An incuse stater from the series 'Sirinos/Pyxoes'

K.A. Sheedy, P. Munroe, F. Salvemini, V. Luzin, U. Garbe and S. Olsen

Abstract

The South Italian silver incuse stater Australian Centre for Ancient Numismatic Studies inv. 07GS729 with the matching obverse/reverse type of the bull with head reverted and the inscriptions 'Sirinos/Pyxoes' was minted sometime between c.540 and 510 BC. We know very little about the mint in which it was struck. Here we present results from SEM studies and from the current joint project of the Australian Centre for Ancient Numismatic Studies (ACANS) and the Australian Nuclear Science and Technology Organization (ANSTO) which explore the techniques for making incuse coinage.

Keywords

[ACANS] [ANSTO] [Australian Centre for Ancient Numismatic Studies] [Incuse Coinage] [Australian Nuclear Science and Technology Organization] [neutron diffraction] [neutron imaging] [Pyxoes] [SEM] [Sirinos] [South Italian coinage] [Sybaris]

One of the most intriguing coins in the remarkable South Italian collection bequeathed to ACANS by the late Dr W. L. Gale is a silver stater (ACANS inv. 07GS729; Fig. 1) with the inscriptions 'Sirinos/Pyxoes' minted c.540-510 BC.[1] It is a product of the distinct incuse style and technique characteristic of the early issues of the first mints in South Italy.[2] The coin has a distinguished pedigree, having first appeared in the collection of Sir Arthur Evans at the end of the 19th century (another example from the Evans collection passed to the Lloyd collection and then to the British Museum; Fig. 2).[3] It was the subject of a short report by Dr Gale himself.[4] The coinage is attended by many

1 *SNG Australia* I, 729. We wish to thank Dr H. Horsnaes for her comments on an earlier draft of the paper. We also wish to warmly thank the journal's two anonymous reviewers for valuable suggestions that have improved the text.

2 Gorini (1975).

3 ACANS 07A729: A. J. Evans Catalogue no. 380. *SNG Lloyd* 448 = BM 1946,0101.448.

4 Gale (1996).

problems and resulting controversies.[5] In this paper we present the results of the first scientific studies of this rare series.

Figure 1. Sirinos/Pyxoes, stater, c.540-510 BC. ACANS inv. 07GS729.Weight: 6.73g. Diameter: 29.6mm. Scale 3:1. Photo© ACANS.

The Sirinos/Pyxoes coinage has the obverse type of a bull to left with head reverted, and an incuse reverse type which repeats this motif in intaglio but with less detail. This is the coinage type of Sybaris; on comparing examples from the two mints (Fig. 1, 3) we can see that the pose of the bull and the style of engraving are similar, and the same ground lines and borders are employed.[6] The ACANS example has an obverse border of dots between two lines, a dotted ground line and a ray border on the reverse.

Figure 2. Sirinos/Pyxoes, stater, c.540-510 BC. British Museum inv. 1946,0101.448. Weight: 7.85g. Photo courtesy of the British Museum. ©Trustees of the British Museum. Scale: 3:1.

5 Horsnaes (2011).

6 Sybaris: *HN Italy* 144-145, cat. 1729-1742.

Figure 3. Sybaris, stater, c.550-510 BC. ACANS inv. 07GS731.Weight: 6.99g. Diameter: 29.6mm. Photo© ACANS.

The only important difference lies in the inscription. The most common formula for the Sirinos/Pyxoes coinage is demonstrated on a stater in London (Fig. 2): obverse, ΣΙΡΙΝ (retrograde) within the exergue; above, ΟΣ; on the reverse, within the exergue, ΠVΧ (retrograde).[7] Other examples complete the reverse inscription as PYXOES.[8] The letters within the obverse exergue of the ACANS example cannot be detected but it shares the same obverse die with the London stater. The weight standard is the Achaean, with a stater of 8.1g.[9] The ACANS coin weighs 6.73g.[10]

The range of problems associated with this coinage is remarkably diverse and cannot be fully addressed in this study.[11] We have, for example, no exact idea of the identity of the *polis* or community for which the coins were minted and, strangely enough, no conclusive evidence for the location of the main settlements that have been proposed. Even the remarkably long inscriptions that identify the minters present problems. This coinage can be grouped with other incuse coinages which employ the bull types of Sybaris but which have different inscriptions (AMI and SO) and with coins with the type of the boar to r. and the inscription PAL-MOL.[12] They are traditionally attributed to towns in Lucania thought to be allied with (if not colonies of) Sybaris.[13] Helle Horsnaes has recently revisited the theory that some or all of these coinages may have been struck

7 British Museum inv. 1946,0101.448 (7.85 g); *BMC Greek Coins, Italy,* 283 no.2.

8 Horsnaes (2011): 198-199.

9 *HN Italy* 3.

10 A lower weight is not uncommon; from a list of 40 known examples prepared by Libero Mangieri (1981), eight weigh between 6 and 7g.

11 The most recent account is provided by Horsnaes (2011).

12 *HN Italy* 108, 124, 143-4; Horsnaes (2011): 202-205.

