Metallurgy in Numismatics 6

Mines, Metals, and Money Ancient World Studies in Science, Archaeology and History

EDITED BY

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AUSTRALIAN CENTRE FOR ANCIENT NUMISMATIC STUDIES

MACQUARIE UNIVERSITY

THE ROYAL NUMISMATIC SOCIETY
SPECIAL PUBLICATION NO. 56

LONDON

2020

ROYAL NUMISMATIC SOCIETY SPECIAL PUBLICATIONS
GENERAL EDITOR: ROGER BLAND

To our daughters:
Lucy Clare Sheedy, Rebecca Allen and Tamara Davis

The Royal Numismatic Society Special Publication No. 56

ISBN 0–901405–37–X

British Library Cataloguing in Publication data
A CIP catalogue record is available from the British Library

Set by New Leaf Design, Malton, North Yorkshire
Printed by Gutenberg Press Ltd, Tarxien, Malta

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ABSTRACT

Three areas in mainland and Aegean Greece are known to have been important sources of silver during antiquity: Laurion in south-east Attica, the Thraco-Macedonian region of northern Greece, and the Cycladic island of Siphnos. The mines of Siphnos are thought to have been a major source of silver for archaic Greece coinage, especially that of Aegina. Lead isotope and elemental analyses have been used in published studies of ores, slag and litharge (lead oxide; PbO) found on Siphnos, and elemental analyses on 12 coins. Here we present elemental analyses of one gold and 29 silver coins from Siphnos. This data leads us to reconsider the claim made by Gale et al. 1980 that the levels of bismuth in Siphnian silver are higher than those recorded levels for Laurion silver. Finally, the evidence of the analyses is considered in relation to the history of minting on Siphnos.

INTRODUCTION: 'WEALTHY' SIPHNOS

During the sixth century BC, the inhabitants of Cycladic Siphnos were held to be 'the richest of the islanders' (Herodotus 3.57) (Wagner *et al.* 1980, 17–58; Sheedy 2000; 2006, 41–57).[1] This rocky island in the western chain of islands in the Aegean covers only 73 km^2, and has little arable land. Its early wealth came from gold and silver mines (Sheedy 2006, 41–57). Revenue from this source was paid out to the citizens (Herodotus 3.57.2). In thanks for this good fortune the Siphnians paid a tithe to Apollo at Delphi and built an ostentatious treasury, the first in marble at this sanctuary, to house their offerings (Sheedy 2000). Just before 525 BC (around the time their treasury was completed), the islanders received an oracle from Apollo, recorded by Herodotus (3.57), that the source of their wealth would be taken from them when their *prytanaion* (town hall) and *agora* (market place) were faced with white marble. They were also warned of "a wooden trap" – which proved to have been set by Samian pirates; although the city walls were not breached they were forced to pay a ransom of 100 talents to free those citizens caught outside the town (Herodotus 3.58). The Siphnians were evidently unable to recover from the loss of these 100 talents so we can infer that the island's mines were already failing. Pausanias (10.11.2) tells another story: the Siphnians continued to pay the tithe to Apollo until through greed they stopped and as a consequence the sea flooded the mines. In the fifth century BC the island was no longer considered wealthy; it paid only three talents to the Delian League (Sheedy 2006, 52). They had evidently slipped from being among the rich, but Brun (2000) has argued that the island was still comparatively prosperous (cf. Isocrates *Aeginetica* 30). By the time of Strabo (10.5.1) it was a by-word for worthlessness.

Siphnos is part of the Attic-Cycladic crystalline complex within the Hellenides (Vavelidis *et al.* 1985; Roche *et al.* 2016); the same is true of the Laurion area. The island features Cycladic Blueschist overlain by a nappe consisting of marble, schist and gneiss. Silver-bearing lead-antimony sulfides and sulfates occur in a near-surface zone of oxidised and strongly weathered rock (Gale *et al.* 1980, 4). Silver occurs on Siphnos in association with the minerals galena (PbS), cerussite ($PbCO_3$) and jarosite ($KFe^{3+}_3(OH)_6(SO_4)_2$) (Vavelidis *et al.* 1985, 63–66, fig. 42).

An interdisciplinary project on prehistoric and ancient metal production on Siphnos, organized by the Bergbau-Museum, Bochum and the Max-Planck-Institut für Kernphysik (Wagner and Weisgerber 1985a), recorded in detail the evidence for mines and metal-rich ores (for summaries see Wagner 2000; Birkett-Smith 2000). Ore deposits occur in the middle and south of the island (Vavelidis *et al.* 1985). There are five deposits of silver-bearing ores (mostly galena dominated) in the island's centre, forming a line between the known mining sites of Agios Sostis, Agios Silvestros, Vorini,

[1] We wish to warmly thank Prof Bernhard Weisser, director of the Münzkabinett der Staatlichen Museen zu Berlin, for his invaluable support of the project 'A Spring of Silver', undertaken by Sheedy, Gore and Davis, to study the composition of the metal used to mint archaic Athenian coinage. The XRF analyses of Athenian and Siphnian coins in the Berlin collection were essential for the writing of this study of Siphnian silver.

Kapsalos and Xeroxylon (Matthaus 1985, 19, fig. 2). Of these, the mine at Agios Sostis on the coast (often linked to the story in Pausanias 10.11.2 that Apollo flooded the mines) is the most famous and the most carefully studied (Weisgerber 1985). To the south, at Agios Ioannis, Apokofto and Aspro Prygos, are deposits of gold (see also Vavelidis 1997). Ancient mines at these sites, however, have suffered badly from the extraction of iron ore in nineteenth and twentieth century (Vavelidis *et al.* 1985, 65; Birkett-Smith 2006).

