

The reducing atmosphere in the furnace will in either case provide lead metal as collector for the precious metals.

Though the Roman mines have been completely exhausted, we do have a reliable indication of the types of ores mined in antiquity. A modern, small gold mine nearby – perhaps the last one in Portugal – had been in operation until quite recently. The type of ore mined here was a mixture of arsenopyrite, pyrite and galena, with some sphalerite, stibnite, etc. and quartz as the main gangue mineral. Gold was present either as native gold or intimately intergrown with other minerals, notably arsenopyrite. The gold concentrations varied between 5 and 25 grams/ton. Silver content from silver-rich galena as well as from alloys with gold could reach 200 grams/ton and more. We have good reason to assume that the ore mined during Roman times was similar in composition and precious metal content.

Taking Pliny's remarks at face value, Roman gold ore beneficiation from Três Minas could have been carried out in a sequence of steps illustrated in the flow chart (Fig. 4). This schematic diagram leaves an option for the recovery of native gold prior to the treatment of the gold-containing complex ore. As the deposit is rich in silver as well, the separation of the precious metals, after cupellation, was probably the final metallurgical step, either

performed on site or in a special refinery. Refined gold (*aurum obrucium*) was mandatory for the minting of Roman gold coins.

Contrasting the ancient descriptions of Pliny along with modern principles of process metallurgy serves to understand better an ancient, technologically-advanced metallurgical process for the recovery of precious metals. The metallurgical flow chart will assist as a model for further archaeological excavations of the various industrial, gold-processing sites at Três Minas. It is ample proof of the interdisciplinary nature of archaeometallurgical research.

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## Romano-British coins from Richborough, Kent

During the excavation of the Roman Saxon Shore Fort at Richborough in Kent, a small hoard of coins (Fig. 1) was discovered which were thoroughly corroded together. The find was published in the coin report for Richborough (Reece, 1968) where a date of the second quarter of the fourth century AD was suggested. The only visible feature on any of the legible coins on the surface of the hoard was a PROVIDENTIAE AVGG reverse type of Constantine I (AD 306–337) which would have been issued between 324 and 326.

This group offered a rare chance to investigate a hoard of coins where the individual coins are still stacked in original positions. The idea was to see if the compositions of the coins change relative to their position and degree of corrosion within a hoard. This project was part of my doctoral research, supervised by Drs Richard Reece and John Merkel, at the Institute of Archaeology, University College London. Usually, the degree of corrosion on coins from the exterior of a hoard is worse than in the centre. It was decided to investigate the range of compositional variation between apparently identical coins in relation to the position of each coin within the Richborough hoard. This information would also be used in conjunction with the analyses of numismatically comparable issues discovered at Tigrith (Deacon, 1990). Using the same issue of coins practically as test blanks of the same composition buried in different environments, enables the post-depositional modification suffered by these coins to be assessed over a period of some 1,668 years.

In order to accomplish this task, it was first necessary to record accurately the relative position of each coin within the corroded hoard in three dimensions. Various

possible methods of doing this were considered, ranging in complexity from simple cardboard models up to sophisticated photogrammetric imaging techniques. It was eventually decided to use a computer-aided design (CAD) programme called Microstation (Intergraph Corporation, 1991). This was chosen mainly because of its ability to interface directly with database programmes as well as for its relatively user-friendly interface.

Although primarily intended as a design programme for architects and engineers, Microstation also has the ability to draw simple standard shapes from sets of Cartesian co-ordinates. In this case it was necessary to reduce each coin in the hoard to a set of three co-ordinates relating to three arbitrarily selected points along the edge of each coin. This was done using a Reflex Metrograph in the Department of Photogrammetry,



Fig. 1. The small hoard of corroded coins dated to the second quarter of the fourth century AD discovered at Richborough.

UCL. This measuring microscope is capable of recording the position of a given point in three dimensions and writing the information to disk as an ASCII file. The coordinates in the file were then read into dBase III plus, one of the data base programmes with which Microstation can be linked. A user command programme was written which instructed Microstation to read the coordinates from the data base and use the data to draw a series of circles corresponding to the coins in the hoard, each coin being given a unique number.