13 Rutter (1997): 24-27.

by indigenous communities, perhaps with the assistance of Greek craftsmen who carved the dies.[14]

Following the pioneering account of J. Perret in 1941, the Sirinos/Pyxoes coinage has been independently studied and classified by H. R. Sternberg and G. Libero Mangieri.[15] Libero Mangieri divided his corpus of some 44 staters and one drachm (plus one stater of a slightly different type) into four groups on the basis of the module (*tozzi, normali, ridotti and snelli*).[16] Rutter *et al, HN Italy* (2001) adhered to the classification of Libero Mangieri.[17] Horsnaes also offers a division into four groups in an important review of this material, but her more convincing system is based on die identification.[18] Horsnaes Group 1, with the legends ΣΙΡΙΝ –ΟΣ (retrograde) on the obverse and ΠVΧ (retrograde) on the reverse, is known from 15 coins all produced, according to Horsnaes, from one (possibly two) obverse and four dies (Horsnaes O1/R1-4).[19] The ACANS coin was included in this group. Group 2, ΣΙΡΙΝΟ–Σ / ΠVΧΟ-ES, contains three staters all struck from the same pair of dies (O2/R5).[20] Group 3, ΣΙΡΙ–ΝΟΣ / ΠVΧΟ-ES, is known from a single coin (British Museum RPK, p.287.1) (O3/R6).[21] Horsnaes Group 4, ΣΙΡΙ–ΝΟΣ / ΠVΧ–OES, has 25 staters and is the largest group but there appears to be only one obverse die responsible which Horsnaes has identified as the same single die used in Group 3 (O3).[22] This die was used in conjunction with at least four reverse dies (R7-10). We are awaiting Horsnaes' final publication of her study. Nonetheless, her work has made clear that few dies were involved in the production of this coinage. She has suggested a chronological separation between the groups, but it is impossible to judge the length of the intervals.[23] They may have all been struck over a very brief period.

This coinage is often attributed to Siris in Lucania.[24] The inscription ΣΙΡΙΝΟΣ might be taken as an adjective for Siris in association with a word such as stater.[25] Zancani Montuoro pointed out that the usual adjective for Siris is *Sirites* (and *Siritis* for the territory) and

14 Horsnaes (2011): 205.

15 Perret (1941); Sternberg (1980); Libero Mangieri (1981).

16 Libero Mangieri (1981).

17 *HN Italy* 413, cat 1722-1725.

18 Horsnaes (2011): 198-200.

19 Horsnaes (2011): 199. We thank Dr Horsnaes for the information (*per. com* November 2015) that she now believes that a second obverse die is present.

20 Horsnaes (2011): 199.

21 Horsnaes (2011): 199. *BMC Greek Coins, Italy*, p. 283, no. 1.

22 Horsnaes (2011): 199.

23 Horsnaes (2011): 205.

24 *HN Italy* 143 provides an extensive bibliography.

25 The most detailed discussion, with a full bibliography, can be found in Fischer, Hansen, Nielsen and Ampolo (2004): 293-295. See also Horsnaes (2011): 201-2.

argued that *Sirinos* was a noun.[26] He concluded that the coinage belonged to a city called Sirinos which he associated with the Sirini who were Lucanians mentioned by Pliny the Elder (*NH* III 15, 97).[27] The ethnic *Sirinos* for the people of Siris, however, was known to Stephanus Byzantinus (*Ethnika s.v.* Siris).[28] The location of Siris is disputed. According to the *Barrington Atlas* (2000) Map 46, it is to be found at lat. 40.10, long. 16.40, some c.5km south of Herakleia Leukania. Fischer-Hansen, Nielsen and Ampolo place both settlements 'on the plateau of modern Policoro, a location suggested by the archaeological evidence and at present widely accepted.'[29] They concluded from the admittedly piecemeal evidence that the city originally founded as Siris was later renamed Herakleia.[30] Diodorus (12.36.4) dated the foundation of Herakleia to 433/2 BC, and claimed that it was established on the site of Siris (and that the former inhabitants were deported).[31]

The meagre references in the surviving ancient texts indicate that Siris was founded by Ionians fleeing the expansion of the Lydian empire, perhaps in the 7th century BC; most probably the settlers came from Kolophon.[32] Strabo (6.1.14) claimed that the native town was originally called Sirinos but the Greek conquerors renamed it Polieion. It was destroyed by a coalition of its powerful neighbours, Croton, Metapontum and Sybaris, but the date of the destruction is unknown. The authors of the entry 'Sirinos/Pyxoes' in *HN Italy* concluded that the destruction occurred in the first half of the 6th century BC and that the coinage was minted in Siris II 'a minor refoundation peopled by Achaeans after the expulsion of the descendants of the Colophon colonizers'.[33]

Pyxoes is usually identified with Pyxus, the later site of Roman Buxentum, and modern Policastro Bussentino.[34] This presents difficulties as it lies on the opposite coast of Italy to Siris, facing the Tyrrhenian Sea. It would seem to be too distant for a joint coinage with Siris II. More importantly, however, Pyxus was not founded till 471/70 BC (Strabo VI. 1. 1). Zancani Montuoro proposed that the town of Sirinos was to be found 30km from Policastro Bussentino in the valley of Lauria near Rivello.[35] Stephanus Byzantinus again complicates matters by noting two locations: Pyxis and Pyxous.[36] Peter Bicknell

26 Zancani Montuoro (1965).

27 Zancani Montuoro (1965).

28 Fischer, Hansen, Nielsen and Ampolo (2004): 293-294, who appear to support this claim.

29 Fischer, Hansen, Nielsen and Ampolo (2004): 294.

30 Fischer, Hansen, Nielsen and Ampolo (2004): 294.

31 Fischer, Hansen, Nielsen and Ampolo (2004): 259.

32 Fischer, Hansen, Nielsen and Ampolo (2004): 294.

33 *HN Italy* 143.