The working of silver and gold surface deposits on the island dates back at least to Early Bronze Age II (Keros-Syros culture) which began *c.* 2,700 BC (Pernicka and Wagner 1985a, 200; Pernicka and Wagner 1985b). But after the evidence of intensive activity during the third millennium the Bochum/Heidelberg survey found little until a second period of activity in the sixth and fifth centuries BC (Pernicka and Wagner 1985a, 205). The more substantial evidence for prehistoric mining and metalwork has continued to dominate recent research on Siphnos (Bassiakos *et al.* 2013).

In his account of a visit to Siphnos in 1884, before the advent of modern mining on the island, J. Theodore Bent (1885) colourfully describes two mines that were still known to the local people (Aghios Sostis and Kapsalos). He noted (1885, 197) that local potters pick up "bits of vitrified lead, which they use for mixing with their clay to prevent it expanding." He also mentioned seeing (1885, 197) "quantities of scoriae, which the ancient smelters have used and cast on one side." Nonetheless, a paucity of slag dumps was reported by the Bochum/Heidelberg survey, despite evidence for intensive mining (Pernicka *et al.* 1985). There are traces of slag-covered pit furnaces (e.g. Ayios Sostis: Pernicka *et al.* 1985, 186–7), and lead oxide mineral litharge (PbO) has been found at three sites (Platy Gialos, Agios Sostis and Kapsalos), indicating that at least some extraction of silver from lead did take place on Siphnos (Pernicka *et al.* 1985). However, even if ancient slag heaps were recycled in the Roman and Byzantine periods, more evidence of slag should be visible. Numerous tuyeres survive (Pernicka *et al.* 1985, 185–6) but none exhibit a slag coating. Should we then conclude (as did Pernicka *et al.* 1985, 197) that their absence can only mean that most Siphnian ores were smelted somewhere else?

Wagner and Wiesgerber Analyses of Siphnian Coinage

Compositional analyses of Siphnian coinage arguably began with Gale *et al.* (1980), who focused on the evidence of the then recently found Asyut Hoard (*IGCH* 1644; Price and Waggoner 1975; see Beer 1980 for a history of the analytical research project). Compositional data for coins in the Asyut hoard derived from neutron activation analysis (NAA) and lead isotope analysis (LIA) (Gale *et al*. 1980). No coins from Siphnos were included in this sample, but LIA of Siphnian ores, slags and litharge (Gale *et al.*, 1980, 10, n. 31 with references to earlier publications; Wagner *et al.* 1980) was used to identify a distinct Siphnian lead isotope field.

45 Aeginetan coins from the Asyut hoard (plus one more Aeginetan tortoise from the 'Wells Hoard') were analysed, with LIA leading to the identification of 10 Aeginetan coins from the Siphnian lead isotope field, with a further four near the edge (Gale *et al.* 1980, 28, fig. 8). The 14 coins in or near the Siphnian field (over 30 % of the sample) typologically extended down to the small skew variety (Price and Waggoner 1975, 73, Group VIIb) which was believed to have concluded *c.*485 BC. Aeginetan coins which fit the Laurion lead isotope field represent 17 % of the sample (9 coins within the field; Gale *et al.* 1980, 36). These Laurion silver Aeginetan coins all carry later reverse patterns (with the exception of one Union Jack variety) which begin *c.*495 BC (Gale *et al.* 1980, 28, 35). This suggested that the Siphnos-derived silver coins of Aegina are earlier, and that *c.*495 BC the mint began to rely on silver from Laurion. The sample was too small to have any confidence in this division but it would then seem that a significant part of the archaic output of the Aeginetan mint was

made from the silver of Siphnos. In a review of these data, and a proposed revision of the conclusions, Stos-Gale and Davis (this volume) now argue in contrast that the role of silver from Siphnos in the production of Aeginetan coinage was minor.

The earliest study quantifying elemental compositions to help determine the provenance of silver in Greek coins used NAA on a similarly large sample of Aeginetan coins, focusing on copper, silver and gold (Kraay and Emeleus, in Kraay 1962). They contrasted the relatively low concentrations of copper (<0.25 %) and gold (<0.04 %) in Athenian owls with the greater copper and gold concentrations in 37 Aeginetan staters (Kraay 1962, 12–14). On the basis of the NAA analyses, three clusters of Aeginetan coins were apparent to Kraay and Emeleus, and they concluded that there were three silver sources: Laurion, Siphnos and a third uncertain source, possibly the Thraco-Macedonian mines (see Stos-Gale and Davis in this volume on the question of silver sources). There were no Siphnian coins in the sample, and none from the Thraco-Macedonian region.

Elemental analyses of Siphnian ores and slag showed a greater silver content in ores from the main area of mineralisation (typically more than 500 g/ton but ranging up to 7,000 g/ton) than was present in Laurion ores (Gale *et al.* 1980, 38). The gold content in Siphnian ores was said to be 'chiefly' in the range of 0.005 % to 0.05 % in the extracted silver (Gale *et al.* 1980, 39) and with all data taken into account they concluded that a gold content in Siphnian silver "from 0.01 to 0.2 and even, rarely, up to 1%" could be expected. These findings supported the theory of Kraay and Emeleus that Siphnian silver typically had more gold than Laurion silver.

