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Coin Minting Techniques in Ptolemaic Egypt: Observe, Analyze, Recreate

ABSTRACT: After Ptolemy Soter took possession of Egypt, he soon installed a closed currency system, at that scale, a novelty in ancient coinage. With regard to the three metals struck in the mint of Alexandria – the only mint in the entire country for almost 300 years – innovations in the manner of minting occurred when the kings were faced with specific needs. Millions of coins were struck. These coins appeared in a succession of series, sometimes struck continuously but not always. The different metals that were used filled different demands and needs. The Greek rulers adapted themselves to the country and to the economic and politic situation, always showing a great sense of resilience with regard to the problems they faced.

We can understand these issues in a new manner and refresh our view of this peculiar coinage by way of recent research on these coins' metallic content but also by way of archaeological experiments conducted on the minting process itself. How can the minting methods help us to understand the distinction between each series, and how can they help us to understand how the workers at the mints struggled with new challenges brought by the head of the mint? How can Egypt help us understand from a broader perspective the minting of coins in the Greek world?

KEY WORDS: Egypt, Ptolemies, metallurgy, bronze coinage, experimental archaeology

ABSTRAKT: *Techniki bicia monet w ptolemejskim Egipcie. Obserwacja, analiza, nowe spojrzenie*

Wkrótce po objęciu w posiadanie Egiptu Ptolemeusz I Soter wprowadził zamknięty system monetarny, co w takiej skali stanowiło *novum* w historii pieniądza starożytnego. Na skutek szczególnych wyzwań, z jakimi musieli się zmierzyć ptolemejscy władcy, w Aleksandrii – jedynej mennicy działającej w kraju przez prawie 300 lat – wprowadzono innowacje w zakresie sposobu produkcji monet bitych

z trzech kruszców. Wyemitowano je w milionach egzemplarzy, w następujących po sobie seriach; czasami emisje miały charakter ciągły. Z powodu różnych wymagań i potrzeb używano odmiennych kruszców. Grecy władcy Egiptu przystosowali się do specyfiki kraju oraz sytuacji ekonomicznej i politycznej, zawsze okazując elastyczność w obliczu problemów, z jakimi musieli się mierzyć.

Dzięki ostatnim badaniom składu stopu, z jakiego bito monety, oraz archeologicznym eksperymentom dotyczącym samego procesu ich produkcji możemy odświeżyć nasze spojrzenie na to mennictwo i zrozumieć je na nowo. W jaki sposób techniki produkcji monet mogą nam pomóc w zrozumieniu różnic między poszczególnymi seriami monetarnymi i jak pracownicy mennic radzili sobie z nowymi wyzwaniami stawianymi przez zarządcę mennicy? Jak przypadek Egiptu może pomóc zrozumieć w szerszej perspektywie produkcję monet w świecie starożytnej Grecji?

SŁOWA KLUCZOWE: Egipt, Ptolemeusze, metalurgia, monety brązowe, archeologia eksperymentalna

WHAT IS THE DATA?

The data on Greek coin minting in general is very scarce.¹ Archaeological excavations have only unearthed very sparse information on the minting of coins during the Greek period, and very few mints have been properly excavated in recent years. Some examples are more well preserved than others, but mints were usually localized after the finding of blanks or, more exceptionally, of coin molds.² The best example may be the excavation of the ancient mint of Marseilles, but the results of the dig have not yet been published.³ Of course, we know of a small number of sites where Roman coins were minted, but it seems hazardous to compare the quasi industrial scale of the minting of Roman coinage with the usual artisanship of Greek minting. Greek and Roman coins differ largely in their characteristics, whether it is the form of the flan, the form of the dies or even the general elemental features. New projects on the minting of Roman coins exist, and they will shed new light on these specific features.⁴ In later periods, an even greater difference exists with regard to the minting of coins; thus, greek coins are hard to compare to those struck in more recent periods.⁵ With regards to Egypt, no information is known on the great mint of Alexandria. The only archaeological evidence of workshops comes

¹ PICARD 2016.

² See: CACCAMO-CALTABIANO 2001; for a conspectus of coin mold finds, see: ARIEL 2012.

³ CHEVILLON 2010; IDEM 2011.

⁴ See for instance N. George's PhD dissertation at the University of Liverpool. Supervised by M. Ponting, the work is titled: *The production of coin blanks and Roman silver coinage from AD 193–271*.