34 Fischer, Hansen, Nielsen and Ampolo (2004): 289-290.

35 Zancani Montuoro (1965).

36 Fischer, Hansen, Nielsen and Ampolo (2004): 289-290. Horsnaes (2011): 201.

also proposed that the Pyxoes on the coins referred to yet another settlement with this name that lay close to Siris II, near modern Policoro (ancient Herakleia).[37]

Here we wish to contribute some thoughts on the type. The type of the bull with reverted head is closely associated with Sybaris. Its use has led to the conclusion that the mints which produced these rare coinages with the inscriptions PAL/MOL, AMI and SO were all part of an empire or alliance ruled by Sybaris.[38] If the Sirinos/Pyxoes coins were struck by a people who identified themselves as being ‘of Siris’ (and inhabiting Siris II) it seems odd that they should use the type of a state which participated in the destruction of their formerly prosperous city. If it was refounded with people from Sybaris (or with a dominant element from Sybaris), it is perhaps surprising that the old name for the city was retained by the conquerors. Horsnaes has proposed that the Sirinos/Pyxoes coins and other related series with the bull type of Sybaris may have been indigenous issues produced with the intent of ‘promoting identity’.[39] This is certainly possible. But the choice of the types (and incuse style) employed by the leading Greek city in the region would have arguably worked to obscure a bid for identity (especially if not everyone could read Greek). Furthermore, naming two different communities on the one coin bearing the same (borrowed) image might have further obscured their separate identities. If we revisit the related coinages we see that there had been a careful attempt to distinguish the types. The PAL/MOL coins have a boar not a bull, and the few AMI coins add a prominent locust over the bull.[40] The very peculiar ‘SO’ coins (three drachms on an unknown weight standard) are difficult to understand, and may well be imitations of the Sirinos/Pyxoes coins as Seltman suggested. Is it possible that we are to read …ΟΣ, with the rest of the inscription missing?[41] It might be claimed that only the Sirinos/Pyxoes coins copy the Sybaris type without attempting to make some alteration or addition to the type. This could suggest a closer relationship with Sybaris itself.

The location of the mint and the identity of the craftsmen involved present further problems which stem from our inability to establish the identity of the issuing community. As Horsnaes has recognized, it is possible that these coins were produced ‘on demand’ in the mint at Sybaris itself.[42] She has also raised the interesting suggestions that they were produced by itinerant craftsmen, perhaps assisted by local smiths. The production of incuse coinage, however, was a rather complex affair and in the next section of this paper we will outline something of the techniques. We would like to

37 Bicknell (1967).

38 Rutter (1997): 24-27.

39 Horsnaes (2011): 205-6.

40 PAL/MOL: *HN Italy* 108, cat. 1105-1106; Horsnaes (2011): 203-4. AMI: *HN Italy* 124, cat. 1356-7; Horsnaes (2011): 203.

41 *HN Italy* 143-4, cat. 1728; Horsnaes (2011): 204-5. Seltman (1911).

42 Horsnaes (2011): 206.

suggest that coins produced in this fashion would have required skills that may not have been at the disposal of many metal workers.

The incuse coinage method

In the mid sixth century BC the city state of Sybaris (Fig. 3), perhaps quickly followed by Metapontum, began to mint a very distinct form of coin whereby the image struck in relief on the obverse is repeated on the reverse but as an incuse or intaglio – hence the name 'incuse coins'.[43] By 525 BC incuse coinage was being minted by four major Achaean colonies on the east coast of Italy facing the Ionian Sea (Sybaris, Metapontum, Croton and Caulonia) and by Poseidonia (itself a colony of Sybaris) on the western coast.[44] These mints all employed the Achaean weight standard. As noted above, the incuse technique was also used to produce a series of small coinages, of which the 'Sirinos/Pyxoes' series is the best represented.[45]

The techniques of producing incuse coinage are being studied in a long-running project at ACANS which has its origins in the publication of the Gale collection (*SNG Australia* I). There are no ancient accounts of minting coins. What we believe we know of minting techniques has been derived from studies of the surviving coins, from attempts to recreate the tools, and from inferences derived from later minting practice.[46] Most numismatists accept that it was the practice of archaic mints issuing precious metal coinages to create blanks by pouring molten metal on to a flat surface or into an open mould, so as to produce a roughly circular or 'bun'-shape that could at times be quite irregular.[47] The amount of molten metal was carefully predetermined. The weight of the blank was adjusted if it did not conform. The blank was held (with pinchers) between two engraved dies and the upper die struck with a hammer, so that the images of both dies were transferred in reverse to the newly created coin.[48] The earliest reverse punches produced a simple incuse depression without a type but with a linear pattern.[49] As the two dies were not mechanically fixed together but completely separate, the orientation of the obverse and reverse images in relation to each other varied on each coin. The standard modern description of Greek minting practices was provided by Hill in 1922.[50]

43 Gorini (1975). *HN Italy* 3, 130-131 (Metapontum), 144-145 (Sybaris).

44 *HN Italy* 22-32.

