingots. Of the coins which have been analysed from his reign, a high gold-in-silver composition is also found (illus 10), again higher than was found in most ingots.

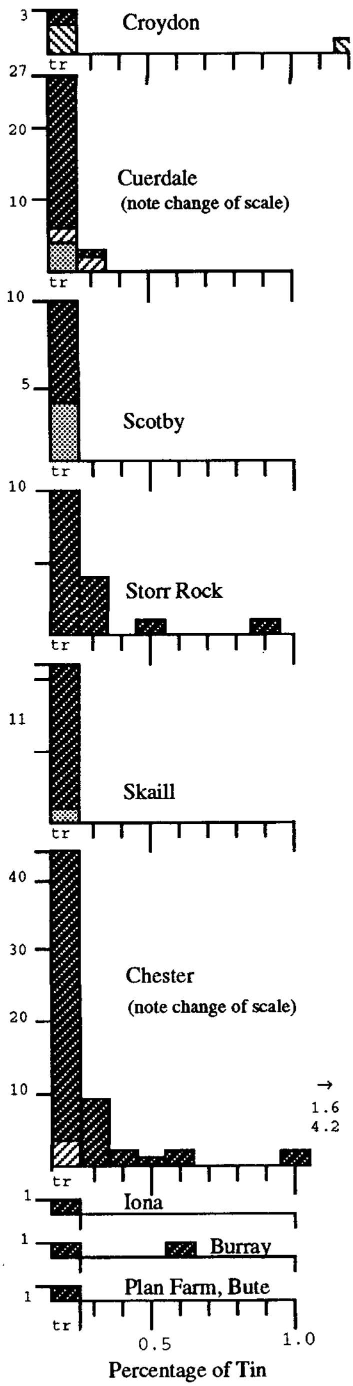
Thus the Cuerdale ingots may have contained some melted Anglo-Saxon coins or a similar source of metal, but the ingots were not exclusively made of this alloy, with many showing a source much lower in gold. Recent analyses by Metcalf & Northover (1988) have shown that the Viking rulers in Northumbria and East Anglia used a different alloy for their coinage than that



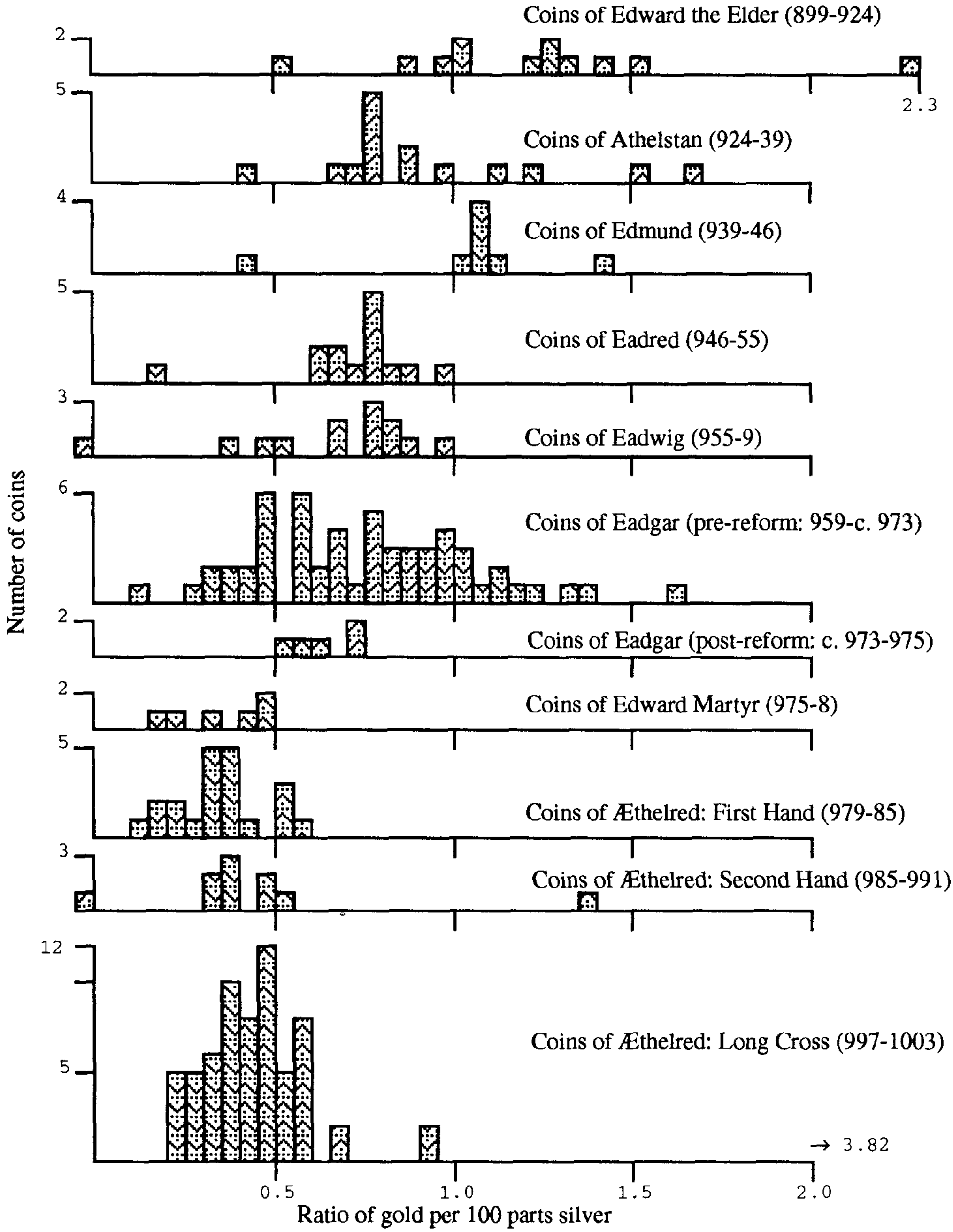

ILLUS 7 Zinc contents



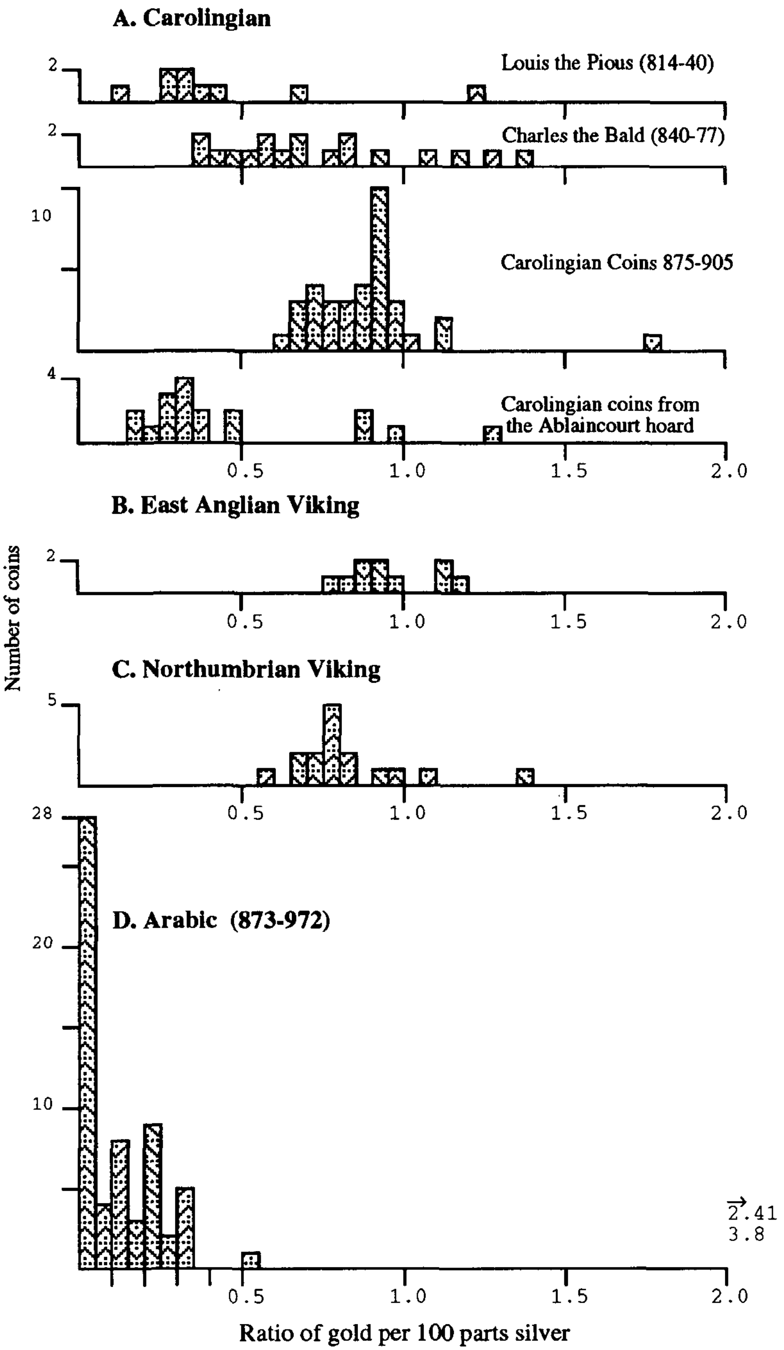

ILLUS 8 Bismuth per 100 parts of silver




ILLUS 9 Tin contents




ILLUS 10 Gold per 100 parts of silver: Anglo-Saxon coins




ILLUS 11 Gold per 100 parts of silver: Carolingian, Viking and Arabic coins

found in Anglo-Saxon coins (Metcalf & Northover 1988). These analyses are particularly useful since the 12 Viking Northumbrian and 10 East Anglian coins tested derive from the Cuerdale hoard. The gold-in-silver contents are less than those found in Anglo-Saxon coins, but still high, averaging 0.81 for the Northumbrian issues and 0.95 for the East Anglian issues (illus 11). These ratios are still higher than most ingots, though the possibility that analytical techniques and calibration account for the differences cannot be discounted. Most issues have some zinc, unlike high-quality coins of Alfred, averaging 0.22% for the Northumbrian issues and 0.2% for the East Anglian, with a wider spread in the northern issues. Unfortunately, the zinc figures are some of the less accurate for the ingots, but almost all the Cuerdale ingots are below 0.2% (illus 7).