⁵ For information on medieval minting techniques, including experimental archaeology and elemental analyses, see: ARLES 2009; ARLES and TEYREGEOL 2011.

from Upper Egypt, where a local workshop which struck imitative bronze coins in the 2nd century BC has recently been unearthed,⁶ and from some discoveries of the Ptolemaic period in Paphos (Cyprus).⁷ Archaeology has not unearthed any dies that were used in the Ptolemaic period in the striking of coins. Even if some of these tools have survived, the number is so low that it is hard to imagine that the sample can be characteristic of all the Greek mints. Moreover, most of the dies used to strike ancient coins are modern counterfeits, which does not aid in our understanding.⁸ In addition, iconography on coin minting is nonexistent for the Greek period.⁹ With what we know about the Roman period, caution needs to be exercised, even if the few coins or coin-like objects that we have are of particular interest.¹⁰

STUDYING COINS AS AN INDICATOR OF THE PROCESS

Considering the poor evidence available to us by way of archaeology and the dearth of texts concerning the way ancient mints were organized, our best chance is to study the coins themselves. Even if most of them do not give any indication as to where they were produced and it is unclear what series a particular coin belongs to, and even if most of them are badly or hastily produced, still, they offer a glance at the way ancient moneyers worked. In addition, elemental composition analysis methods have proved to be useful in understanding how metals were used to produce the coins, whether they are made of gold, silver, or bronze. Finally, in cases in which coins can be cut, metallographic studies give some insights into the process of minting: from how the blank was made to how the coin was struck. Therefore, if one is going to study the coins themselves to make conclusions about the mints where they were produced, then all available methods should be used.

Forms and preparation

The Ptolemies struck coins in three metals: gold, silver, and bronze. Even though gold coins were not minted anymore after the latter half of the 2nd century BC, silver and bronze coins were issued by the mint of Alexandria from the first years of the dynasty until the death of Cleopatra VII. Whereas gold and silver coins show similar features in terms of their form and the minting process, bronze coins

⁶ FAUCHER et AL 2012.

⁷ DASZEWSKI 1972; NICOLAOU 1972; NICOLAOU 1990.

⁸ W. Malkmus (1989–1993 = 2008) provided a list of all the ancient dies known at his time, classifying them on a spectrum from authentic dies to modern forgeries. Numerous discoveries of dies in Celtic environments in recent years may nevertheless help us to understand the different characteristics of these tools. See, most recently: HOLLARD 2014.

⁹ J. Chamay (2002) argued that a coin striking operation can be seen on a red-figure Attic cup, but it is more likely that the image represents a simple metal worker, with no link to numismatics; see: FAUCHER 2013: 260.

¹⁰ See: WOYTEK 2013.

are different. As a result, these two types of coinage should be studied separately. This will help us understand how their external (or visible) features can be used to show how they were produced.

1. *Gold and silver*

Not much is known about the process used to manufacture blanks for precious metal coins in the ancient Greek world. These lumps of metal, which were used to make coins and which were usually round in shape, do not usually betray how they were produced. One thing that we need to understand is how this piece of metal was modeled. A certain amount of metal, of regular weight or volume, was melted down from a solid state (from a chunk, a ball, or from some other form of small size) into a flat and round shape. One would expect this transformation to leave some traces on the outside of the coin (traces of a mold of some sort or that of a funnel, depending on the technique used) but for most of these coins, no traces appear and it seems that the vast majority of the blanks were not modified after they were melted. Some scholars have seen traces of flattened metal either on the flan or, more often, on the edge of some silver coins (Fig. 1).¹¹ These traces have led them to propose a two-piece mold that would have produced a piece of metal in the form of a ball. The junction between the two parts of the mold would have had a linear excrescence that would have been flattened in the minting process. However, because it would have been a difficult and time-consuming process to flatten these balls – not to mention the fact that there are no traces that this operation was actually used – it is unlikely that this technique was used in the past. These excrescences also appear on some late Ptolemaic silver coins. To the best of my knowledge, no reasonable explanation for this phenomenon has yet been proposed. Unfortunately, the present paper does not provide any new information in this respect, but more attention needs to be paid to these traces in the future, because, in my opinion, they provide the key to understand the manner in which a large group of precious metal coins were manufactured in ancient Greece.