45 Taras minted a small issue of incuse coins 510 -500 BC: *HN Italy* 93. Rhegium and Zancle both produced very small issues of incuse drachms c.510 BC. *HN Italy* 187.

46 For Greek coinage see Hackens (1975). A general account can be found in Kraay (1976), 1-19. For studies based on reproducing minting instruments and processes see Sellwood (1963) and Faucher (2009). On the question of the earliest preserved Greek die see Sheedy (2014) with bibliography on the surviving Greek dies.

47 Hill (1922) and Faucher (2009).

48 Hackens (1975).

49 Hackens (1975).

50 Hill (1922). Now see Faucher (2009).

The earliest coins of South Italy, the incuse issues, were produced using different methods from those outlined above.[51] The most obvious difference lies in the fact that the reverse type is the same as that on the obverse but is rendered as a 'negative' image sunk into the flan. But we should note that it is not a mirror image; the reverse type is nearly always a simpler version, lacking much of the detail used to mark out minor features. Naster has pointed out that the reverse in fact often carries elements that are in relief, notably the legend.[52] The standard account of this method was provided by Gorini in 1975.[53] Here we outline some of the salient points. In the first phase of production (c.540-510 BC) the flans are very thin (2-3mm) and broad (26 – 29mm in diameter). From c.510 BC the flan contracts to around 24mm in diameter and becomes of 'medium' thickness. After c.470 BC those mints still using the incuse technique adopt a thicker flan averaging around 20mm or less in diameter. A distinct feature of these flans is their regularity. Unlike the coins of the mainland they are evenly circular. A proper reverse type is in use from the very beginning of this coinage and not a simple reverse incuse square. The types are centred with great precision on both sides of the coin. The types are very closely aligned so that the obverse type almost appears to have been created when the reverse type was pushed in. Hill seems to have been the first to observe that a crucial feature of this technique of coin manufacture was the use of fixed or hinged dies.[54]

Scientific studies of the Sirinos/Pyxoes stater, ACANS inv. 07GS729

The scientific examination of the incuse coins of South Italy began with a study by C.F. Elam in 1931. [55] Within her sample of fifteen Greek coins were two archaic incuse staters from South Italy (Sybaris, Kroton).[56] In addition to the irregular boundaries of the grain structures within the metal of the stater from Sybaris, there were also "a number of blow-holes and inclusions particularly noticeable at the periphery of the coin, where they were not closed by the pressure of striking".[57] Elam observed that the dendritic structure (the crystal growth) was not distorted in this region of the coin (the edge), which also indicates the absence of homogenising heat treatments. In short, Elam concluded that the flan of the Sybaris stater had not been subjected to working prior to minting.

In 2003, as part of a new investigation of the incuse coinage method, the flans of three incuse staters from Metapontum and Kroton were restudied by P. Munroe (UNSW)

51 Gorini (1975); Kraay (1976): 163-4; Rutter (1997) 17-21.

52 Naster 1948.

53 Gorini (1975).

54 Hill (1922): 16. Noe concluded that the incuse coins of Metapontum had been struck with 'a pair of interlocking dies'. Noe/Johnston (1984): 3.

55 Elam (1931): 62.

56 Sybaris stater: Elam (1931): 62, No. 8, figs. 10-12.

57 Elam (1931): 62.

using a JEOL 840 scanning electron microscope.

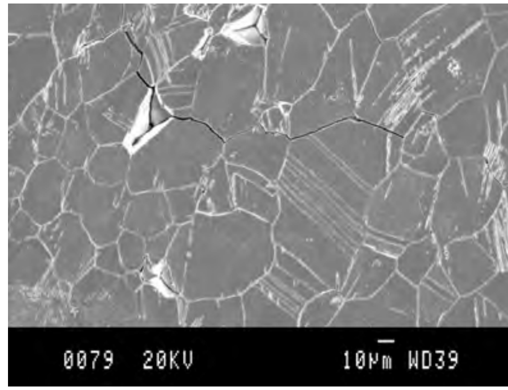


Figure 4. SEM photo of recrystallized, equiaxed grains with annealing twins in metal of incuse stater of Metapontum (Private Coll).