Metcalf & Northover have also analysed 34 Carolingian coins, most from the Cuerdale hoard. Their findings (1988, 101–2) suggest variation in alloys between mints, so that one should not expect to find one Carolingian standard with which to compare other objects. Nevertheless, certain general trends in the material can be observed. The gold-in-silver contents were widespread, but with a peak at 0.9–0.95 (illus 11), again generally higher than obtained for the ingots. Interestingly, the six coins from the Melle mint, probably from locally mined silver, show a slightly lower gold-in-silver content, averaging 0.84, which is at the higher end of Cuerdale ingots analysed. However, differences in other elements preclude the ingots from being interpreted as directly from Melle silver.

Eighteen coins, primarily from north-eastern Carolingian mints, from the nearly contemporary Ablaincourt hoard, were analysed by cupellation techniques, showing a much lower gold-in-silver content (illus 11; Lafaurie & Pechiney 1988). These coins, however, are at the other end of the ingot spectrum, lower than most Cuerdale ingots, and more reminiscent of Arabic coinage in their ratios. If these findings are accurate, and not the result of calibration (Metcalf & Northover 1988, 105), they indicate at first glance silver more similar to Arabic coins, though without the high purity often found. Unfortunately, there were no bismuth analyses, which might allow further comparison with Arabic silver.

Arabic coins are found in 20 hoards from the British Isles, dating from c 875 to c 970, including Croydon, Cuerdale, Storr Rock and Skaill (Graham-Campbell 1987, 337). Of these 20 hoards, 15 contained non-numismatic silver, and of these finds, 11 certainly had ingots. As a result, the circulation of Arabic coins and ingots coincided, and it was thought possible that some ingots were composed of melted Arabic coins. Fortunately, analyses of 10th-century Arabic coins have revealed some distinctive alloys, with very high silver, low gold, and a moderate amount of bismuth (illus 11; Cowell & Lowick 1988; McKerrell & Stevenson 1972; Werner & Cowell 1975; Arrhenius, Linder Welin & Tapper 1972–3).

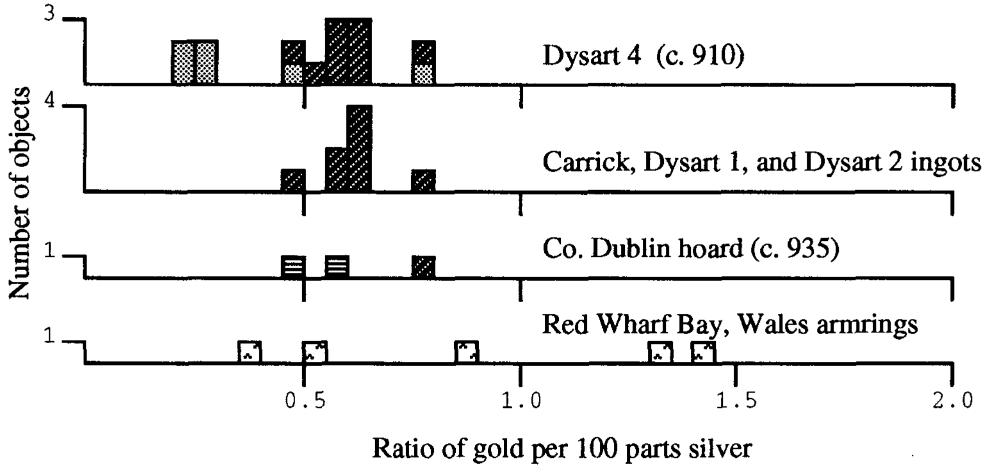
The recent analyses of Arabic coins by Cowell & Lowick have also highlighted regional differences, particularly in the amount of bismuth (Cowell & Lowick 1988, 71–2). Coins from the Hindu Kush in Afghanistan show a distinctive alloy of very pure silver, very low gold (generally below 0.1%), and high bismuth (greater than 0.5%). In contrast, analyses of coins from mints to the north of this area, including Samarkand, and from Baghdad, exhibit slightly higher gold (0.2%), lower silver, correspondingly higher copper, and lower bismuth (0.2–0.5%). Further analyses may reveal greater chronological and geographical differences.

Where their mints are known, the Arabic coins in the hoards with analysed ingots are generally from the eastern Caliphate, particularly from the mints of the Hindu Kush or those to the north (Blunt & Dolley 1959, 230; Lowick 1976, 21–3; Stevenson 1966). In this, as in other respects, the Cuerdale hoard was unusual in that (as far as can be ascertained) most of its coins were from Transcaucasian mints (Lowick 1976, 22–4). Only 10 coins have been analysed, dating from 873 to 905, all from the eastern Caliphate. They all contain very little gold (all but two less than 0.1%) and high silver (all but one is greater than 96%), with all but two of the resulting gold-in-silver contents being less than 0.1. The coins have relatively high bismuth (lowest 0.1%, highest 2.6%), those from the Tashkent and Samarkand mints having 0.2 to 0.4%, and those from the Hindu Kush mints, with one exception, all greater than 0.64%.

Only a very few Cuerdale ingots revealed an alloy similar to Arabic coins. Comparison of the gold-in-silver contents of Arabic coins with those of the Cuerdale ingots (illus 11 & 1) shows strong differences. Only two Cuerdale ingots contained gold of 0.2% or less (L 33; L 56), both of which had higher bismuth than most ingots (0.1%), but less than the Arabic coins. Two of the four rod fragments analysed with the ingots also had low gold, but one had no bismuth detected (L 62), the other 0.1% (L 61). Although, as noted above, bismuth readings are not as accurate as we would like, concentrations greater than 0.2% should have been detected.

Since it is likely that many of the ingots in the Cuerdale hoard derive from Ireland, the analyses of ingots and hacksilver from the Dysart 4, Co. Westmeath, hoard, deposited shortly after Cuerdale in c. 910, were most welcome. Unfortunately these analyses, which were chemical analyses on samples from the objects, did not determine bismuth or zinc (Ryan *et al.* 1984). Many of the Dysart ingots and objects also had significant concentrations of iron, often around 1%, unlike most other analyses of contemporary silver. This may relate to different forms of analysis, or to the incorporation of some surface silver with corrosion products in the sample. The silver contents of the Cuerdale ingots are generally higher than the Dysart ones, but it is unclear if this is a factor of the different types of analysis. The spread of the gold-in-silver contents in the Dysart material (illus 12) is not as wide as that found in the Cuerdale analyses (illus 1), and if one looks at only the eight ingots analysed, they are quite compact at between 0.46 and 0.71. The inclusion of the ornaments widens the spread, with several being much lower, as in the case of the Cuerdale rod fragments, but the ratio remains within that illustrated by Cuerdale material.

Thus, although the differences in techniques hinder exact comparisons, there is some indication that the silver used in ingots may be derived from similar sources. This lends further confirmation to observations of the similarity of the two hoards (eg Graham-Campbell 1987, 332; Kenny 1987, 509). It is worth noting that the large ingots found in the nearby Carrick, Dysart 1




ILLUS 12 Gold per 100 parts of silver: Irish silver

and Dysart 2 hoards, which were also analysed, are similar to the Dysart 4 silver, a finding confirmed by limited lead isotope analysis. This is significant because these large ingots are of a different type from those found elsewhere, and may well be of Irish origin (Ryan *et al.* 1984, 357–9, 364).

Analyses of five Hiberno-Viking armrings from Red Wharf Bay, Dinorben, Wales, provide further evidence of Irish silver. The armrings are from a coinless hoard, but are of an Irish type dating c 850 to c 950; a number of similar examples are found in the Cuerdale hoard, and a fragment in the Croydon hoard (Graham-Campbell 1976, 51–3). The silver contents were quite high, all over 93%, with little or no zinc, bismuth, or tin. However, the gold contents were variable, with a resulting widespread gold-in-silver content (Northover 1986), different from the Dysart 4 analyses (illus 12). Although the high silver content allows comparisons, as Boon noted, to Arabic coins and the Skaill 'ring-money' (Boon 1986, 100), the other trace elements are less compatible. The lack of bismuth and the high gold content (lowest 0.36%) are at variance with most Arabic coins, while the lack of zinc, bismuth, and the higher gold in four of the five armrings are at variance with the Skaill 'ring-money'.

In addition to the four rod fragments from the Cuerdale hoard analysed by us, a fragment of a bossed penannular brooch from the hoard has also been analysed by XRF (Lang & Graham-Campbell 1976). Unfortunately, only silver and copper contents were noted for the brooch, with the result that one can note only high silver purity.