Gale *et al.* (1980, 41, table 12) incorporated elemental analyses of Siphnian coins carried out by M. Cowell at the British Museum (nine coins using X-ray Fluorescence spectrometry (XRF)) and by Ch. Lahanier at the Bibliothèque nationale de France, Paris (three coins using XRF). The gold content of these 12 coins was 0.2–0.6 % for sixth century BC coins and 0.02–0.2 % for early fifth century BC coins (Gale *et al.* 1980, 40) (now see Table 1). They did not explain why the gold content decreased over this short period. The XRF data (Gale *et al.* 1980, 41, table 12) showed that (a) the purity of Siphnian silver coins is very high (nearly all >97 %; with 7 coins >98 %); (b) the gold content is relatively high (8 coins >0.1 %); (c) Cu concentrations are 0.1–2.0 % (11 coins) and (d) lead concentrations are as high as 0.3–2.0 %, but with most <1 %.

GOLD COINS OF SIPHNOS

Siphnos is the only Cycladic island known to have certainly produced a gold coinage, though this is seldom recognized (Sheedy 2006, 48; the existence of a gold coinage of Tenos seems

Figure 1. Gold drachm (4.295g). Siphnos, *c.*375–357 BC. Berlin inv.18207419. Image courtesy of the Staatliche Museen zu Berlin, Münzkabinett

Figure 2. Silver tetrobol (3.72g). Siphnos, fourth century BC. British Museum inv. 1887,1003.5. Image courtesy of the trustees of the British Museum

unlikely, but see Étienne 1990, 235, cat. 201). The presence of gold mines on Siphnos has been confirmed by the Bochum/Heidelberg survey. A tiny (0.11 g) unpublished electrum fraction in New York (ANS 1944.100.27956) has been attributed to Siphnos without good reason (see Sheedy 2006, 48, pl. 18), and it seems more likely that the coin belongs to an unknown mint in Asia Minor (as suggested by Waggoner 1983, cat 315). The gold coins of Siphnos are confined to one issue that today is represented by a single drachm now in Berlin (inv.18207419; Dressel 1898, 216–7, cat. 1411, pl. 5, 4; ex Photiades Coll.1411). This rather beautiful coin (Fig. 1) depicts the head of Apollo wearing a tainia and, on the reverse, an eagle in flight (the traditional coin types of the island) combined with the inscription ΣΙΦ. At 4.295 g, it is a drachm or hemi-stater on the Attic weight standard (Dressel 1898, 217). The fourth century BC coinage of Siphnos has yet to be studied. Nonetheless, it is possible to see that the reverse die employed for the gold drachm in Berlin was also used to mint the well preserved fourth century silver tetrobol in London (inv. 1887,1003.5; Fig. 2). This gold issue was then contemporary with the last known phase of silver coins from Siphnos.

The first known analysis of the Berlin drachm, which was reported by H-D Schultz, was undertaken with an electron microprobe (Pernicka and Wagner 1985a, 207-8, table 3; the measurements were of the obverse). The gold content was given as ~92 % and the sum of calcium, iron, copper, zinc and silver was estimated at <8 %. Our XRF analysis of the gold drachm (with the data normalized to 100%) has now revealed a gold content of 96.4 %, with 2.92 % silver and 0.677 % copper (Table 1, cat. 29).

A more precise dating for the fourth century BC coinage of Siphnos is suggested by comparisons with Euboean League issues produced between 375 and 357 BC (for earlier attempts at dating these Siphnian coins see Gardner 1913). Depictions of the nymph Euboea maintain formalised hair strand patterns (Wallace 1956, cat. 1–13) until a change to a naturalistic hair rendering *c.* 357 BC (Wallace 1956, cat. 14–19). The depictions of Apollo on Siphnian coins (e.g. Figs 1, 2) show a similar formal pattern with clearly delineated hair strands but the more naturalistic hair rendering is unknown. The eagle on the Siphnian gold drachm is set within a shallow round incuse, and not in a square frame. The change from a square to a round incuse can also be seen in the coinage of the Euboean League where it occurs in the period *c.* 375-357 BC (Wallace 1956, cat. 1–13).

Siphnian silver staters were traditionally minted on the Aeginetan standard. After *c.* 475 BC, however, Siphnos began minting tetrobols around 3.80 g. Sheedy (2006, 49–50) suggested that Siphnos had adjusted the weights of these issues so that they might pass on either the Aeginetan standard common in the Cyclades during the archaic period, or on the Attic standard – perhaps reflecting the importance of Athens in fifth century Aegean trade.

It seems likely, however, that Siphnos simply reduced the average weight of its fractions at this time because it had less silver (and in this study we have identified the various fractions according to the Aeginetan standard rather than the Attic). The practice of reduced weight fractions continued into the fourth century. The Berlin gold coin is the first example of a Siphnian issue that is clearly on the Attic standard.

There were very few gold coinages minted in Greece in the first half of the fourth century BC. Athens had minted an emergency gold coinage *c.* 407–404 BC (which included drachms) but then ceased (Robinson 1960), and would not produce another gold issue until 295 BC.

Is there an historical context that might explain this surprising gold issue? In 376 BC, after the battle of Naxos, most of the Cycladic city-states joined the Second Athenian Confederacy (Rutishauser 2012, 160–1). The Confederacy was not formally dissolved until 338 BC. There was no 'Cycladic coinage alliance' and nothing similar to the Ionian coinage alliance suggested by the ΣYN issues (Rutishauser 2012, 152). If Siphnos paid its *syntaxeis* (contributions; see Rutishauser 2012, 168–9) in coin then perhaps this gold drachm was part of the supposedly voluntary contributions of the island towards supporting the Athenian navy.

SILVER COINS OF SIPHNOS

Discussion of the chemical composition of Siphnian silver coins was initially determined by XRF analyses of nine examples in London (from M. Cowell) and a further three in Paris (Ch. Lahanier), first published in Gale *et al.* (1980). The data were confined to copper, silver, gold and lead, and there were no certified reference materials reported in the analytical suite, so the accuracy of these measurements is unconstrained. These data were re-published in Pernicka and Wagner (1985a, 207), which appears to offer a larger range of coins; however, although the weights of five additional coins are recorded, there are no new elemental analyses, and furthermore the silver concentrations of the coins from Paris are omitted. This small sample size with unconstrained analytical accuracy is the context and justification for our new measurement program.