Munroe found that (Fig. 4) the metal of all three contained the same recrystallized, equiaxed grains (though the grains were different in size from coin to coin). He also saw that many of the grains displayed annealing twins. Annealing twins are created through the recrystallization of worked and annealed metals and are distinguished by the appearance of pairs of parallel lines across the metal grain during the process of crystal growth. These bands are characteristic in face centred cubic metals, such as silver, that have been deformed at room temperature and then annealed.[58] Munroe was thus able to confirm the conclusions of an unpublished 1980 study by Williams and Lock that these same coins showed evidence of hammering and annealing.[59] These conclusions were also reached by *Giovannelli et al.* in a study of the compositional, crystallographic and microstructural properties of five further silver incuse coins from Metapontum and Caulonia.[60] But there had still not been a modern study of the incuse staters of Sybaris that would test Elam's claims.

The Gale Sirinos/Pyxoes coin was examined by Munroe in regard to the shape of the edges. Here we hoped to learn something about the technique by which the flan had been created before minting. The photos (Fig. 5a-c) graphically illustrate that the edges were placed under intense pressure with the striking of the upper die. These rounded edges suggest the flan was prepared in a mould.

58 La Niece (1998).

59 Williams (1983). We thank Rick Williams for making the three incuse coins available for study.

60 Giovannelli (2005).

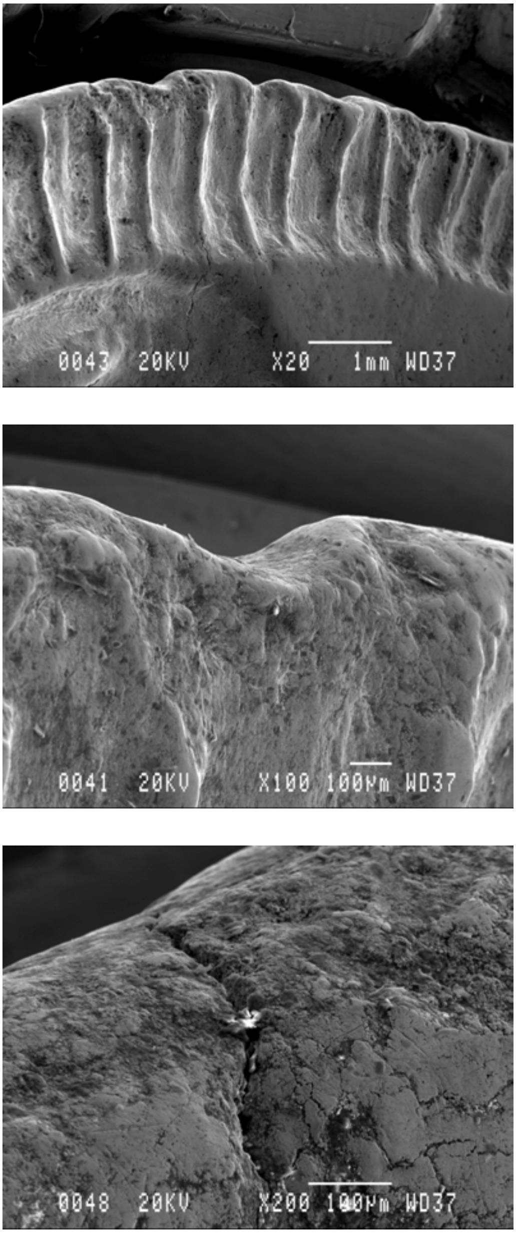


Figure 5a-c. SEM photos of the edge of Sirinos/Pyxis stater, ACANS inv. 07GS729.

In 2014 the Australian Centre for Ancient Numismatic Studies (ACANS) and the Australian Nuclear Science and Technology Organization (ANSTO) undertook a joint project to explore the fabric of the incuse coinage using a combination of neutron diffraction, neutron texture analysis and neutron tomography. Among the coins studied was the ACANS Sirinos/Pyxis stater. Here we outline the methods of analysis and present some preliminary results.

Neutron imaging can be described as 'the direct production of images by transmitting a beam of neutrons through an object onto a detector… Although this may still seem to be "direct" imaging, in fact the image is "re-constructed" by software in a computer and sophisticated mathematical processes can be used to enhance particular features or generate virtual slices of the imaged object.'[61] Neutron radiography and tomography are based on measuring the degree to which an object attenuates the probing neutron beam and this depends on the elemental composition and density within its volume. The result of the interaction between the probe and the sample is a shadow image of the object yielding information on its inner structure and composition. In particular, neutron tomography involves the collection of radiographic projections while the object is rotated around its vertical axis over a range of (at least) 180°. These projections

61 Anderson (2006): vi.

are then used to create an image stack representing a virtual three-dimensional model of the object.[62]

Figure 6a. 3D model of the Sirinos/Pyxis stater, ACANS inv. 07GS729; 6b. orthogonal cross section showing pores; 6c. orthogonal cross section showing crack.

Fig. 6a shows each side of the coin as a 3D model. Tomography has highlighted two major cracks (one running diagonally from above the head of the bull joins a second crack passing across the coin from side to side) which are more visible on the reverse. They are also apparent in Fig. 6c (a cross section) and in Fig. 7 (an image taken from the obverse). These cracks developed on the surface and spread from 0.10mm up to 1.20mm into the bulk of the flan. There is no sign that the coin has been repaired. It is hardly

62 Hounsfield (1980).

likely that the coin was released from the mint if the cracks were visible. Were they created when the coin was minted (but not evident on the surface) or did they result from later impact or stresses when the coin was in circulation?