A few distinctive alloys stand out in the Cuerdale ingots for which there are no parallels in coins or objects. For example, six ingots contain very pure silver, lead concentrations either not detected or less than 0.1%, gold between 0.7 and 0.9% and no zinc (L50; L59; L63; L69; Am 524; Am 532); this is an unusual alloy, particularly since cupellation does not appear to affect lead below 0.5% (McKerrell & Stevenson 1972, 198). It may be that lead is not distributed homogeneously throughout the alloys and that these analyses happened to be at low concentration areas. However, similar low-lead analyses occurred in sufficient numbers to suggest that it is not an experimental effect. Another Ashmolean ingot has similarly low lead, but almost no gold (Am 530); it represents another of the few candidates for being derived from Arabic silver. Five ingots in the Chester hoard also have very low lead concentrations (C67; C83; C101; C105; C107), but they vary in all other elements with the exception of gold, which ranges between 0.4 and 0.6. However, as noted above, the gold concentration is remarkably clustered in the Chester ingots, and this range reflects the major peak. Few other objects seem to be made of this alloy. One Skaill rod fragment (RMS IL66) contains no lead, but has slightly less gold than the Cuerdale ingots; no 'ring-money' from the hoard has lead less than 0.6% (White & Tate 1983). An Ashmolean analysis of a spiral ring fragment from the Co Dublin hoard (Am 554) has less than 0.1% lead, and a similar gold content to the Skaill fragment. The Co Dublin ring fragment is from a so-called Permian ring, a type which is generally viewed as an eastern Baltic import to Scandinavia or, in one variation, a Scandinavian imitation. When they occur in the British Isles they are viewed generally as imported from Scandinavia (Brooks & Graham-Campbell 1986, 95–6). Unfortunately, the Dublin fragment is too small to distinguish between an eastern import or an imitation. Three 19th-century analyses of an Irish ingot and Hiberno-Viking armrings also have no lead, though with varying gold contents (Mallet 1853, 319). However, the eight analyses of silver objects of varying date are unusual in recording little or no lead at all, suggesting an analytical factor. The recent analyses of objects and ingots from Co Westmeath hoards did not reveal any very low-lead alloys (Ryan *et al.* 1984).

Of the large number of Anglo-Saxon coins which have been analysed dating from the reign of Alfred, only six, four from Eadgar's reign (three post-reform) have lead concentrations of 0.1%

or less (Metcalf & Northover 1986, 50, and Table of Analyses, nos. 412, 419, 422, 423, 521, 604). No Carolingian, Viking Northumbrian or Viking East Anglian issues contain this alloy. Only five 10th-century Arabic coins contain such low lead, but all have extremely low gold, yielding gold-in-silver contents less than 0.1 (Cowell & Lowick 1988, nos. 9, 12, 19, 37, 38).

### Mould Duplicates

Several groups of mould-duplicated ingots exist in the Cuerdale hoard, the most notable being the so-called 'mark' ingots. At least 16, and possibly as many as 20, examples were found of this distinctive type of ingot which is trapezoidal in shape and cross-section. Twelve are extant. They are not strictly speaking mould duplicates, since the mould was modified sometime during its use, with a cross cut into the mould, thereby yielding a cross in relief. This mould in turn cracked, and some ingots have the cross in relief and the line where the crack occurred. The ingots are fresh in appearance, with few pecks cut into the silver. This ingot form is unique to England and Scotland, the only close parallel being a smaller ingot from Newry, Co Down (Kruse 1988, 68).

Six of the ingots were analysed, five by us (L 45–9) and one by the Ashmolean Museum (Am 522). One turned out to be a forgery (L 47; see below). The remaining five ingots show a roughly similar composition, although there is some variation in elements, and the Ashmolean ingot has an atypically large lead content. This alloy was a mixture of silver from several sources, resulting in a composition very much at the lower range of silver, highest copper, and highest zinc of the Cuerdale ingots tested.

No other Cuerdale ingots appear to match this alloy, although aside from the higher zinc content in comparison to other Cuerdale analyses, it is not very distinctive. A much smaller ingot with suggestions of very worn raised patterning, possibly a raised X or V (Am 525), is of a different alloy, being very pure with greater gold and no zinc. Ingots from later hoards often contain some zinc, and several roughly correspond to the mould duplicates (eg Storr Rock (RMS IL 294), Skaill (RMS IL 54) and Chester (C.77)). However, the alloy is not distinctive enough to allow any generalizations. Although a few Viking Northumbrian and Viking East Anglian issues are also similar (eg Metcalf & Northover 1988, nos. 42, 52), no 10th-century Anglo-Saxon coins correspond, with most containing far more zinc and higher gold-in-silver contents.

### Forgery

The detection of a forgery was one of the most spectacular results of the analyses. The ingot is one of the distinctive trapezoidal 'mark' ingots (L 47). Nothing is known of its history before Philip Nelson acquired the object in the 1940s or 1950s (Graham-Campbell forthcoming). The weight of the ingot (191.79 g compared to c 250 g for the other mould duplicates) had marked it as atypical (Lewis 1982, 54–5), but no suspicion as to its authenticity had been noted. The ingot contains no silver, but instead is of tin. It shares a number of characteristics in form with the other mould duplicates, and either represents a Viking Age forgery from the same mould or a 19th- or 20th-century ingot cast in a mould formed from one of the duplicates.

Distinguishing between a modern and ancient forgery is extremely difficult. If the object is a modern forgery, its model must have been one of the ingots with a raised cross made before the crack appeared. Three of these are extant, one in the Ashmolean (Am 522), one acquired by the British Museum in 1873 (British Museum 73,11–1,1), and one from the Assheton Collection (A1), at present on loan to the British Museum. The Ashmolean ingot was acquired by Sir Arthur Evans sometime before his death in 1908 and donated by his son in 1909 to the Ashmolean Museum.

Unfortunately, details are vague concerning the other two ingots. The Assheton collection at one point contained four 'mark' ingots, although only one of these is recorded as having been distributed by the Duchy of Lancaster after the Cuerdale inquest. The sources of the other three Assheton ingots are unknown (Graham-Campbell forthcoming). The British Museum ingot was purchased by the Museum in 1873 from a dealer, with no further details known. The possibility also remains that the model no longer survives, since several of the 'mark' ingots are unaccounted for (*ibid*).

Like the forgery, the British Museum and Ashmolean ingots have definite pecks, though the majority of the other mould duplicates are without pecks. Moreover, the pecks on the British Museum ingot and the forgery are roughly in the same place. The Ashmolean ingot is rather pitted on top, unlike the other examples or the forgery. As a result, it is less likely that this ingot could have been used to make the mould.

No sources mention any lightweight ingots amongst the duplicates (*ibid*.). Unfortunately, the early account by Hawkins is ambiguous in its discussion of the weights of these ingots. He noted the presence of the duplicates, but concluded that the 'ingots are not adjusted to any particular weight, those cast even in the same mould varying . . . between 3900 and 4000 grains' (Hawkins 1847, 112). This range indicates a low weight of 252.79 g; of the extant mould-duplicate ingots, the lowest (other than the forgery) weighs 250.58 g (Assheton Collection A2). Hawkins probably settled for imprecise and round numbers in the weights he published, and 3900 grains would best approximate to this ingot. Of the other ingots in the hoard, he stated (*ibid*) that they ranged in weight from 2000 grains [=129.60 g] to less than 100 grains [=6.48 g]; the extant complete ingots range from 139.93 g to 5.50 g. It is odd therefore that Hawkins did not report the weight of the forgery if he had it to hand, even within a wide range of tolerance such as 3000 grains [=194.40 g], since it would have best illustrated his argument that the ingots were not cast to any standard. The possibility remains, however, that the forgery was amongst the material abstracted from the hoard before it was surrendered to the authorities (Graham-Campbell forthcoming).

Against these arguments, one can note the crispness of the forgery, and its obvious similarity in details to the other ingots. If the mould was formed from an existing ingot, the ingot must have had extremely good relief, which, however, both the British Museum and Assheton ingots do indeed have. Although there have been very few analyses of ingots apart from this study, Viking Age base ingots are not unknown (Stenberger 1958, 234).

Consequently, the question as to the age of the forgery remains open, though the evidence strongly supports a 19th-century date. The lack of any mention of it in Hawkins's account remains the most persuasive argument. If the ingot is of modern date, the British Museum ingot appears at present to be the most likely candidate for having been copied; if so, it would date the forgery to the third quarter of the 19th century. Forgeries of coins from Cuerdale had certainly proved to be problematic by the 19th century (Dolley & Blunt 1961, 93).

### SCOTBY, CUMBRIA AND STORR ROCK, SKYE (c 935)

Three small hoards with ingots were deposited c 935 in different areas of the Irish Sea province: Scotby, Cumbria (Kruse 1986) whose entire non-numismatic contents of six ingots and four rod fragments were analysed; the Storr Rock, Skye, hoard with 23 pieces of hacksilver (Graham-Campbell 1975–6, 119), of which 15 are ingot fragments and were analysed; and the Co. Dublin hoard with one ingot and two fragments of spiral rings (Graham-Campbell 1976, 49), which were analysed by the Ashmolean Museum (App 1). Like the ingots in the Cuerdale hoard, the analysed silver in these hoards displays a wide range of results, and is not from a single silver source, not even within the same hoard.

The composition of the Storr Rock and Scotby ingots is broadly similar, suggesting access to the same sorts of silver at this period. The results are not inconsistent with earlier ones from Cuerdale, but in part this is due to the widespread sources evident in this find. The gold-in-silver contents (illus 1) suggest a more compact range, particularly from Storr Rock, much tighter than Cuerdale, and more similar to the Dysart 4 analyses (illus 12). The Co. Dublin ingot and ring fragments also fit into this range. One Scotby ingot had exceptionally high gold content, perhaps the result of melting a gilt object. The Scotby and Storr Rock objects are slightly less pure than the Cuerdale ones, with three Storr Rock ingots being much baser (illus 2), a difference accounted for mainly by increased copper and tin (illus 6, 9).

The Storr Rock ingots, as noted above, have more tin than contemporary or earlier ingots, with two particularly so (illus 9). The largest tin content is also matched by the Co Dublin ingot (see the Appendix). A general trend of slightly more zinc and bismuth as compared to the Cuerdale objects can be seen (illus 7–8). In the Scotby hoard, two rod fragments (G & J) with an unusual alloy are also very similar in composition, so much so that it is very possible they were from the same object, even though the cut faces do not match up now, or may have been cast from the same melt.

A number of Anglo-Saxon coins, most from Scottish hoards, have been analysed and provide comparative material (McKerrell & Stevenson 1972). Coins of Athelstan (925–39), contemporary with the find, are also of high-purity silver. They display a wider gold-in-silver content, however, than that found in analysed coins from the reign of Edward the Elder, which could indicate new sources of silver were being utilized in the country (illus 10). Too few analyses of coins have been undertaken, and too few coins can be localized to mints, for it to be possible to determine if these differences reflect regional supplies. The Anglo-Saxon coins display a wider and generally higher gold-in-silver content than the non–numismatic analyses; only the lower cluster in the Athelstan coins overlaps the high end of the non-numismatic analyses.