This research reports new elemental analyses (Table 1) for a range of Siphnian silver coins with two aims. First, we re-analyse 11 of the 12 coins reported in Gale *et al.* (1980), in order to check the veracity of those older measurements. Second, we increase the number of analysed silver coins from Siphnos to a total of 29 coins. We then discuss these new data in the context of the typology and analysis of Siphnian coinage established by Sheedy (2006, 41–57).

METHODS

Twelve legacy analyses (Gale *et al.* 1980) were tabulated and 11 of these coins were re-located and re-measured (Table 1). Elemental compositions of 24 coins were measured on each side using a PANalytical Epsilon 3 energy dispersive XRF, with a 15 W, rhodium anode tube operated at 50 kV for the elements reported (Table 2). Data were corrected for the presence of the patina by subtraction of environmental contaminants, with the remaining data normalised to 100 % (following Gore and Davis 2016), thereby approximating the interior composition of the coin metal. Compositional values (Table 1) are the arithmetic mean of a single measurement from each of the obverse and reverse. Analytical inaccuracy of the XRF was constrained by measurement of 12 certified reference materials (MBH, UK: 131XAGP2A, 131XAGP3A, 131XAGP4A, 131XPAG1, 131XPAG2, 132X925Zn1, 132X925Zn3, 132XAGB87, 132XAGB92, 132XAGB94, 133XAGQ2, 133XAGQ3; summarised in Fig. 3). In general, elements with concentrations of <0.1 wt% have relative errors of 10-100 %, and elements present at >1 wt% have relative errors of <10 % (Fig. 3).

LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry) was also carried out on six Siphnian coins held in the collection of the Département des Monnaies,

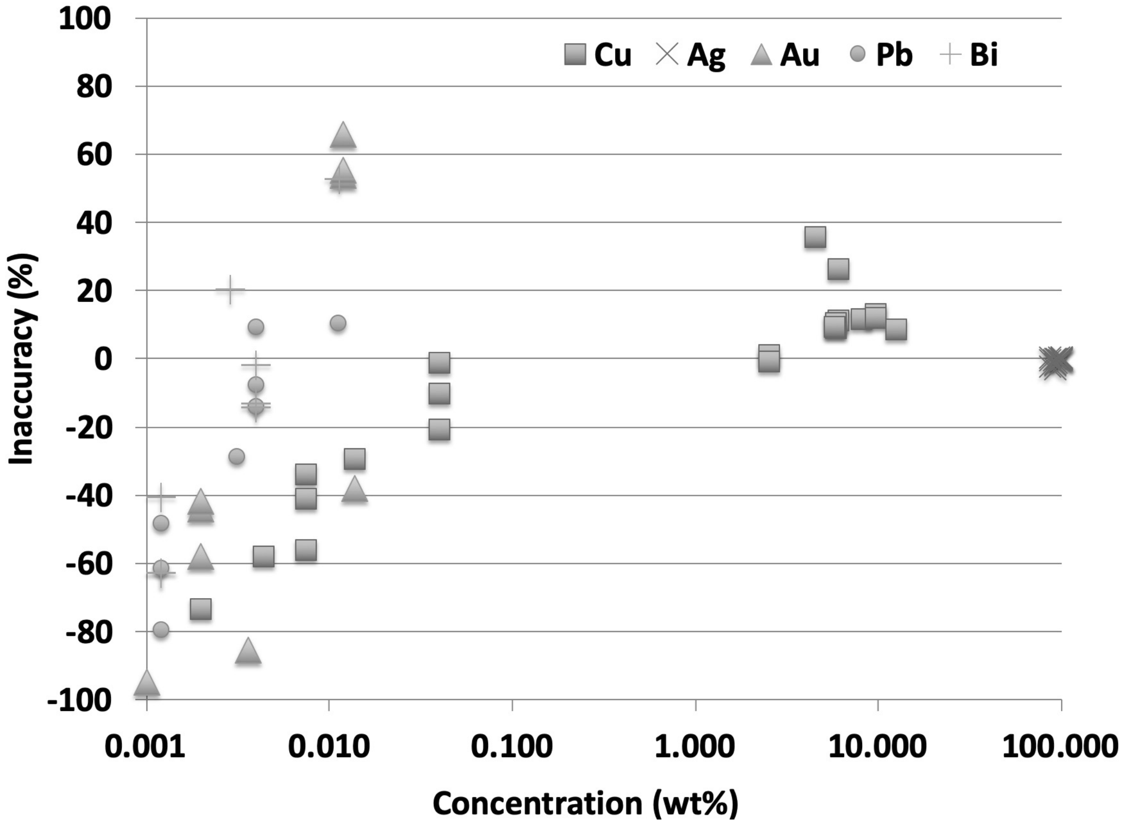

Figure 3. Analytical inaccuracy for the new measurements using XRF spectrometry (PANalytical Epsilon 3)

médailles et antiques in the Bibliothèque nationale de France to give a complementary characterisation of this set of coins. LA-ICP-MS permits a rapid and almost non-destructive determination of the concentration of many elements in silver coins (Sarah *et al.* 2007; Sarah and Gratuze 2016) and gold coins (Blet-Lemarquand *et al.*, this volume) with very low detection limits (less than 1 mg/kg). Micro-sampling was conducted with a laser ablation device. The ablated matter is ionised in a plasma torch, and the extracted ions were analysed using a mass spectrometer. Traces of sampling on the coin are virtually invisible to the naked eye. Single spot analysis is used in order to reach deep into the coin being analysed. Depth profile mode was chosen to measure continuously the composition of all the elements, starting at the surface of the coin. This mode makes it possible to remove the surface layer (that can be enriched with elements such as Zn and Pb) from the calculations and to characterise the underlying unaffected alloy. Two to three different samples are generally taken from each coin. The relative error of this method is <2% for silver content >90% and <10% for minor elements in most cases.