Figure 7. Detail of Sirinos/Pyxis stater, ACANS inv. 07GS729 showing break running from upper left to lower right.

We would like to propose that they were probably created when this coin was struck but that they were not immediately visible. Figs. 6b and 6c show orthogonal cross sections of the coin which vividly demonstrate the thinness of the metal and how closely the obverse relief and reverse incuse types are aligned. They also demonstrate that the design of these dies placed considerable pressure on the flan when it was struck. A few pores, which were detected in Fig. 6b, can be seen to lie close to the surface of the flan on the reverse. At the moment we are still investigating the reasons for their presence. Nonetheless, despite their presence we are inclined to believe on the evidence of the following poles figures that the metal blank was subjected to working prior to being struck.

Neutron diffraction studies can provide qualitative and quantitative data about 1) phase composition; 2) crystal and magnetic structures of each constituent phase; 3) microstrains and macro (residual) strains; and 4) crystallographic texture.[63] In this paper, however, we will focus only on the crystallographic texture; our investigation of other aspects of the data is still ongoing within the context of the broader study of incuse coinage. When metals are worked (rolled or hammered and subsequently annealed) these actions cause crystallographic preferred orientations in the alignment of the

63 Kockelmann (2006): 175; Liang (2009).

atomic lattice planes of metal grains.[64] The texture of a polycrystalline material, such as metal, is defined as the orientation distribution function (ODF) of its crystallites.[65] Pole figures are used for the graphical representation of the texture in a material for particular crystallographic lattice planes (hkl). A pole figure is usually plotted as a 2D stereographic projection of the density distribution for spheres of direction in the sample coordinate system. The circular shape of the pole figure is unrelated to the circular shape of coins. Our measurements were taken from the entire coin (and not from select regions).[66] Coloured bands indicate the intensity of the diffraction which relates to the proportion of crystallites oriented in a specific direction.[67] Higher intensities (red) indicate the most preferred alignment of (hkl) planes in certain directions while low intensity (blue) shows the least preferred alignment of (hkl) planes.

The tests were carried out with the use of ANSTO's neutron residual stress diffractometer.[68] It needs to be emphasized at this point that our study is still ongoing. Here we present observations which arise from a comparison of coins produced by different techniques. A graphical representation of the orientations of the crystallites (texture pattern) through pole figures of the (111) crystal planes of silver for a stater from Cycladic Naxos which was minted at the same time as the South Italian incuse coins is shown in Fig. 8: sample 1. We can compare this to the pole figure for an English silver penny of Edward I (1272-1307) (Fig. 8: sample 2) which was made by beating a sheet of silver to about 0.5mm and then cutting out a circular coin blank of the appropriate diameter before striking the coin between two dies.[69] The metal of the penny was strengthened through processes, such as hammering, which cause dislocation, nucleation and propagation within the crystal structure of the metal (dislocation is here defined as a crystalline defect or irregularity). As noted above, we still need to learn a good deal more about the manufacture of ancient coins (in contrast to mediaeval minting). The flan of the Naxian stater was evidently not worked before the coin was minted (and this observation is supported by the irregular shape of the coin and its 'lumpy' surface).

The texture data and pole figure for the Gale Sirinos/Pyxoes stater (Fig. 8: sample 3) may be compared with that obtained from other incuse coins. The main features of the data from two coins of Sybaris that we have studied (ACANS 07GS730-732; Fig. 8: sample 4-5) are very similar, and this is evident from the pole figures. In turn they are

64 Siano (2006).

65 Bunge (1989): 265.

66 The pole figures were created by illuminating the entire coin. The coin is then rotated in 2 directions as diffractions patterns are taken. These diffraction patterns were taken at angles α and β. We should repeat that the pole figure is a projection onto a plane. See Reimers (2008).

67 Liang (2009).

68 Kirstein (2009).

69 Sellwood 1962.

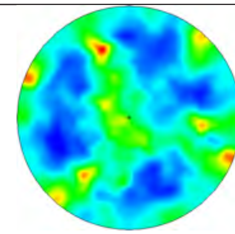
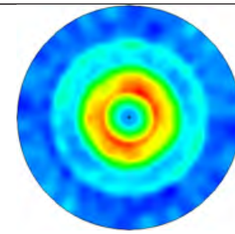
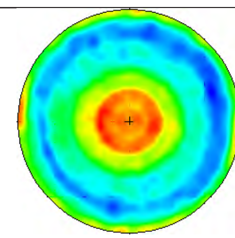
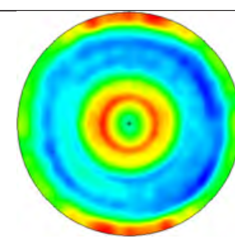
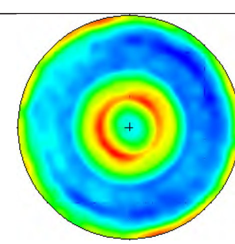
Sample information	Sample view	Ag(111) pole figure
1. Naxos c. 540/530-520/515 BC, ACANS 07A01. Non-incuse stater. Ø 19.5 mm; th ~ 3.3 mm; M = 10.25 g		 min: 0.37 max: 2.81
2. Edward I (1272-1307). Private collection. Silver penny Ø 18 mm; th ~ 0.5 mm; M = 1.37g.		 min: 0.50 max: 1.98
3. Sirinos/Pyxoes c. 540-510 BC, ACANS 729. Incuse stater. Ø 29.6 mm; th ~ 1.0mm; M = 6.74 g		 min: 0.44 max: 1.62
4. Sybaris c. 550-510 BC, ACANS 730. Incuse stater. Ø 29.6 mm; th ~ 1.0mm; M = 7.73 g		 min: 0.54 max: 1.60
5. Sybaris c. 550-510 BC, ACANS 731. Incuse stater. Ø 29.6 mm; th ~ 1.0mm; M = 7.00 g		 min: 0.45 max: 1.81