2. *Copper alloys*

Things are easier when it comes to copper alloys. Different discoveries, in different parts of the Greek world (but mostly in the East), of molds, in stone or in clay, but also of rods of metal, provide us with an important source of information for understanding the manner in which blanks were created. With regard to this matter, the Ptolemaic kingdom is a good source of information. Besides the molds

¹¹ NASTER 1958. For earlier sources of information about this phenomenon, see: HILL 1922: 6–7; VILLENOSY 1900: 60.

found in Paphos, blanks have been found in French excavations in Alexandria; a chapelet of blanks has also been found in the diggings inside the Karnak temple in Luxor. A closer look at the copper alloy coins struck by the Ptolemies show that five different techniques were used during the period. The coins struck at the beginning of the period [series 01 and the beginning of series 02 (c. 315 – c. 285)] are concave and have edges with a rounded shape. At the same time, some bronze coins seem to have been produced in the same way that precious metal coins were produced, because they show the same traces on their edges (Fig. 2). The second part of series 02 (c. 285–261) shows a shift towards bigger coins, ones that are also flatter, with beveled edges, a sign indicating that a two-piece mold was used. The majority of the coins struck after series 03 (except those from series 10) bear two small cavities, one on each side, at the center of the coin. Besides having beveled edges, the vast majority of these coins show traces of runners that have been cut and filed on opposite sides on the edges. During the second part of the Ptolemaic period (after series 6, at the beginning of the second century), some coins show signs of low quality, much like coins produced by the third technique but of even lower quality. Sometimes, visible chunks of lead can be detected inside the coin, but cracked edges and smoother surfaces are also visible. It is very likely that these coins are counterfeits – manufactured in clay molds using the lost-wax technique – of coins then in circulation.

– *Blanks from rod bars*

The first technique that was used to produce Ptolemaic coin blanks is also the oldest process that was used to create copper alloy blanks in the Greek world. A long bar of bronze, with a diameter slightly smaller than the size of the coin to be produced, was cut in small discs with tongues and a chisel. Some blanks which came from rods have been found during excavation of the “Radio” site in Alexandria.¹² Other examples have been found around the Mediterranean Sea: in Thasos, where different elements from each step in the process have been unearthed in the city,¹³ but also in Pella and Argos.¹⁴ The technique is simple. By cutting bars of metal, moneyers produced small round discs, which they then flattened by hammering. This technique usually produces rounded flans which are rather thick and which – due to the different phases of annealing and hammering (see below) – are usually quite dark in color.

¹² PICARD and FAUCHER 2012: 24.

¹³ PICARD 2016; FAUCHER 2013: 184.

¹⁴ HACKENS and KONSOLAKI 1980.

– *Blanks from single cavity molds*

With the launch of series 02 at the beginning of the 3rd century BC, the mint of Alexandria started to strike larger coins like diobols or triobols, ones that weighed 20 g or more. Subsequently, but not immediately, perhaps because it proved too difficult to handle the production of large numbers of blanks using the first technique, the coins started to look different. The surface was flatter than on the coins preceding them, and the edges were beveled, making the surface of the obverse on these coins slightly smaller than that of the reverse. With regard to the coins of this period, the edges do not show any signs of runners or traces of scratches. These edges must have resulted from the metal being poured into a mold carved out of individual cavities with beveled edges.

– *Blanks from molds with multiple cavities*

The far-reaching fiscal and monetary reforms that were enacted by Ptolemy II were accompanied by the introduction of a new coinage introduced in c. 261 (series 03). While this coinage maintained the same repertoire of images, it now contained coins that weighed up to 100 g. The technique used to produce the blanks for this coinage is the same technique that was used with the previous set of coins, with two exceptions. First, these coins have runners; at the very least, there are indications that the runners were trimmed off. Secondly, these coins have two small cavities located roughly at the center of each side of the coin. These characteristics correspond to molds that have been found in Paphos and in other places around the Mediterranean, most notably in Judea. The metal was poured into a limestone mold (or more likely – with regards to Egypt – into a mold made from some other material) and then flooded into the runners from cavity to cavity, filling up the mold with melted metal. The blanks were then cut off from their chapelet before the runners were trimmed off and carefully filed down.

– *Molded coins*

Early on in the Ptolemaic period (at the beginning of the 3rd century),¹⁵ people started to cast counterfeit coins. They used the lost-wax technique to mold official coins, ones struck with a die. The coins produced in this way are usually of poorer quality; the surface is smoother and the edges sometimes show traces of casting. If these imitations were sporadic at the beginning of the period, by the 1st century BC, they represent the majority of the coins in circulation. The fact that large quantities of these coins have been found in excavations indicates that the poor quality of these coins did not prevent the Egyptians from using them. Despite the fact that millions

¹⁵ PICARD and FAUCHER 2012: 27.

of coins were produced in this way, the only evidence as to how these coins were produced is a mold in clay that has been found in the Egyptian Delta, in Tanis.¹⁶ The phenomenon of cast imitations was largely underestimated in the past due to the fact that, first of all, museums were not choosing (or considering) these coins for their collection because of their poor quality, and secondly, their poor state of preservation led archaeologists to avoid cleaning them or even registering them to begin with.