Once the relative coin positions in the hoard were accurately recorded (Fig. 2), the concretion was carefully dismantled. The cleaning and dismantling of the corroded hoard was accomplished mechanically, using a scalpel. The coins were given a quick cleaning in order to enable an exact identification against the assumption that all of the coins were the same issue. It was apparent that the degree of corrosion differed quite considerably from area to area. Some of the coins around what, for convenience sake, may be termed the 'top-front' of the hoard were visibly more corroded than those elsewhere. The original orientation of the hoard was not recorded by the excavator (Cunliffe, 1968).

Each coin was sampled by drilling two or three small (0.8mm) holes into the cylindrical edge and collecting the metal. The first millimetre or so was discarded to avoid the corrosion products on the surface. The degree of corrosion varied: one of the coins was totally mineralized whilst others were affected by intergranular corrosion to a considerable depth, despite being clearly identifiable. Those coins which were positioned to the exterior of the hoard were more corroded than those which had only a small segment of the edge exposed. Many of the coins retained some of the white-metal (silver) coating which had covered them when new. This coating was usually found in the corrosion products surrounding the coins, having been lifted from the coin's surface by the corrosion.

Drilled examples from 73 coins were analyzed by atomic absorption spectroscopy. Routine methods were used for the determination of copper, lead, tin, zinc, silver, iron, nickel, arsenic, gold and antimony (see Hughes et al. 1976). The analyses were conducted in three batches which were run consecutively. The same sets of standard solutions and standard reference materials were employed for each batch to improve analytical consistency. Antimony and cobalt levels were found to be too low at the initial dilution (10mg to 25ml), to achieve the desired accuracy for this study. Consequently, these two elements were run again using fresh solutions of a higher concentration (10mg to 10ml).

The compositional results were broadly consistent with the previously gravimetric analyses of these issues reported by Cope (1972). However, statistical methods revealed significant differences between the compositions of the Richborough coins and identical issues from the Tingrith hoard. A total of 20 coins of the same issue also were analyzed from Tingrith. To establish whether the compositional differences were statistically significant, standard t-tests were conducted. The results show significant differences in compositions between the Richborough and Tingrith coins for the following elements: nickel, lead, gold and silver. The concentrations of tin, zinc, iron and arsenic were similar. The size of the sample population and the limited number of elements allows the use of t-tests without encountering problems asso-

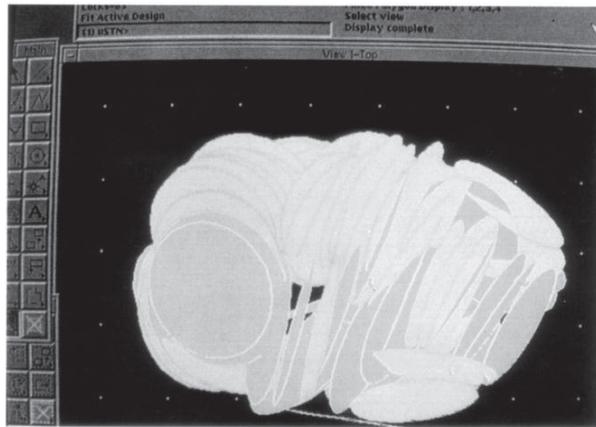


Fig. 2. This three-dimensional computer model of the hoard of coins was made before cleaning and dismantling of the corroded hoard.

ciated with 'multiple comparisons' (Miller, 1966). The observed statistical differences are not spurious. The t-test comparisons were also applied to coins from the Tingrith hoard which were not the identical issue to those in the Richborough hoard. It was unexpected that the compositions were again not significantly different. As a control, t-tests were also conducted on two random samples taken from the Richborough hoard alone. The results did not show significant differences in composition.

Together with the data base feature, the three-dimensional computer image (Fig. 2) was used to identify similar compositional data. For example, coins with silver concentrations over 0.7% could be highlighted and the image rotated to examine relative positions of these coins in the hoard to study the effects of differential corrosion relative to coin positions and elemental compositions.

In summary, this brief report proposes a potentially routine technique for the recording of three-dimensional objects. Microstation proved very powerful as a documentation and research tool for technical studies of ancient coins. The compositional data were studied in relation to the positional data for the coins in the Richborough hoard. This is a new approach. There is considerable potential for exploiting this approach for technical studies of coins as well as documentation of three-dimensional objects for archaeological conservation.

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