Figure 8. Pole figures from neutron diffraction studies.

comparable with the pole figure from the English penny (Fig. 8: sample 2). The pole figure for the Gale Sirinos/Pyxoes stater is generally similar to those of the Sybaris coins and the English penny and may be contrasted with the Naxian stater. The pole figure for the Sirinos/Pyxoes stater, however, does show an interesting difference: the broad maximum of intensity in the centre of the (111) pole figure is an indication that the flan was worked at a higher temperature, and suggests 'hot forging' rather than 'cold hammering'.

These analyses of the Gale Sirinos/Pyxoes stater are presented within the context of our current ongoing exploration of the techniques of manufacturing South Italian incuse coinage. They demonstrate a clear adherence to the same minting practices being followed by the mints at Sybaris, Metapontum, Croton, Caulonia and Poseidonia. The technique was perhaps not easily copied. It arguably required skilled metalworkers who were familiar with the pioneering practices created at Sybaris for the making of coins. It also required a willingness to take on coinage – which at this time was a novel invention and something that was still largely unknown to many Greek and non-Greek communities. We still have a lot more to learn about the Sirinos/Pyxoes coinage. But we can now see that it was produced by a mint with the same expertise as that in Sybaris, the source of the Sirinos/Pyxoes coin type.

Abbreviations

HN Italy = N. K. Rutter (ed.) *Historia Numorum Italy* (London 2001).

SNG Australia I= *Sylloge Nummorum Graecorum, Australia I. The Gale Collection of South Italian Coins* (Sydney, 2008).

Bibliography

Anderson (2008) = I. S., Anderson, R. L. McGreevy & H. Z. Bilheux, *Neutron imaging and applications: a reference for the imaging community* (New York, 2008).

Bicknell (1967) = P. J. Bicknell, 'Aminaia', *Klearchus* 35-36 (1967), 131-143.

Bunge (1989) = H. J. Bunge, 'Advantages of Neutron Diffraction in Texture Analysis', *Textures and Microstructures* 10 (1989), 265-307.

Elam (1931) = C. F. Elam, 'An Investigation of the Microstructures of fifteen silver Greek coins (500–300 B.C.) and Some Forgeries', *Journal of the Institute of Metals* 45 (1931), 57–69.

Faucher (2009) = T. Faucher, F. Téreygeol, L. Brousseau and A, Arles, 'À la recherche des ateliers monétaires grecs: l›apport de l›expérimentation'. *RN* 165 (2009), 43-80.

Fischer, Hansen, Nielsen and Ampolo (2004) = T.Fischer, M. H. Hansen, T.H. Nielsen and C. Ampolo, Italia and Kampania, in M.H. Hansen and T.H. Nielsen (eds.), *An Inventory of Archaic and Classical Poleis* (Oxford, 2004), 249-320.

Gale (1996) = W. L. Gale, 'The First Italian Coinage', *Celator* 10 (1996), 34.

Giovannelli (2005) = G. Giovannelli, S. Natali, B. Bozzini, and A. Siciliano, G. Sarcinelli and R. Vitale, 'Microstructural Characterization of Early Western Greek Incuse Coins', *Archaeometry* 47 (2005), 817-833.

Gorini (1975) = G. Gorini, *La monetazione incusa della Magna Grecia*. (Milan, 1975).

Hackens (1975) = T. Hackens, 'Terminologie et techniques de fabrication', in T. Hackens (ed), *Numismatique antique. problèmes et méthodes* (Nancy-Louvain 1975), 3-16

Hill (1922) = G. F. Hill, 'Ancient methods of coining', *NC* 1922, 1-42.

Horsnaes (2011) = H. W. Horsnaes, 'Coinages of Indigenous Communities in Archaic South Italy – The Mint as a Means of Promoting Identity?' in M. Gleba and H. W. Horsnaes (eds.), *Communicating Identity in Italic Iron Age Communities* (Oxford, 2011), 197-209.

Hounsfield (1980) = G. N. Hounsfield, 'Computed Medical Imaging'. Science 210 (4465), 22–28.

Kirstein (2009) = O. Kirstein, V. Luzin and U. Garbe, 'The Strain-Scanning Diffractometer Kowari', *Neutron News* 20, no. 4, 34-36.