The Storr Rock ingots and, to a lesser extent, the Scotby objects, have a greater amount of zinc than earlier Cuerdale examples (illus 7). However, the use of zinc in Anglo-Saxon coins is greater than that found in the ingots. It is possible that the ingots are reflecting the admixture of either Anglo-Saxon coins or of the same brass that was presumably added to the coin stock.

A number of Arabic coins dating between 905 and 935 have been analysed for comparison. These include six coins from the Storr Rock and Skaill hoards, of which five can be provenanced (three from Samarkand, one from Tashkent and one from Baghdad; McKerrell & Stevenson 1972, 209; Stevenson 1966). As noted above, the Arabic coins from Samarkand and Baghdad in general display lower bismuth, c. 0.2 to 0.6%, higher gold, around 0.2%, slightly lower silver, 91 to 97%, and resulting higher gold-in-silver contents (most 0.1 to 0.2). Although most of the Storr Rock and Scotby objects do not compare closely with Arabic coins, there are two exceptions if one looks at only the Samarkand and Baghdad coins. A Scotby rod fragment (H) and Storr Rock ingot (RMS IL 292) are similar, although the ingot contains more zinc than is commonly found in these Arabic coins.

The impression gained in this period is of a mixture of sources of silver available to producers of coins and ingots. This mixture is, in many respects, less pronounced for ingots than coins, and displays few geographic distinctions for ingots. Moreover, the gold-in-silver contents in general show a much smaller range than in the earlier Cuerdale find, perhaps owing to more limited sources or perhaps to increased remelting leading to more homogenization of silver. Unfortunately no dated Irish artefacts from this post-Cuerdale period have been analysed to determine if the affinities in this material continue.

SKAILL, ORKNEY (c 950)

The Skaill hoard is the second largest Viking Age hoard from the British Isles, originally containing 8 kg of silver. Most of this was of non-numismatic silver, particular 'ring-money', penannular brooches, neckrings and armrings. Only 21 coins were in the hoard, 19 of which were Arabic (Graham-Campbell 1975–6, 119–21). Despite the large amount of non-numismatic silver, only 10 ingots are known from the find.

A widespread gold-in-silver content is found in the Skaill ingots, without any clustering (illus 1). There is little difference in the ratios between the ingots and the 'ring-money' tested by White & Tate (1983), although the 'ring-money' is not quite as pure, and one example is very base, below 80% silver. Values for silver, bismuth, lead and zinc are similar to the hoards deposited 15 years earlier. All ingots had only traces of tin or none at all, as was the case at Scotby and with the majority of the Cuerdale ingots (illus 2–9). Again this pattern is at variance with Anglo-Saxon coins, which continue to have more widespread and higher gold-in-silver contents (illus 10). The coins of Edmund (939–46) and Eadred (946–55) are more debased than those of Athelstan, with the moneyers adding far more zinc and copper in the reign of Eadred (Forbes & Dalladay 1960–1; Harris 1962; McKerrell & Stevenson 1972).

A greater amount of zinc is found in the Skaill ingots (illus 7) than the Cuerdale or Dysart 4 examples, a spread not that dissimilar from the Storr Rock ingots or even from the coins of Edmund. The 'ring-money' from Skaill shows even more zinc than the ingots (White & Tate 1983), suggesting perhaps a greater admixture of Anglo-Saxon coins for these objects, more scrap brass in the crucible, or possibly a different composition of brass being added.

Although some bismuth occurs in coins from Edward the Elder onwards, rarely is there more than 0.3%, a situation also reflected in the ingots from previous finds, which rarely have more than 0.2%. The Skaill ingots and 'ring-money', however, have several examples with more than 0.3% and only one (the rod fragment RMS IL 66) with none. Although the analysed Arabic coins available for comparison with Skaill generally date to several decades earlier, these include some of those found with the hoard. As with the Storr Rock and Scotby finds, few ingots from Skaill compare with the analysed coins from the Hindu Kush. However, if one looks at the Samarkand and Baghdad mints again, a few possible comparisons can be drawn. In particular, two of the ingots are similar (RMS IL 516 & IL 93), and a third possible (RMS IL 57), although only one contains no zinc.

Two large pins from ball brooches, probably from the Skaill hoard, together with a hoop and terminal of a similar brooch definitely from the hoard, were previously analysed by one of us (JT). The results show different compositions for the intact pin-head and shaft, with the shaft being composed of much higher silver and less zinc. This difference in part derives from analysis of the surface of the shaft (and thus affected by silver enrichment), and in part by the different treatments of the two sections of the object. Similarly, the second pin-head, and the hoop and terminal to which it may have belonged originally, also reveal some differences, perhaps with extra copper deliberately added to the parts which were cast (Graham-Campbell 1984, 292–3).

As a result, these objects cannot be paralleled directly to the ingots, for which no such considerations existed during casting. Nevertheless, there are similarities in elements. The gold-in-silver contents of the brooch parts are within the range of the ingots and the 'ring-money', although one of the pin-heads and hoop are at the upper range. All other elements can be matched in the range revealed by ingots and 'ring-money'.

CHESTER, CHESHIRE (c 965)

The Chester hoard is the only hoard with ingots (other than the Croydon hoard deposited almost 100 years earlier) that was found inside the Anglo-Saxon kingdom proper. It is an odd hoard, with over 524 coins, including Anglo-Saxon, Viking Northumbrian and Carolingian issues, and 141 hacksilver pieces, the majority of which, 98, are ingots (Webster 1953; Kruse 1988, 253–6). Of these, 62 ingots were analysed. Many of the coins were quite old at the time of deposition, leading to speculation that this was a savings hoard (Metcalf 1986, 149). The ingots also included objects that had long been in circulation, as suggested by the heavy pecking on many of the fragments.

Consequently, one would suspect silver composition to vary much like the Cuerdale material. However, although there are some distinctly base ingots in the material, the gold-in-silver contents are tightly compact, with a decided peak between 0.5 and 0.7 (illus 1). This either represents a single source of silver or homogenization due to a large number of remeltings; given the age structure of the hoard, the latter interpretation is more likely. The gold-in-silver contents parallel the main clustering in the Dysart 4 and Storr Rock ingots. Bismuth levels correspond to the Skaill and Storr Rock ingots, with most showing less than 0.2%, but a few greater (illus 8). Similarly, the zinc levels correspond to Skaill, although the Chester ingots span a greater range (illus 7). The debased ingots, as might be expected, have high concentrations of zinc.

Comparison with Anglo-Saxon coins is rendered difficult by the different alloys within the reigns of Eadred, Eadwig, and pre-reform Eadgar (959–c 973) (McKerrell & Stevenson 1972; Forbes & Dalladay 1960–1; Harris 1962; Metcalf & Northover 1986). The coinage varies widely in fineness, with some as fine as previous issues, but many which are very base. In one case, two coins by the same moneyer and of the same type are 34% and 92% silver respectively (McKerrell & Stevenson 1972, nos. 629, 630). However, even if one limits the comparison to coins of the same type, no peaks are visible, and the range is very wide. A number of the analysed coins have been attributed to the Chester mint (McKerrell & Stevenson 1972, 195), giving some idea of local silver stocks.

The coins are often debased with large amounts of zinc, but many coins of fine silver have a large percentage of zinc, continuing the trend of the previous reigns. Even among coins with silver contents greater than 85%, the zinc contents are very much higher than are found in the Chester ingots. Gold contents, and gold-in-silver contents of the coins display even more variability than previous issues (illus 10). A new lower gold-in-silver source is present, and is even lower than most 10th-century ingot finds, although the Cuerdale hoard had a number of ingots encompassing this spread. This change has given rise to some speculation about new silver supplies arriving into England during Eadgar's reign (Metcalf 1986, 145). Some, though not all, of the low gold-in-silver contents evident in Eadgar's coins are reflected in 10th-century ingot material. As a result, Eadgar's moneyers may have begun to utilize some of the silver stocks which had also been used for ingots.

A very few Ottonian coins dating to the second half of the 10th century have been published (Kraume & Hatz 1967). Difficulties remain in integrating these analyses with others, but the results suggest a different source of silver than that found in the ingots. These analyses are of particular interest, since some must reflect the new silver sources from the Rammelsberg mountains which began to be exploited around this time (Spufford 1988, 74). The gold content of these coins is very low, less than 0.3% in most cases, although silver content is high, and the resulting gold-in-silver contents are consequently very low, much lower than those found in the ingot material. The published results show a greater similarity to Arabic silver.

Mould Duplicates

A group of five mould duplicates from Chester were recovered and, like those from Cuerdale, they indicate an alloy quite different from other ingots. Three were analysed, of which two show very similar composition (1950/75A; 1950/75D); the third may well be different, having 4.2% tin, half the zinc of the others, and twice the lead (C.57). Another very heavy ingot in the hoard (1950/75E) also has a similar alloy. These ingots are some of the basest analysed, with a silver content of less than 76% (illus 2). Nevertheless, since the gold-in-silver content is consistent, these ingots may be from the same general source but with a greater amount of debasement, particularly with zinc and copper.

Other parallels in the ingot material, either earlier or later, are lacking. Although Eadgar's pre-reform coinage is very uneven in alloy, none of those analysed (McKerrell & Stevenson 1972; Metcalf & Northover 1986) provides any close parallels either.

### IONA, ARGYLL (c 986)

The Iona hoard contained over 350 coins, a small fragment of a gold rod, a silver ingot, and a silver mount, possibly of Anglo-Saxon manufacture (Graham-Campbell 1975–6, 122). The analysed ingot has a composition without any distinguishing characteristics, but consistent with many ingots in earlier hoards. No zinc or bismuth was detected, which fits in closer with the ingots from the first half of the 10th century, though this is not unknown in the second half (illus 7–8). The gold-in-silver contents match the peak of the Chester ingots (illus 1). However, there is little else that can be concluded from the analysis of a single object.