In this study of the Siphnos coins in Paris, however, two examples (FG 387 and FG 389) which the data obtained by Lahanier (see Table 1) suggested were plated, required another method of analysis. Fast Neutron Activation Analysis (FNAA) was performed to obtain the mean composition of these coins for 10 elements (Guerra and Barrandon 1998).

Some 43 measurements from our XRF study (Table 1, source 4) are presented from one gold and 29 silver coins (Table 1). Data were analysed using one-way analysis of variance (ANOVA) using Minitab v.17 for Windows (Minitab Inc.). α=0.05 was used for all analyses. Where the ANOVA showed a significant interaction, a Tukey's post-hoc test for differences of means was performed. Since Series III consisted of one coin only, it is not discussed as a separate group in these data analyses. Elemental data were analysed raw, and also expressed as a ratio to Ag concentrations to remove the constant sum effect, and then $\log_{10}$ transformed to avoid spurious negative correlations (Aitchison's solution; Aitchison 1986, Rollinson 1992). However, because log-transformed ratios are not intuitive for most readers, the raw compositional data will be discussed throughout the manuscript.

RESULTS

The following analysis pertains to the recent XRF data (Table 1, source 4). The data from LA-ICP-MS and FNAA is in agreement with the XRF results. Concentrations of copper ranged from 0.04 to 4.3 %, with an arithmetic mean of 0.80 % and a geometric mean of 0.38 %. ANOVA of both untransformed and transformed data showed a significant difference between the groups (ANOVA; d.f.=23, F=5.68, P=0.0056), and a Tukey's test (T=4.06, P=0.0032) revealed that Series IV coins have a significantly greater copper content than Series II coins. Concentrations of silver ranged from 94.0 to 99.3 %, with an arithmetic and geometric means of 97.5 %. An ANOVA of the untransformed data showed that there were no significant differences (ANOVA; d.f.=23, F=1.77, P=0.1847) between the Series. Concentrations of gold ranged from 0.007 to 0.58 %, with an arithmetic mean of 0.19 % and a geometric mean of 0.081 %. An ANOVA of both untransformed and transformed data revealed a strong, significant interaction (ANOVA; d.f.=23, F=12.83, P <0.0001), and a Tukey's test revealed that both Series I (T=4.83, P=0.0006) and Series IV (T=5.18, P=0.0003) have more gold than Series II coins. Concentrations of lead ranged from 0.006 to 1.56 %, with an arithmetic mean of 0.39 % and a geometric mean of 0.172 %. ANOVA of both untransformed and transformed data showed a weak, but significant difference between the groups (ANOVA; d.f.=23, F=3.37, P=0.0388), and a Tukey's test revealed that Series I has significantly less lead than Series II (T=3.05, P=0.0295). Concentrations of bismuth ranged from 0.001 to 0.086 %, with an arithmetic mean of 0.027 % and a geometric mean of 0.016 %. ANOVA of both untransformed and transformed data revealed no significant interactions at the 5 % level, although in general the concentration of bismuth decreased monotonically from Series I to Series IV.

DISCUSSION

Our first aim was to compare our XRF data with those obtained by Cowell and Lahanier over 27 years ago. Table 1 shows that there is a reasonably close match in both the estimates of the amount of silver and in the minor and trace elements. The second aim was to re-examine the earlier chemical characterisation of Siphnian silver coins. In general, the purity of the silver remains high (97.6 to 99.5 %) as does gold (0.01 to 0.6 %) relative to concentrations in Athenian silver coins (Gale *et al.* 1980, 12: in Athenian owl coins "gold content varies chiefly between 0.02 and 0.05 %").

We have reported bismuth concentrations (<0.15 %), which are thought to be a diagnostic element for silver sources (L'Héritier *et al.* 2015). Concentrations of gold are directly linked to the ores from which the silver was extracted and are not altered by smelting and refining (see for instance Gale *et al.* 1980; Meyers 2003 and quoted references). Bismuth is only slightly altered by these processes (Gitler *et al.* 2009, 34; L'Héritier *et al.* 2015). It is important to note that our study has shown bismuth concentrations which are usually lower than those reported by Gale *et al.* 1980 as typical of Laurion silver (1980, 33: in Athenian owls "bismuth lies chiefly between 0.05 and 0.25%"). Gale *et al.* (1980, 40, fig. 10) had observed that ten Aeginetan coins believed to have been manufactured from Siphnian silver "are relatively higher in bismuth than Laurion silver". These different conclusions must underline the dangers of inferring typical levels for trace elements from coins only suspected of being made of Siphnian silver. We (Sheedy, Gore and Davis) are currently studying XRF data from over 1,000 archaic Attic coins. Our impression is that the concentrations of bismuth in Laurion silver typically sit between 0.01 and 0.04 % and are comparable to concentrations in Siphnian silver.

Copper and lead concentrations change with smelting and are a reflection of technology and practices. Curiously, Siphnian silver coins typically have slightly lower concentrations of lead in comparison with Athenian coins. It now seems highly probable that where copper concentrations exceed 0.5 %, as often happens in Attic silver coins, copper had been deliberately added (this is noted, for example, by Gitler *et al.* 2009, 38).