Kockelmann (2006) = W. Kockelmann, S. Siano, L. Bartoli, D. Visser, P. Hallebeek, R. Traum, R. Linke, M. Schreiner and A. Kirfel, 'Applications of TOF Neutron Diffraction in Archaeometry', *Applied Physics A* 83 2 (2006), 175-182.

Kraay (1976) = C.M. Kraay, *Archaic and Classical Greek Coinage* (London, 1976).

La Neice (1998) = S. La Niece, 'Metallography in Numismatics' in A. Oddy and M. Cowell (eds), *Metallurgy in Numismatics* 4, *Royal Numismatic Society Special Publications*, 114-133.

Liang (2009) = L. Liang, R. Rinaldi and H. Schober (ed.s) 2009: *Neutron Applications in Earth, Energy and Environmental Sciences.* New York.

Libero-Mangieri (1981) = G. Libero Mangieri, 'Sibari, Sirino e Pissunte.' *Rivista Italiana di Numismatica* 83 (1981), 3-26.

Perret (1941) = J. Perret, *Siris. Recherches critiques sur l'histoire de la Siritide avant 433/2* (Paris, 1941).

Reimers 2008 = W. Reimers, A. R. Pyzalla, A. K.Schreyer and H. Clemens, Neutrons and Synchrotron Radiation in Engineering Materials Science: From Fundamentals to Material and Component Characterization. Published Online: 14 March 2008.

Rutter (1997) = N. K. Rutter, *The Greek Coinages of Southern Italy and Sicily*. (London, 1997).

Sellwood (1962) = D. Sellwood, 'Medieval minting techniques.', *British Numismatic Journal* 31 (1962), 57-65.

Sellwood (1963) = D. Sellwood, "Some experiments in Greek minting technique." *NC* (7) 3 (1963), 217-231.

Seltman (1911) = E. J. Seltman, A propos d'une monnaie récemment attribuée aux Sontini (Italia méridionale), Revue Numismatique 15 (1911), 161-3.

Sheedy (2014) = K. A. Sheedy, 'The Sounion 'Wappenmünzen die' Revisited', *Nomismatika Khronika* 32 (2014), 21-26.

Siano (2006) = S.Siano, L. Bartolio, J. R. Santisteban, W. Kockelmann, M. R. Daymond, M. Miccio & G. De Marinis.' 'Non-destructive Investigation of Bronze Artifacts From The Marches National Museum of Archaeology Using Neutron Diffraction', Archaeometry 48 1 (2006), 77-96.

Spagnoli (2009) = E. Spagnoli, 'La moneta di Sibari: : struttura e metrologia', *International Numismatic Congress Proceedings of the XIVth International Numismatic Congress*, vol.1, (2009), 405-41.

Sternberg (1980) = H. R. Sternberg, 'Die Silberprägung von Siris und Pyxis.', *AttiTaranto* 20 (Naples, 1980), 123-140.

Williams (1983) = R. J. Williams, *The Incuse Staters of Kroton*. Ph.d thesis. Monash University.

Zancani Montuoro (1965) = P. Zancani Montuoro, 'Pixunte' in *Enciclopedia dell'Arte Antica* VI, 222.

Authors

Dr Ulf Garbe, Instrument Scientist, Bragg Institute, Australian Nuclear Science and Technology Organization (ANSTO) and president of the International Society for Neutron Radiation. Ulf was responsible for construction and operation of the new neutron imaging beam line DINGO. He developed the non-destructive local texture measurement method with neutron radiation and ANSTO and FRM II.

Dr Vladimir Luzin, Instrument Scientist, Bragg Institute, Australian Nuclear Science and Technology Organization (ANSTO). He is co-responsible for the KOWARI Residual-Stress Diffractometer. His fields of expertise include materials science, specifically stress and texture analysis by means of neutron, X-ray diffraction, synchrotron radiation, and electron back scattering diffraction (EBSD) in connection with material's (mechanical) properties.

Professor Paul Munroe is currently Head of School and Professor, School of Materials Science & Engineering, UNSW. His fields of research are Metals and Alloy Materials, Functional Materials, Carbon Sequestration Science.

Scott Olsen, Scientific Operations Group Leader and Quality Co-Ordinator for the Bragg Institute and the neutron-beam program at OPAL, Australian Nuclear Science and Technology Organization (ANSTO). He is responsible for all the maintenance and upgrade of existing neutron beam instruments. Scott has an interest in the technology of ancient coin production.

Dr Floriana Salvemini, Instrument Scientist, Bragg Institute, Australian Nuclear Science and Technology Organization (ANSTO). Her expertise is in the area of neutron imaging and diffraction for the investigation of Cultural Heritage, physical metallurgy and archaeometallurgy. In addition, she has a strong interest in the application of non-invasive techniques for the study of works of art.

Associate Professor Kenneth Sheedy is the Director of the Australian Centre for Ancient Numismatic Studies, Macquarie University. His current research interests are the technology for manufacturing ancient coins, the incuse coinage of South Italy, the archaic coinage of Athens and the archaeology and coinage of the Cyclades.