### BURRAY, ORKNEY (c 1000)

The Burray hoard, like the Skaill hoard, was composed primarily of ornaments and hacksilver (Graham-Campbell 1975–6, 123), and little of the silver was stored in ingots; in this case, there were only two ingots, one of which was completely hammered and may well be a ring fragment. This object was very debased, containing no gold at all, with a composition similar to the 'ring-money' analysed from the Burray hoard (White & Tate 1983, 250). The ingot fragment was of better silver quality than sterling, with a composition totally unlike the 'ring-money', but consistent with many other 10th-century ingots, and within the range of Anglo-Saxon coins.

### PLAN FARM, BUTE (c 1150)

Although the Plan Farm hoard is post-Viking Age in date, its composition has many affinities with the earlier hoards (Graham-Campbell 1975–6, 123–4). The composition of the silver ingot is not dissimilar to the Viking Age ingots, with gold-in-silver contents at the lower end of that of the Chester ingots (illus 1). Again, there is little to distinguish the alloy of this ingot from the other Viking Age ingots. However, the ingot is a distinct chronological outlier, there being no silver ingots available for comparison at this date: there are no ingots in any of the Scottish hoards between those from Burray and from Bute, while the latest English ingots appear in the Chester hoard, and the latest Irish ingots in the Fourknocks, Co. Meath, hoard of c 1030.

| Museum no. | Ref. | Cu | Zn | Au | Pb | Bi | Ag | Sn | Au per 100 Ag | "silver" | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Croydon** | | | | | | | | | | | | |
| L 64 | VI 82 | 9.1 | 0.2 | 0.7 | 0.7 | 0.0 | 89.1 | tr | 0.74 | 90.5 | 99.9 | |
| **Cuerdale** | | | | | | | | | | | | |
| RMS IM 24 | VI 053 | 3.1 | nd | 0.6 | 0.3 | nd | 95.8 | tr | 0.64 | 96.7 | 99.8 | |
| RMS IM 25 | VI 077 | 4.7 | 0.2 | 0.5 | 0.6 | nd | 93.9 | tr | 0.50 | 95.0 | 99.9 | |
| RMS IM 26 | VI 059 | 2.1 | 0.2 | 0.6 | 0.9 | nd | 96.1 | tr | 0.61 | 97.5 | 99.8 | |
| L 32 | VI 141 | 5.9 | 0.1 | 0.3 | 1.0 | nd | 92.5 | tr | 0.37 | 93.8 | 99.8 | |
| L 33 | VI 434 | 4.0 | 0.1 | 0.2 | 0.5 | 0.1 | 95.1 | tr | 0.17 | 95.8 | 99.8 | |
| L 34 | VI 430 | 3.0 | 0.1 | 0.9 | 0.4 | nd | 95.4 | 0.3 | 0.90 | 96.6 | 100.0 | c |
| L 36 | VI 161 | 5.8 | 0.1 | 0.6 | 0.4 | nd | 93.0 | tr | 0.66 | 93.9 | 99.8 | h |
| L 37 | VI 094 | 5.1 | nd | 0.3 | 0.8 | 0.2 | 93.5 | tr | 0.30 | 94.6 | 99.8 | |
| L 41A | VI 440 | 3.6 | nd | 0.5 | 1.0 | nd | 94.6 | tr | 0.57 | 96.2 | 99.8 | h |
| L 42 | VI 137 | 5.8 | 0.1 | 0.5 | 0.5 | nd | 92.9 | tr | 0.55 | 93.9 | 99.8 | |
| L 44 | VI 431 | 3.9 | 0.1 | 0.6 | 0.4 | nd | 94.8 | tr | 0.59 | 95.8 | 99.8 | |
| L 45 | VI 134 | 6.4 | 0.2 | 0.5 | 0.7 | 0.1 | 92.1 | tr | 0.51 | 93.2 | 99.8 | |
| L 46 | VI 121 | 6.2 | 0.3 | 0.6 | 0.8 | nd | 91.8 | 0.3 | 0.63 | 93.1 | 100.0 | c |
| L 48 | VI 130 | 6.9 | 0.4 | 0.7 | 0.9 | nd | 90.9 | 0.3 | 0.73 | 92.4 | 100.0 | |
| L 49 | VI 433 | 5.8 | 0.1 | 0.7 | 0.8 | nd | 92.4 | tr | 0.76 | 93.9 | 99.8 | |
| L 50 | VI 432 | 3.5 | nd | 0.8 | nd | nd | 95.6 | tr | 0.78 | 96.3 | 99.8 | |
| L 51 | VI 149 | 3.4 | nd | 0.8 | 0.4 | nd | 95.1 | tr | 0.85 | 96.4 | 99.8 | |
| L 52 | VI 153 | 4.0 | 0.1 | 0.5 | 0.5 | 0.1 | 94.7 | tr | 0.57 | 95.8 | 99.8 | |
| L 53 | VI 145 | 4.0 | 0.1 | 0.4 | 0.7 | nd | 94.6 | tr | 0.42 | 95.7 | 99.8 | |
| L 54 | VI 435 | 2.2 | 0.1 | 0.4 | 0.6 | 0.1 | 96.6 | tr | 0.36 | 97.5 | 99.8 | c |
| L 55 | VI 157 | 2.9 | 0.1 | 0.3 | 0.5 | 0.1 | 96.0 | tr | 0.32 | 96.8 | 99.9 | |
| L 56 | VI 171 | 4.6 | 0.1 | 0.2 | 0.9 | 0.1 | 94.0 | tr | 0.22 | 95.1 | 99.8 | |
| L 57 | VI 107 | 3.7 | 0.1 | 0.5 | 0.4 | nd | 95.1 | tr | 0.54 | 96.0 | 99.8 | |
| L 58 | VI 114 | 3.4 | 0.1 | 0.4 | 0.7 | nd | 95.2 | tr | 0.45 | 96.3 | 99.8 | c |
| L 59 | VI 090 | 3.5 | nd | 0.7 | 0.1 | nd | 95.5 | tr | 0.76 | 96.3 | 99.8 | |
| L 60 | VI 086 | 4.5 | nd | 0.4 | 0.4 | 0.1 | 94.5 | tr | 0.37 | 95.2 | 99.8 | |
| L 61 | VI 438 | 3.1 | 0.1 | 0.2 | 0.6 | 0.1 | 95.9 | tr | 0.19 | 96.7 | 99.8 | h |
| L 62 | VI 439 | 1.5 | nd | 0.1 | 0.5 | nd | 97.7 | tr | 0.10 | 98.3 | 99.8 | h |
| L 63 | VI 437 | 1.7 | nd | 0.7 | nd | nd | 97.4 | tr | 0.71 | 98.1 | 99.8 | |
| L 66 | VI 102 | 1.5 | nd | 0.7 | 0.1 | nd | 97.6 | tr | 0.68 | 98.3 | 99.8 | |
| L 47 | VI 126 | 0.1 | 0.4 | 0.1 | 1.0 | 0.3 | nd | 98.1 | 0.00 | 0.7 | 100.0 | |
| **Scotby** | | | | | | | | | | | | |
| Scotby A | VI 008 | 5.5 | 0.6 | 0.6 | 2.3 | nd | 90.9 | tr | 0.68 | 93.8 | 99.8 | |
| Scotby B | VI 441 | 6.3 | 0.2 | 0.3 | 0.5 | 0.1 | 92.5 | tr | 0.34 | 93.3 | 99.8 | |
| Scotby C | VI 015 | 6.1 | 0.1 | 0.3 | 0.5 | 0.1 | 92.7 | tr | 0.37 | 93.6 | 99.8 | |
| Scotby D | VI 021 | 6.6 | 0.1 | 0.7 | 0.4 | nd | 92.1 | tr | 0.71 | 93.2 | 99.8 | |
| Scotby E | VI 442 | 4.1 | nd | 0.7 | 0.3 | 0.1 | 94.6 | tr | 0.75 | 95.7 | 99.8 | |
| Scotby F | VI 028 | 2.4 | 0.1 | 1.6 | 0.3 | nd | 95.5 | tr | 1.70 | 97.4 | 99.8 | |
| Scotby G | VI 031 | 5.1 | 1.2 | 0.4 | 1.2 | 0.1 | 91.8 | tr | 0.41 | 93.4 | 99.8 | h |
| Scotby H | VI 035 | 2.8 | nd | 0.2 | 0.7 | 0.2 | 95.9 | tr | 0.17 | 96.8 | 99.8 | h |
| Scotby I | VI 444 | 4.0 | nd | 0.5 | 0.4 | nd | 94.9 | tr | 0.50 | 95.8 | 99.8 | h |
| Scotby J | VI 042 | 5.5 | 1.1 | 0.5 | 1.1 | 0.1 | 91.5 | tr | 0.49 | 93.1 | 99.8 | h |