At least three plated silver coins of Siphnos have been detected (Sheedy 2006, cat. 9, 13 and 27) (see Table 1, cat. 30, 31 for analyses of Paris FG 387 and FG 389) – a significant number within the sample from this fairly small range of issues. We believe that these plated coins were minted by the Siphnian state; the style of the engraved types is extremely close to contemporary dies used by the Siphnians. The practice of official mints producing plated coins was not uncommon (van Alfen 2005), but it is extremely rare to find a fourrée from the Cyclades (we are aware of only one example from another Cycladic mint, a plated archaic stater from Thera: Classical Numismatic Group (CNG) Sale 317 (2013) 58). The production of plated coins by the Siphnian mint should be viewed as a response to falling stocks of silver.

Our discussion of the data employs a typological and chronological framework for Siphnian coinage established by Sheedy (2006). In Series I, there is a noticeably wide distribution of stater weights (Table 3) but it is clear that the mint is adhering to the Aeginetan weight standard. As noted above, in Series II the fractions show an evident reduction from the Aeginetan weight standard. In the 4th century BC the tetrobols continued to be issued at a reduced weight (Table 3).

The first issues of Siphnos, Series I (Fig. 4), belong to the years *c.* 540–525 BC (Sheedy 2006, 177–178). This is the era of the largest output of staters but the low number of surviving examples is surprising; the 17 didrachms recorded were minted from six obverse and six reverse dies. The XRF data of Lahanier and our project (Table 1, cat. 30) and our FNAA analyses concur that the stater Paris FG 387 is plated. The concentrations of Ag among the coins sampled are very high – between 96.6 % and 99.3 % with an average of 98 %. There is a range in copper concentrations from 0.04–1.69 % but most analyses are greater than 0.5 %, suggesting deliberate addition. Lead concentrations seem surprisingly low, from 0.006 % to 0.10 % but with the earlier data suggesting slightly higher concentrations.

The unusual drachm in New York (00.999.42388; Fig. 5) with a reverse incuse diagonal cross was probably minted in the years after Series I (though for convenience we have placed it in this series). The diagonal cross was adopted by other island mints in the western Cycladic chain after *c.* 480 BC (see Sheedy 2006, Koressos Series III; Melos Series III). This denomination is otherwise unknown at the mint (weight 5.54 g), but the composition of this one example (Table 1, cat. 6) is consistent with Siphnian silver coins.

Series II (*c.* 475–460 BC; Sheedy 2006, 178–180) began after a break in minting of roughly half a century. The eight surviving didrachm staters (Fig. 6) were minted with four obverse and five reverse dies. The mint in this series showed a greater interest in tetrobols and a range of smaller fractions. FNAA data and previous Specific Gravity (SG) analysis demonstrate that the tetrobol Paris FG 389 is plated (Table 1).[2] The average weight of the staters is slightly lighter than Series I coins (Table 3). This includes the three staters in Sheedy (2006, cat. 19) (Fig. 6) which are all of low weight (and are worn). The concentrations of silver and

[2] Analyses of FG 389 by XRF and FNAA have produced data showing very different concentrations of copper (around 15 % and 7 % respectively for XRF and FNAA). Lahanier had measured the specific gravity of this coin using a pycnometer (stated in a report held by the BnF) and he proved that it is around 9.4 kg/m^3. This datum tallies with a 30 % copper concentration if it is hypothesised that FG 389 is made of a binary silver-copper alloy. The discrepancy between the FNAA and the specific gravity may be due to porosities inside the coin as a result of copper corrosion phases leached from the coin. Moreover, the surface of this coin was highly scratched, probably to get rid of corrosion products. These indications lead us to think that FG 389 is a plated coin.

Figure 4. Silver stater (12.35g). Siphnos, *c.*540-525 BC. New York 1967.152.287. Photo courtesy of the American Numismatic Society

Figure 5. Silver drachm (5.54g). Siphnos, *c.*525-500 BC (?). New York 0000.999.42399. Photo courtesy of the American Numismatic Society

Figure 6. Silver stater (11.44g). Siphnos, *c.*475-460 BC. Cambridge, McClean Collection 7286. Photo K.A. Sheedy

trace elements conform to the results for Series I. Series III (*c.* 460–455 BC; Sheedy 2006, 181) is a brief extension of Series II, and is known only from a small group of obols and hemiobols. The one hemiobol analysed is 97.5 % silver.

The Siphnian silver issues of the fourth century belong to a brief phase of minting *c.* 375–357 BC (Fig. 2). A small hoard found on Siphnos (*IGCH* 91), dated *c.* 320–300 BC (and thus well after the minting of silver on the island may have ceased), contained one didrachm (Fig. 7) on the Aeginetan standard (11.02 g) and three tetrobols from Siphnos (Newell 1934; 3, cat. 1–4), all of relatively low weight (Table 3, cf. Table 1, cat. 24–27). Analyses of two

Figure 7. Silver stater (11.09g). Siphnos, late fifth or fourth century BC. New York 1944.100.27959. Photo courtesy of the American Numismatic Society

hoard tetrobols show a change from earlier concentrations as a result of smelting (the gold and bismuth concentrations are as expected): 1944.100.27960 (Newell 1934, cat. 3) has only 94.0 % silver but 4.29 % copper (Table 1, cat. 25) while 1944.100.27961 (Newell 1934, cat. 2) has 95.4 % silver and 3.28 % copper (Table 1, cat. 26). But these are exceptional. In general, slightly higher concentrations of copper exist in all fourth century coins from Siphnos.