ELEMENTAL COMPOSITION

Another way to look at a coin is to analyze its metallic content.¹⁷ This approach offers a way of understanding how the moneyers used the available resources and why they used certain amounts of metal in respect to others. It is the mint that decided whether a certain alloy would be used; this decision may have been affected by the opinion of the head of the mint, an artisan specialized in metalworking. While the value of a coin predominantly consisted in the amount of the coin's main metal (gold or silver), things were different for copper alloys – known as fiduciary coins – wherein the value of each metal did not influence the face value of the coin. And yet, the amount of each metal used to make a coin was very important indeed for the moneyers, for the metal content affected the ductility of the blank and its hardness. The metal content influenced the ease with which the coin was struck; it also affected the amount of stress that the dies would experience during striking and, ultimately, their lifetime. In addition, the metallic composition affected the melting temperature of the metal, which thus had an influence on the amount of fuel that would need to be used. For example, while copper melts at 1083° C, a copper alloy consisting of 20% tin (which results in bronze) has a melting point of c. 900° C.¹⁸

Therefore, information about the coin's metallic composition is absolutely essential in order to understand the minting process. Ancient Egypt represents an ideal case with regards to this question since coins from most of the series (for gold, silver, and bronze) have been analyzed for the Persian and Ptolemaic periods¹⁹ (billon coins of the Roman period have also been studied extensively²⁰).

Analyses of Ptolemaic gold coins have shown that the authorities never really altered their content, most of them being close to 100% gold.²¹ From a metallurgical

¹⁶ JUNGFLAISCH and SCHWARTZ 1955: 214–215.

¹⁷ Here is not the place to describe the relevance of each method of analysis. For recent sources providing more information about these methods of analysis, see: BLET-LEMARQUAND et AL 2014; BLET-LEMARQUAND et AL 2005; and PONTING 2012.

¹⁸ PICON 1966, as cited in: BLET LEMARQUAND 2013.

¹⁹ A synthesis of recent results and bibliography is to be published in: OLIVIER and FAUCHER, forthcoming.

²⁰ See Chapter 20, "Egypt", in: BUTCHER and PONTING 2014: 604–664.

²¹ DUYRAT and OLIVIER 2010.

point of view, this is surprising since pure gold is more susceptible to wear than gold alloyed with some amount of silver or copper. The coins struck before the Ptolemies for example are about 93% gold and 6–7% silver.²² Other artifacts from this period – jewels for example – are also usually made of a lower percentage of gold. Here, gold was alloyed with silver or copper not so much to reduce the cost of production as to provide a metal easy to work with. In any case, these analyses do not provide us with any evidence as to how gold coins were minted.

The silver content of the coins minted during the Ptolemaic period can provide us with interesting information. J. Olivier provides an extensive set of analyses of these coins in his PhD dissertation.²³ During the second part of the Ptolemaic dynasty, the metallic composition is clearly linked to the output of the mint. More than the average content of the silver in the coins, which slightly decreases over time, differences in the silver content within the same years suggests that the flans were hastily prepared and that control procedures had, to some degree, become slack. The decrease in silver content happened at the same time that the form of the flan changed. This change in the flan was certainly a way for the mint to adapt the blanks to the coin's new constraints with regards to its metallic composition. At the end of the period, around 50 BC, the content of the silver in the coins dropped dramatically to an average of one-third of the total. This change, clearly a way to save precious metal or, at least, to strike more coins with the same amount of raw material, affected the manufacturing of the coins. It is not clear yet how these post-reform coins were produced, but they have a different look, both externally and internally.

Copper alloy coins are the most susceptible to changes in the amount of copper because of the difference between the coin's face value and its intrinsic value.²⁴ The beginning of the Ptolemaic period is characterized by coins made of "good" bronze, that is, coins which average a copper content of 88% and a tin content of 12%. This proportion gave the bronze a nice golden color; it also made the coins hard but not brittle. Because a new technique was introduced – that of pouring the metal into molds to obtain blanks – the mint of Alexandria lowered the tin content by, sometimes, adding a small amount of lead (but never more than 4%). It is unlikely that the increase in lead content and the decrease in tin are related to the change in the technique used to produce the blank (the higher the tin content, the more fluid the alloy – up to a certain point²⁵). Severe changes in the alloy only appear in the second half of the 2nd century. At this point, large quantities of lead were added

²² FAUCHER 2015.