Table 1 Analyses
Key: Elements tested for: Cu (copper); Zn (zinc); Au (gold); Pb (lead); Bi (bismuth); Ag (silver); and Sn (tin). Amounts are percentages. nd=not detected. tr=trace. Comments in right-hand column: c=corrosion; h=hacksilver fragment

| | | Cu | Zn | Au | Pb | Bi | Ag | Sn | Au per 100 Ag | "Silver" | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Storr Rock** | | | | | | | | | | | |
| RMS IL 289 | VI 539 | 13.0 | 0.1 | 0.4 | 1.2 | 0.2 | 85.0 | tr | 0.49 | 86.6 | 99.8 |
| RMS IL 290 | VI 527 | 8.5 | nd | 0.4 | 0.4 | 0.1 | 90.3 | 0.3 | 0.42 | 91.1 | 100.0 |
| RMS IL 291 | VI 535 | 4.1 | nd | 0.4 | 0.3 | 0.1 | 95.0 | tr | 0.45 | 95.7 | 99.8 |
| RMS IL 292 | VI 547 | 3.8 | 0.2 | 0.2 | 0.7 | 0.4 | 94.5 | tr | 0.23 | 95.4 | 99.8 |
| RMS IL 293 | VI 559 | 11.9 | 1.4 | 0.5 | 1.1 | nd | 84.8 | 0.3 | 0.59 | 86.4 | 100.0 |
| RMS IL 294 | VI 567 | 6.1 | 0.1 | 0.5 | 0.7 | 0.1 | 92.3 | tr | 0.57 | 93.5 | 99.8 |
| RMS IL 295 | VI 531 | 4.9 | 0.1 | 0.8 | 0.3 | nd | 93.8 | tr | 0.82 | 94.9 | 99.8 |
| RMS IL 297 | VI 563 | 5.7 | 0.2 | 0.5 | 0.7 | 0.1 | 92.7 | tr | 0.52 | 93.9 | 99.8 |
| RMS IL 298 | VI 543 | 6.4 | 0.1 | 0.4 | 1.4 | 0.1 | 91.5 | tr | 0.45 | 93.3 | 99.9 |
| RMS IL 299 | VI 523 | 5.4 | 0.2 | 0.4 | 0.5 | nd | 93.2 | 0.3 | 0.44 | 94.1 | 100.0 |
| RMS IL 300 | VI 514 | 17.6 | 0.6 | 0.5 | 0.7 | 0.1 | 79.7 | 0.9 | 0.56 | 80.8 | 100.0 |
| RMS IL 301 | VI 551 | 6.4 | 0.2 | 0.5 | 0.7 | 0.1 | 92.0 | tr | 0.54 | 93.2 | 99.9 |
| RMS IL 303 | VI 510 | 6.6 | 0.2 | 0.7 | 0.5 | nd | 91.9 | tr | 0.76 | 93.1 | 99.8 |
| RMS IL 304 | VI 519 | 8.1 | 0.2 | 0.5 | 1.8 | 0.1 | 89.0 | 0.5 | 0.51 | 91.2 | 100.0 |
| RMS IL 306? | VI 555 | 5.9 | 0.1 | 0.4 | 0.6 | 0.2 | 92.7 | tr | 0.41 | 93.8 | 99.8 |
| **Skaill** | | | | | | | | | | | |
| RMS IL 51 | VI 490 | 7.0 | 1.3 | 0.7 | 0.8 | 0.1 | 90.0 | tr | 0.76 | 91.5 | 99.9 |
| RMS IL 52 | VI 480 | 4.1 | 0.1 | 0.5 | 0.3 | 0.1 | 94.7 | tr | 0.53 | 95.6 | 99.8 |
| RMS IL 53 | VI 741 | 5.1 | 0.1 | 0.4 | 0.6 | 0.1 | 93.6 | tr | 0.47 | 94.6 | 99.8 |
| RMS IL 54 | VI 482 | 7.3 | 0.3 | 0.6 | 0.8 | 0.1 | 90.7 | tr | 0.69 | 92.1 | 99.8 |
| RMS IL 55 | VI 486 | 8.0 | 0.6 | 0.6 | 1.1 | 0.1 | 89.4 | tr | 0.64 | 91.1 | 99.8 |
| RMS IL 56 | VI 481 | 6.5 | 0.4 | 0.7 | 0.6 | 0.1 | 91.6 | tr | 0.72 | 92.8 | 99.8 |
| RMS IL 57 | VI 479 | 4.2 | 0.1 | 0.3 | 0.6 | 0.2 | 94.5 | tr | 0.29 | 95.3 | 99.8 |
| RMS IL 93 | VI 498 | 3.1 | 0.1 | 0.2 | 0.6 | 0.3 | 95.6 | tr | 0.22 | 96.4 | 99.8 |
| RMS IL 94 | VI 502 | 3.5 | nd | 0.3 | 0.2 | 0.1 | 95.7 | tr | 0.26 | 96.2 | 99.8 |
| RMS IL 516 | VI 506 | 4.5 | nd | 0.1 | 0.7 | 0.4 | 94.1 | tr | 0.11 | 94.9 | 99.8 |
| RMS IL 66 | VI 494 | 8.1 | nd | 0.5 | 0.1 | nd | 91.1 | tr | 0.58 | 91.7 | 99.8 |
| **Chester** | | | | | | | | | | | |
| C.57 | VI 460 | 16.7 | 1.2 | 0.5 | 3.1 | nd | 74.3 | 4.2 | 0.62 | 77.9 | 100.0 |
| 1950/75A | VI 463 | 24.2 | 2.9 | 0.4 | 1.2 | 0.1 | 71.1 | tr | 0.55 | 72.7 | 99.9 |
| 1950/75D | VI 465 | 20.3 | 2.4 | 0.4 | 1.2 | 0.1 | 75.6 | tr | 0.46 | 77.1 | 99.8 |
| 1950/75E | VI 467 | 20.8 | 1.6 | 0.5 | 1.2 | nd | 75.8 | tr | 0.65 | 77.5 | 99.8 |
| C.60 | VI 468 | 15.4 | 0.5 | 0.6 | 2.6 | 0.2 | 80.4 | 0.4 | 0.70 | 83.5 | 100.0 |
| C.61 | VI 475 | 9.6 | 0.1 | 0.4 | 15.0 | 0.1 | 74.4 | 0.4 | 0.51 | 89.8 | 100.0 |
| C.62 | VI 214 | 8.9 | 0.2 | 0.5 | 0.9 | 0.1 | 89.3 | tr | 0.50 | 90.6 | 99.8 |
| C.63 | VI 445 | 8.8 | 0.2 | 0.6 | 1.3 | 0.1 | 88.4 | 0.6 | 0.68 | 90.3 | 100.0 |
| C.64 | VI 446 | 5.5 | 0.2 | 0.5 | 0.6 | nd | 93.1 | tr | 0.54 | 94.1 | 99.8 |
| C.65 | VI 224 | 5.7 | 0.3 | 0.4 | 1.5 | 0.1 | 91.9 | tr | 0.45 | 93.8 | 99.8 |
| C.66 | VI 228 | 6.3 | 0.3 | 0.5 | 0.7 | nd | 92.0 | tr | 0.54 | 93.2 | 99.8 |
| C.67 | VI 447 | 1.7 | 0.4 | 0.6 | 0.1 | nd | 97.0 | tr | 0.64 | 97.7 | 99.8 |
| C.68 | VI 235 | 8.2 | 0.2 | 0.5 | 0.7 | 0.1 | 90.1 | tr | 0.54 | 91.3 | 99.8 |
| C.69 | VI 239 | 9.6 | 0.4 | 0.4 | 0.8 | 0.1 | 88.5 | tr | 0.46 | 89.7 | 99.8 |
| C.70 | VI 448 | 7.6 | 0.4 | 0.4 | 0.7 | 0.1 | 90.7 | tr | 0.43 | 91.8 | 99.8 |
| C.71 | VI 246 | 7.6 | 0.1 | 0.3 | 1.4 | 0.4 | 90.1 | tr | 0.33 | 91.8 | 99.8 |
| C.72 | VI 250 | 5.4 | 0.1 | 0.5 | 0.6 | 0.1 | 93.1 | tr | 0.57 | 94.2 | 99.9 |
| C.73 | VI 254 | 7.6 | 0.2 | 0.5 | 1.0 | 0.1 | 90.5 | tr | 0.55 | 92.0 | 99.8 |
| C.74 | VI 451 | 19.6 | 0.3 | 0.5 | 1.0 | 0.1 | 78.0 | 0.6 | 0.59 | 79.4 | 100.0 |
| C.75 | VI 476 | 7.8 | 0.1 | 0.5 | 0.4 | nd | 91.1 | tr | 0.51 | 91.9 | 99.8 |
| C.76 | VI 452 | 12.0 | nd | 0.4 | 0.3 | 0.1 | 87.0 | tr | 0.49 | 87.8 | 99.8 |