CONCLUSIONS

This chapter presents the first comprehensive survey of the composition of the silver issues from Siphnos. These data had been noticeably absent from earlier discussions of the composition of archaic Greek coinage and Greek silver sources in which, paradoxically, there is already widespread speculation regarding the importance of Siphnos. These new analyses have introduced data on elements, mostly notably bismuth, which need to be considered in any discussion of the characteristics of Siphnian silver. Importantly, we have presented the coin analyses within a clearly defined chronology, and provided examples from each phase of minting (of precious metals) on the island. This will facilitate further study of changing practices which altered the purity of the metal.

The gold and silver mines of Siphnos began failing around 525 BC and the island's inhabitants lost their reputation for riches. We might then have expected a decrease in the purity of their silver coins after 525 BC. We can see a progressive lowering of the average weight of the different denominations during the fifth and fourth centuries BC, but the purity of their coins was never really compromised. They preferred to reduce the weights of the issues and to strike plated coins if the silver supplies did not support the intended volume of coinage.

Characterisation of Siphnian silver by Gale *et al.* (1980, 41), on the basis of XRF analyses of 12 Siphnian coins and earlier, by Kraay and Emeleus (1962) using NAA analyses of Aeginetan coins thought to be of Siphnian silver, can be confirmed in most aspects with the notable exception of bismuth. The gold concentration was chiefly 0.005 % to 0.05 % in the extracted silver of Siphnos (Gale *et al.* 1980, 39). The new analyses of the coins, however, consistently showed higher gold concentrations (the great majority fall between 0.01–0.60 %). There is no evidence to support the suggestion of Gale *et al.* (1980, 40) that the concentration of gold falls among coins of the early fifth century BC (or even in later issues). Concentrations of bismuth found in Aeginetan coins believed to be of Siphnian silver were reported to be "relatively higher" than in Laurion silver (Gale *et al.* 1980, 40). We can now see that bismuth in the Siphnian coins we have analysed occurs at approximately the same concentrations reported by Gale *et al.* for the silver of Laurion. Concentrations of copper and lead, as noted above, change with smelting and are a reflection of technology. Copper

Table 1. Elemental compositions of silver coins. n.r. = element not reported. The column 'Ref" refers to the data sources: (1) Source: M. Cowell, in Gale *et al.* (1980). Method: XRF spectrometry. (2) Source: Ch. Lahanier, in Gale *et al.* (1980). Method: XRF spectrometry. (3) Source: Ch. Lahanier, in Pernicka and Wagner 1985a, table 3, 207. Method: XRF spectrometry. (4) Source: this study. Method: XRF spectrometry. (5) Source: this study. Method: LA-ICP-MS. (6) Source: this study. Method: FNAA

Cat.		*Denomination/ Weight (g)*	*Ref*	*Sheedy 2006*	*Cu (%)*	*Ag (%)*	*Au (%)*	*Pb (%)*	*Bi (%)*
	SERIES I c.540-525 BC Obv.Eagle/ Rev. Incuse.								
1	New York 1967.152.287	Stater, 12.35	4	1a	1.43	97.3	0.461	0.121	0.037
2	London RPK.p101A.1. Ses. (BMC1)	Stater, 12.77	4	2a	0.796	98.3	0.385	0.006	0.024
2	London RPK.p101A.1.Ses. (BMC1)	Stater, 12.77	1	2a	1.1	98.4	0.2	0.3	n.r.
3	Cambridge McClean 7285	Stater, 12.07	4	2b	1.18	97.5	0.389	0.017	0.082
4	Paris Delepierre 2457	Stater, 11.45	2	4	1.1	98.2	0.61	0.1	n.r.
4	Paris Delepierre 2457	Stater, 11.45	5	4	1.3	98.2	0.2718	0.0542	0.1457
5	London G.4269. (BMC2)	Stater, 11.12	4	8	1.69	96.6	0.577	0.105	0.072
5	London G.4269. (BMC2)	Stater, 11.12	1	8	2.5	96.6	0.55	0.3	n.r.
6	New York 0000.999.42399	Drachm, 5.54	4	–	0.271	99.3	0.067	0.137	0.037
7	New York 1944.100.27957	Hemidrachm, 2.95	4	10	0.355	98.0	0.281	0.066	0.015
8	London 1878-0301.230. (BMC3)	Hemidrachm, 2.88	4	11	0.107	98.8	0.077	0.025	0.002
8	London 1878-0301.230. (BMC3)	Hemidrachm, 2.88	1	11	1.3	98.0	0.37	0.3	n.r.
	SERIES II c.475-460 BC Obv.Head of Apollo/ Rev. Eagle.								
9	Paris FG 388	Stater, 11.90	4	14	0.135	98.0	0.007	0.123	0.001
9	Paris FG 388	Stater, 11.90	2	14	0.32	99.1	0.18	0.39	n.r.
9	Paris FG 388	Stater, 11.90	5	14	0.02	99.5	0.0072	0.4309	0.0003
10	London 1845,0109.7. (BM 4)	Stater, 12.08	4	16	0.040	97.8	0.013	1.35	0.016
10	London 1845,0109.7. (BM 4)	Stater, 12.08	1	16	0.1	97.9	0.02	2.0	n.r.
11	Paris de Luynes 2381	Stater, 12.05	2	17	0.43	97.7	0.1	1.8	n.r.
11	Paris de Luynes 2381	Stater, 12.05	5	17	0.15	98.5	0.0591	1.2280	0.0947
12	Cambridge McClean 7286	Stater, 11.44	4	19b	0.719	98.4	0.022	0.090	0.086
13	Athens (Kambanis)	Stater, 11.19	4	19c	0.494	94.3	0.035	0.064	0.062
14	London 1950,0401.8.	Tetrobol; 3.66	4	20	0.051	98.8	0.012	0.443	0.038
14	London 1950,0401.8.	Tetrobol; 3.66	1	20	0.2	98.5	0.06	1.3	n.r.
15	London 1841,B.2173. (BM 6)	Tetrobol; 3.71	4	21	0.058	98.5	0.021	0.573	0.037
15	London 1841,B.2173. (BM 6)	Tetrobol; 3.71	1	21	0.2	98.6	0.08	1.1	n.r.
16	New York 1944.100.27958	Tetrobol; 3.82	4	22e	0.412	95.7	0.023	0.856	0.017
17	London EH,p471.Sic. (BM 5)	Tetrobol; 3.97	4	25	0.522	98.5	0.131	0.100	0.002
17	London EH,p471.Sic. (BM 5)	Tetrobol; 3.97	1	25	0.25	99.3	0.07	0.4	n.r.
18	London 1949,0411.707	Trihemiobol; 1.43	4	28	0.096	98.2	0.058	0.619	0.031
19	Paris FG 390	Hemiobol; 0.52	4	29iv	0.116	97.5	0.025	1.56	0.022