| | | Cu | Zn | Au | Pb | Bi | Ag | Sn | Au per 100 Ag | "Silver" | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Chester cont.** | | | | | | | | | | | | |
| C.77 | VI 267 | 6.6 | 0.3 | 0.6 | 0.7 | nd | 91.8 | tr | 0.60 | 93.0 | 99.8 | |
| C.78 | VI 454 | 6.4 | 0.2 | 0.4 | 0.7 | 0.1 | 92.0 | tr | 0.45 | 93.2 | 99.9 | |
| C.79 | VI 473 | 10.4 | 1.1 | 0.4 | 0.8 | 0.1 | 87.1 | tr | 0.49 | 88.3 | 99.8 | |
| C.80 | VI 477 | 6.6 | 0.1 | 0.5 | 0.7 | nd | 91.9 | tr | 0.54 | 93.1 | 99.8 | |
| C.81 | VI 283 | 5.3 | 0.1 | 0.5 | 2.8 | 0.1 | 91.1 | tr | 0.52 | 94.4 | 99.8 | |
| C.82 | VI 455 | 6.8 | 0.4 | 0.4 | 0.6 | 0.1 | 91.6 | tr | 0.40 | 92.5 | 99.8 | |
| C.83 | VI 469 | 15.4 | 0.1 | 0.5 | nd | nd | 83.8 | tr | 0.57 | 84.3 | 99.8 | |
| C.84 | VI 456 | 8.0 | 0.1 | 0.5 | 0.5 | 0.1 | 90.8 | tr | 0.50 | 91.8 | 99.9 | |
| C.85 | VI 457 | 8.6 | 0.1 | 0.5 | 1.9 | 0.1 | 88.6 | 0.3 | 0.51 | 90.9 | 100.0 | |
| C.86 | VI 470 | 14.4 | 1.5 | 0.5 | 1.7 | nd | 81.4 | 0.5 | 0.61 | 83.6 | 100.0 | |
| C.87 | VI 458 | 4.2 | 0.1 | 0.8 | 0.9 | nd | 93.8 | tr | 0.85 | 95.5 | 99.8 | |
| C.88 | VI 308 | 6.0 | 0.1 | 0.5 | 0.3 | 0.1 | 93.0 | tr | 0.51 | 93.7 | 99.9 | |
| C.89 | VI 312 | 8.6 | 0.2 | 0.2 | 0.6 | 0.3 | 90.0 | tr | 0.21 | 90.8 | 99.8 | |
| C.91 | VI 316 | 7.8 | 0.3 | 0.3 | 0.6 | 0.1 | 90.8 | tr | 0.35 | 91.7 | 99.8 | |
| C.92 | VI 320 | 7.7 | 0.3 | 0.5 | 0.6 | 0.1 | 90.6 | 0.3 | 0.50 | 91.6 | 100.0 | |
| C.93 | VI 324 | 8.8 | 0.3 | 0.3 | 0.8 | 0.2 | 89.4 | tr | 0.38 | 90.5 | 99.8 | |
| C.94 | VI 328 | 5.7 | 0.2 | 0.5 | 0.6 | 0.1 | 92.8 | tr | 0.54 | 93.8 | 99.8 | |
| C.95 | VI 332 | 7.4 | 0.6 | 0.5 | 0.7 | 0.1 | 90.3 | 0.3 | 0.52 | 91.5 | 100.0 | |
| C.96 | VI 336 | 6.6 | 0.7 | 0.4 | 1.9 | 0.1 | 90.1 | 0.3 | 0.47 | 92.3 | 100.0 | |
| C.97 | VI 341 | 5.5 | 0.1 | 0.4 | 0.2 | 0.1 | 93.6 | tr | 0.45 | 94.3 | 99.9 | c |
| C.98 | VI 474 | 13.0 | 0.7 | 0.5 | 1.9 | 0.1 | 82.9 | 1.0 | 0.58 | 85.3 | 100.0 | |
| C.99 | VI 349 | 7.2 | 0.5 | 0.3 | 0.7 | 0.3 | 91.0 | tr | 0.36 | 92.0 | 99.9 | |
| C.100 | VI 353 | 6.3 | 0.3 | 0.4 | 0.7 | 0.1 | 91.9 | 0.3 | 0.45 | 93.0 | 100.0 | |
| C.101 | VI 357 | 6.3 | nd | 0.5 | 0.1 | 0.1 | 92.8 | tr | 0.56 | 93.4 | 99.8 | |
| C.102 | VI 362 | 11.3 | 0.6 | 0.4 | 1.2 | nd | 86.3 | tr | 0.49 | 87.9 | 99.8 | |
| C.103 | VI 366 | 4.9 | 0.1 | 0.5 | 0.6 | 0.1 | 92.3 | 1.6 | 0.54 | 93.4 | 100.0 | |
| C.104 | VI 371 | 6.9 | 0.1 | 0.4 | 1.1 | 0.1 | 91.3 | tr | 0.43 | 92.8 | 99.8 | |
| C.105 | VI 471 | 20.9 | 0.1 | 0.4 | 0.1 | 0.1 | 78.3 | tr | 0.50 | 78.8 | 99.8 | |
| C.106 | VI 380 | 5.6 | 0.1 | 0.3 | 0.6 | 0.1 | 93.2 | tr | 0.32 | 94.1 | 99.8 | |
| C.107 | VI 384 | 4.4 | nd | 0.5 | 0.1 | nd | 94.9 | tr | 0.47 | 95.4 | 99.8 | |
| C.108 | VI 388 | 3.6 | 0.1 | 0.4 | 0.6 | nd | 95.2 | tr | 0.42 | 96.2 | 99.8 | |
| C.109 | VI 392 | 7.4 | 0.4 | 0.4 | 0.8 | 0.1 | 90.0 | 1.0 | 0.49 | 91.2 | 100.0 | |
| C.110 | VI 396 | 8.7 | 0.7 | 0.4 | 0.7 | 0.1 | 89.2 | tr | 0.48 | 90.3 | 99.8 | |
| C.111 | VI 472 | 9.2 | 0.1 | 0.4 | 0.2 | 0.1 | 89.9 | tr | 0.47 | 90.5 | 99.8 | |
| C.112 | VI 404 | 7.7 | 0.9 | 0.4 | 1.3 | 0.2 | 89.3 | tr | 0.47 | 91.1 | 99.8 | |
| C.113 | VI 408 | 6.6 | 0.1 | 0.4 | 0.7 | 0.1 | 91.9 | 0.3 | 0.41 | 93.0 | 100.0 | |
| C.114 | VI 412 | 6.9 | 0.1 | 0.4 | 0.6 | 0.1 | 91.8 | tr | 0.46 | 92.8 | 99.8 | |
| C.115 | VI 416 | 4.2 | 0.1 | 0.4 | 0.8 | 0.1 | 94.3 | tr | 0.43 | 95.4 | 99.8 | |
| C.116 | VI 420 | 7.4 | 0.3 | 0.4 | 1.0 | 0.1 | 90.5 | 0.3 | 0.49 | 91.9 | 100.0 | |
| C.117 | VI 424 | 6.8 | 0.1 | 0.4 | 0.6 | 0.1 | 91.7 | 0.3 | 0.48 | 92.7 | 100.0 | |
| C.118 | VI 429 | 10.6 | 0.1 | 0.4 | 0.8 | 0.1 | 87.8 | 0.3 | 0.42 | 88.9 | 100.0 | |
| **Iona** | | | | | | | | | | | | |
| RMS IL 715? | VI 76 | 5.40 | nd | 0.50 | 0.70 | nd | 93.20 | tr | 0.56 | 94.4 | 99.8 | |
| **Burray** | | | | | | | | | | | | |
| RMS IL 271 | VI 4 | 4.6 | 0.1 | 0.4 | 1.0 | tr | 93.6 | tr | 0.44 | 95.0 | 99.7 | |
| RMS IL 266 | VI 44 | 24.4 | 5.2 | nd | 1.4 | nd | 68.4 | 0.6 | 0.04 | 69.8 | 100.0 | h? |
| **Plan Farm** | | | | | | | | | | | | |
| RMS FE 44 | VI 486 | 10.8 | 0.1 | 0.3 | 0.5 | tr | 88.0 | tr | 0.39 | 88.8 | 99.7 | |

## CONCLUSIONS

The silver used to form the ingots found in Viking Age hoards in Scotland and north-west England displays enough similarities to be viewed as part of a related economic system. However, enough differences exist to indicate no single source for the silver. This is in marked contrast, for example, to a number of objects from Scandinavian hoards which have been analysed, particularly for Hårdh (1976, 110–27), most of which date to the 10th and to the first half of the 11th century. In almost all Swedish cases, the alloys contain gold below levels of detection, and are very similar to Arabic coins, though often without bismuth. Similarly, analyses of ingots and armrings from Gotland and mainland Sweden show a high similarity to Arabic coinage (Arrhenius, Linder Welin & Tapper 1972–3). This is an interesting and useful diagnostic feature, which should allow some indication of Scandinavian imports into the British Isles.

It is clear that few of the ingots derive from Arabic silver, although some tenative parallels with coins from Samarkand and Baghdad mints have been noted. Nor do the analyses suggest an exact parallel to any other coinage circulating with the ingots, regardless of the preferences for the coins also included in the hoards. Most likely the ingot silver represents a mixture of available silver, numismatic and otherwise, available at the time. The same is true for coinages, of course, but for Anglo-Saxon, Carolingian and Arabic coinages at least, the evidence is now accumulating for regional alloys (Metcalf & Northover 1986, 50; 1988, 102; Cowell & Lowick 1988). General changes in ingot alloy, such as the inclusion of slightly more zinc, parallel Anglo-Saxon coinage, although the exact concentrations are different.

The nature of the copper alloy used to debase the silver stock remains an interesting question. For all ingots, the ratio of zinc to zinc+copper is 3.6%, but the values range from 0.2 to 20.2%. Of the ingots from Cuerdale, only one has this ratio above 5%, whereas all other groups have a higher spread; 13 of the Chester ingots are above 5%, and one as high as 20%. These figures are well below the high figures found in the debased ninth-century English coins analysed by Metcalf & Northover (1985) and are more similar to later English coins (Metcalf & Northover 1986; 1988), though these late 10th-century coins in general showed larger variations. Unfortunately, it is difficult to compare the ingots with the Anglo-Saxon coins from the first three-quarters of the 10th century, the period to which most of the ingots date, since most of the analyses were carried out by McKerrell & Stevenson (1972) and were less accurate in their measurements of zinc and copper.

As noted above, the zinc probably derived from scrap brass. However, the levels are far less than the c 20% zinc found in ninth-century coins (Metcalf & Northover 1985, 161–2; 1988, 104–5), suggesting that copper as well as brass was also added to the melt. However, given the levels of detection, especially for zinc and tin, combined with uncertainties of the behaviour of the various constituent metals of the alloys on re-melting, it is difficult from the present data to speculate further.

Although the alloys of ingots and the few hacksilver fragments overlap, there is a hint that some hacksilver forms are composed of different silver, often one much lower in gold (eg Cuerdale L 60; L 61), perhaps indicating a greater mixture of Arabic silver. Nevertheless, the 'ring-money' in the Skaill hoard, which fulfilled many of the functions of ingots as an economic medium (Kruse, forthcoming 1993), shows little difference to the ingots, beyond there being slightly more zinc, and a few which are baser. On the other hand, the one unambiguous ingot from the Burray hoard is very different in its composition from its associated 'ring-money'. It may be an older object included in the hoard (though it has few pecks), or may be indicative of silver used in other ornaments. In this regard, the analyses of the Skaill pins caution against direct comparisons, since considerations of wear and use appear to affect compositions of different parts of the object (Graham-Campbell 1984, 292–3). Ingots, as a result, are best compared to coins or objects such as Hiberno-Viking armrings or 'ring-money' which fulfilled some economic function in the economy.