Table 1. *Continued.*

Cat.		*Denomination/ Weight (g)*	*Ref*	*Sheedy 2006*	*Cu (%)*	*Ag (%)*	*Au (%)*	*Pb (%)*	*Bi (%)*
20	New York 1967.152.288	Tetartemorion; 0.30	4	31i	0.076	97.8	0.012	0.933	0.013
21	Oxford	Tetartemorion; 0.31	4	31iii	0.184	97.6	0.024	1.13	0.015
	SERIES III c.460-455 BC Obv.Head of Artemis/ Rev. Eagle.								
22	Paris FG 391	Obol, 0.84	4	32	0.190	99.1	0.049	0.206	0.009
22	Paris FG 391	Obol, 0.84	5	32	0.1	99.35	0.0409	0.3694	0.0125
	SERIES IV 4th CENTURY BC Obv.Head of Apollo/Rev. Eagle.								
23	London 1887,1003.5	Tetrobol; 3.72	4		1.35	97.6	0.431	0.056	0.008
23	London 1887,1003.5	Tetrobol; 3.72	1		1.5	97.9	0.35	0.3	n.r.
24	New York 1944.100.27959 (Hoard)	Stater, 11.09	4		0.485	97.8	0.580	0.060	0.003
25	New York 1944.100.27960 (Hoard)	Tetrobol; 3.47	4		4.30	94.0	0.306	0.304	0.012
26	New York 1944.100.27961 (Hoard)	Tetrobol; 3.34	4		3.28	95.4	0.210	0.352	0.013
27	New York 1944.100.27962 (Hoard)	Tetrobol; 3.68	4		0.907	97.6	0.356	0.597	0.013
28	London 1949,0411.706	Tetrobol; 3.52	1		2.0	97.8	0.5	0.3	n.r.
	GOLD ISSUE c.375-357 BC								
29	Berlin 18207419	Drachm, 4.295	4		0.677	2.29	96.4	<0.001	0.013
	PLATED COINS								
30	Paris FG 387	Stater, 11.65	3	9	20.5	n.r.	0.22	0.1	n.r.
30	Paris FG 387	Stater, 11.65	6	9	80.3	19.3	0.053	0.05	n.r.
31	Paris FG 389	Tetrobol; 2.95	3	27a	15.1	n.r.	0.1	1.24	n.r.
31	Paris FG 389	Tetrobol; 2.95	6	27a	6.8	92.3	<0.01	0.59	n.r.

Table 2. XRF measurement conditions. Current was set automatically, increasing until the instrument could not count further X-rays (typically around 100,000 counts per second); typical currents are shown. "Time" is the period the spectrometer counted X-rays (also known as "live time"). Filter compositions and thicknesses (μm) are given

Elements	*Voltage (kV)*	*Current (μA)*	*Time (s)*	*Filter (μm)*	*Detector mode*
Ag	50	266	120	Cu 300	Normal
Cu, Au, Pb, Bi	50	300	120	Ag 100	Normal

Table 3. Weights (g) of Siphnian coins (Sheedy 2006)

Coin weights (g)	*Series I*	*Series II*	*Series III*	*4th century BC*
Staters				
Above 12.40	xx			
12.31-40	xxxx			
12.21-30	xx			
12.11-20	x			
12.01-10	x	xxx		
11.91-12.00	x	x		
11.81-90				
11.71-80				
11.61-70	x			
11.51-60	xx	x		
Below 11.50	xxx	xxx		x (11.02)
Tetrobols				
3.91-4.00		xxx		
3.81-90		xxxx		
3.71-80		x		X
3.61-70		xx		X
3.51-60		xxx		
Below 3.50		x (plated)		XX
Hemidrachms				
2.90-3.00	xx			
2.80-90	x			
Obols				
0.81-90			xxx	
Hemiobols				
0.61-70		xxx		
0.51-0.60		xxxx		
Below 0.50			x	
Tetartemoria				
0.31-40		x		
0.21-30		xx		

was evidently added, perhaps from the start, but it is worth repeating that the purity of the island's silver coinage was maintained.

It has been pointed out that the scale of minting on Siphnos does not seem to match the island's reputed wealth (at least in the sixth century BC) from its mines (Price 1980, 51: "the coinage of the island is insignificant"). It is likely that the Siphnians only minted coin when there were local payments (distribution of profits?) to be made in coin and that otherwise precious metal was exported as bullion (Sheedy 2006, 54–57). Part of the mined ores was crushed and refined on Siphnos and it was here that it was smelted. This metal was used, among other purposes, for the production of local coinage. The absence of slags, however, appears to suggest that Siphnos exported the greater part of its gold and silver rich ores, after beneficiation, to be refined elsewhere.

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