Future work should place many of these alloys, numismatic and non-numismatic, in a firmer context, and thereby gradually build a more complete picture of the economic circulation of bullion, both within and between regions. To minimize methodological problems, such programmes should be as large a possible, with techniques sensitive to the indicative elements. Further work on Irish silver, on certain artefact forms (particularly those with regional associations), and on Scandinavian ingots would all help shed light on many of these issues. Lead isotope analysis also holds out great promise for identifying ore sources, and may prove useful for provenancing objects which are not too heterogeneous.

## NOTES

1 In the text, objects are cited by an abbreviation usually for the museum and a shortened form of the museum number:
Ashmolean Museum. All objects prefixed by Am in the text. All have a museum number of the form 1909.nnn. Only the last number cited.
Carlisle Museum & Art Gallery. Scotby ingots all have the number 78–1935.32. Individual objects distinguished by a letter, as outlined in Kruse 1986.
Grosvenor Museum, Chester. The Chester ingots have numbers of the form 44.S.1969.C.nn or 1950/75A. Only the C.nn is cited for registrations of the former form.
National Museums & Galleries on Merseyside (Liverpool Museum). All objects prefixed by L in the text. All Cuerdale objects begin with 53–114–nn. Only the last number cited.
Royal Museum of Scotland. All objects prefixed by RMS in the text, followed by full number.

2 We would like to acknowledge the generosity of the Ashmolean Museum in performing these analyses, and, in particular, Arthur MacGregor for making the necessary arrangements, and Fiona Macalister for carrying out the work.

## APPENDIX

### XRF ANALYSIS OF VIKING SILVER FROM THE ASHMOLEAN MUSEUM

Fiona Macalister

Twenty-five samples were analysed at the Research Laboratory for Archaeology and the History of Art, University of Oxford (Table 2). Of the 25, 19 were from the Cuerdale hoard (c 905), three from the Co Dublin hoard (c 935) and three from the Croydon hoard (c 872). All were ingots or ingot fragments with the exceptions of three ring fragments and a piece of slag from the Cuerdale hoard, and two ring fragments from the Co Dublin hoard.

Before each sample was analysed a small area, approximately 3 x 3 mm, was cleaned using a glass bristle brush and acetone, to remove the effects of surface enrichment of the silver. In the first few samples three readings were taken from each in order to obtain some idea of homogeneity of the sample and in two cases to see whether cleaning had been carried deep enough, beyond the level of silver enrichment. For the majority of samples only one reading was taken.

Details of the X-ray fluorescence equipment and the method of analysis are described by Pollard (1983). Silver standards are used to calibrate the equipment and the samples may then be compared with these calibrations to determine the alloy composition. In silver alloys the minimum detectable limits are for gold and lead, 0.10%, copper, 0.20% and zinc, 0.25%, but their accuracy is difficult to determine below 0.5%. The figures for tin are slightly questionable, since it is difficult to detect with any accuracy unless present in a few percent. This also applies to bismuth, which was, however, only found to be present as a trace in four samples.

| Museum no. | Cu | Zn | Au | Pb | Bi | Ag | Sn | Au per 100 Ag | "silver" | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Croydon** | | | | | | | | | | |
| 1909.556 | 7.6 | 1.9 | 2.6 | 1.3 | 0.0 | 85.4 | 1.2 | 3.0 | 89.3 | 100.0 |
| 1909.557 | 8.0 | 1.6 | 0.7 | 0.7 | tr | 89.2 | 0.0 | 0.7 | 90.5 | 100.0 |
| 1909.559 | 5.6 | 0.0 | 0.5 | 2.1 | 0.0 | 91.8 | 0.0 | 0.6 | 94.4 | 100.0 |
| **Cuerdale** | | | | | | | | | | |
| 1909.522 | 5.6 | 0.0 | 0.5 | 2.1 | 0.0 | 91.8 | 0.0 | 0.6 | 94.4 | 100.0 |
| 1909.523 | 3.0 | 0.0 | 0.8 | 0.8 | 0.0 | 95.5 | 0.0 | 0.8 | 97.1 | 100.0 |
| 1909.524 | 3.0 | 0.0 | 0.9 | 0.0 | 0.0 | 96.2 | <.40 | 0.9 | 97.0 | 100.0 |
| 1909.525 | 0.8 | 0.0 | 0.9 | 1.1 | 0.0 | 97.1 | 0.0 | 0.9 | 99.2 | 100.0 |
| 1909.526 | 1.3 | tr | 0.9 | 1.6 | 0.0 | 96.2 | <.40 | 0.9 | 98.7 | 100.0 |
| 1909.527 | 3.5 | <.25 | 0.5 | 0.7 | tr | 95.3 | <.40 | 0.5 | 96.5 | 100.0 |
| 1909.528 | 3.0 | <.25 | 0.9 | 1.0 | 0.0 | 95.2 | 0.0 | 0.9 | 97.0 | 100.0 |
| 1909.529 | 4.5 | <.25 | 0.7 | 0.8 | 0.0 | 94.0 | 0.0 | 0.7 | 95.5 | 100.0 |
| 1909.530 | 2.4 | 0.0 | <.1 | <.1 | 0.0 | 97.6 | <.40 | 0.1 | 94.2 | 100.0 |
| 1909.531 | 1.0 | 0.0 | 0.7 | 1.0 | 0.0 | 97.3 | <.40 | 0.7 | 99.0 | 100.0 h |
| 1909.532 | 1.9 | 0.0 | 0.9 | <.1 | tr | 97.2 | 0.0 | 0.9 | 98.2 | 100.0 |
| 1909.533 | 6.5 | 0.7 | 0.9 | 0.5 | 0.0 | 91.4 | <.40 | 0.9 | 92.8 | 100.0 |
| 1909.534 | 5.1 | <.25 | 0.6 | 0.8 | 0.0 | 93.6 | 0.0 | 0.7 | 95.0 | 100.0 |
| 1909.535 | 5.7 | <.25 | 0.6 | 2.7 | 0.0 | 90.0 | 0.9 | 0.7 | 93.4 | 100.0 |
| 1909.536 | 2.5 | 0.7 | 0.9 | 2.4 | 0.0 | 92.9 | 0.6 | 0.9 | 96.3 | 100.0 |
| 1909.537 | 4.7 | 0.3 | 1.2 | 1.1 | 0.0 | 93.0 | <.40 | 1.2 | 95.3 | 100.3 |
| 1909.538 | 2.8 | <.25 | 0.8 | 0.8 | 0.0 | 95.7 | <.40 | 0.8 | 97.2 | 100.0 h |
| 1909.549 | 3.6 | 0.0 | 0.2 | 1.1 | 0.0 | 95.1 | 0.0 | 0.2 | 96.4 | 100.0 h |
| 1909.551 | 6.2 | 0.0 | 0.8 | 1.0 | 0.0 | 91.5 | 0.5 | 0.9 | 93.3 | 100.0 s |
| **Dublin** | | | | | | | | | | |
| 1909.553 | 4.7 | 0.0 | 0.7 | 0.9 | 0.0 | 92.8 | 1.0 | 0.8 | 94.3 | 100.0 |
| 1909.557 | 2.1 | <.25 | 0.5 | <.10 | tr | 97.5 | <.40 | 0.5 | 98.0 | 100.0 h |
| 1909.559 | 5.6 | 0.0 | 0.5 | 2.1 | 0.0 | 91.8 | 0.0 | 0.6 | 94.4 | 100.0 h |

Table 2 Analyses: Ashmolean Museum
Key: Elements tested for: Cu (copper); Zn (zinc); Au (gold); Pb (lead); Bi (bismuth); Ag (silver); and Sn (tin). Amounts are percentages. nd=not detected. tr=trace. Comments in right-hand column: c=corrosion; h=hacksilver fragment; s=slag

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## NOTES TO THE ILLUSTRATIONS

All analyses are by the authors, with the exception of:

Illus 1–9: Ashmolean analyses of Croydon are denoted by a different symbol.
Illus 1: Cuerdale (Ashmolean): see Appendix; Skaill and Burray 'ring-money': White & Tate 1983.
Illus 10:

Edward the Elder: McKerrell & Stevenson 1972; Forbes & Dalladay 1960 (1 coin); Harris 1962 (1 coin).
Athelstan: McKerrell & Stevenson 1972.
Edmund: McKerrell & Stevenson 1972; Harris 1962 (2 coins).
Eadred: McKerrell & Stevenson 1972; Forbes & Dalladay 1960 (2 coins); Harris 1962 (2 coins).
Eadwig: McKerrell & Stevenson 1972; Harris 1962 (1 coin).
Eadgar (pre-reform): McKerrell & Stevenson 1972; Metcalf & Northover 1986 (5 coins).
Eadgar (post reform): Metcalf & Northover 1986.
Edward Martyr: Metcalf & Northover 1986.
Æthelred (First Hand): Metcalf & Northover 1986; McKerrell & Stevenson 1972 (3 coins).
Æthelred (Second Hand): Metcalf & Northover 1986.
Æthelred (Long Cross): Metcalf & Northover 1986; McKerrell & Stevenson 1972 (4 coins).

Illus 11: Louis the Pious and Charles the Bald: Metcalf and Northover 1989; Coins 875–905: Metcalf & Northover 1988; Ablaincourt hoard: Lafaurie & Pechiney 1988; East Anglian Viking coins: Metcalf & Northover 1988; Northumbrian Viking coins: Metcalf & Northover 1988; McKerrell & Stevenson 1972 (4 coins); Arabic coins: Cowell & Lowick 1988 (46 coins); Werner & Cowell 1975 (1 coin); McKerrell & Stevenson 1972 (13 coins); Arrhenius *et al.* 1972–3 (2 coins).

Illust 12: Dysart & Carrick hoards: Ryan *et al.* 1984; Co Dublin hoard: see Appendix; Red Wharf Bay armrings: Northover 1986.