²³ OLIVIER 2012. For a presentation of the general trends, see: HAZZARD 1990.

²⁴ For an analysis of the bronze coins of the Ptolemies, see: FAUCHER 2013: 17–89.

²⁵ WATELET and LEVESQUE 1788: 513.

to the alloy. The addition of lead to the alloy during the Hellenistic period is not only visible in Egypt but all around the Mediterranean Sea.²⁶ At this time, despite the fact that large quantities of molded forgeries were produced, there is no visible evolution in the technique used by the official mint of Alexandria. Several explanations have been offered for this phenomenon. Some of them are of a technical nature. We saw earlier that the addition of lead lowers the melting point, thus saving fuel during the process. Other explanations are economic in nature. The use of large quantities of lead, five to ten times cheaper than tin, reduced the mint's operating costs. While an explanation based on economics is possible, the money that would have been saved as a result of conducting these operations would have been insignificant at the state level.²⁷ In Ptolemaic Egypt, changes in the metallic content of the bronze coins occurred either after changes in the technique had already been implemented (when the blanks were no longer made from bars but in casting molds) or after a recall of the coinage (after the recall of series 5, series 6, and series 9). At this point, it is quite likely that the mints were receiving a greater quantity of material that they needed to melt. If this was indeed the case, then it would have been easier to use both recycled material – to facilitate melting – and lead, which was cheap and easily available. Here, the bronze coins struck by Cleopatra are a good example: this is the only issue in which the coins have a high content of both lead and tin. The mint of Alexandria was certainly unable to get rid of all the lead included in the alloy of the recalled coins (or else they did not want to cover the costs) and in order to improve the quality of the coins (at least in the eyes of the users), they simply added large quantities of tin to the freshly minted coins.

METALLOGRAPHY

The study of the structure of metals and alloys provides another source of information on the minting process. Its limitation lies in the fact that coins have to be cut or abraded in order to look at their structure.²⁸

It is therefore impossible to obtain any information on gold coins, considering their high value. Metallographic studies on silver coins are rare, though some have been conducted for the Ptolemaic period. My study of silver coins exclusively dealt with the issues of the last two Ptolemies, Ptolemy XII and Cleopatra VII. The silver content in the coins during this period dropped dramatically. Some of the coins struck with this debased content also show an important drop in weight,

²⁶ BLET-LEMARQUAND 2013: 49–54.

²⁷ If the minting of coins is considered as a whole, the value of the bronze struck is unlikely to have been as high as 2% of the total value of the metals minted even if as many silver coins as bronze coins were struck.

²⁸ For an overall presentation of the method, see: LA NIECE 1988.

even though they look exactly like their heavier equivalents. Here, metallography thus helps us to understand both why there were heavy and light coins but also if there was a difference in the minting technique. The results do not reveal any changes in the technique even if some coins have an interior that is hard to relate to any known technique for preparing blanks. It turns out that the light coins are highly susceptible to corrosion and that this corrosion specifically attacked the copper, resulting in coins with a high silver content but with a microstructure full of micro holes, formerly containing copper (Fig. 3). If our current state of knowledge is inadequate to describe the method used to cast the blanks, the discrepancies among the coins and their poor appearance clearly indicate that less care was taken in the minting process.

Metallographic testing is easier to conduct on copper alloy coins for several reasons. For one thing, the low commercial value of these coins makes it possible to cut them. Second of all, because two or more metals are alloyed in these coins, they offer a greater amount of information. The size of the grains, their form, any signs of distortion – all these things provide us with data on how the blanks were produced.

The cross section of a coin made of a copper alloy enables us to see, in the first place, if the blank, after being melted, cooled down rapidly or not. During the cooling process, as the metal solidifies, the structure of the alloy changes: assuming there is no sudden change in temperature, dendrites and large grains will form (Fig. 4).²⁹ Some series 2 blanks – those produced from a bar of bronze, cut down and then hammered – show signs of deformation (small flattened grains). In order to restore its ductility, a blank needed to be annealed so that it could then be hammered down again. If this was done, distorted twin lines and strain lines are visible within the coin's grains (Fig. 5). These images, as well as the flattened sulfur inclusions in the same coins, show that rod bars were used during this period, thus confirming the hypothesis made from observing the outside of the coin.

All coins with beveled edges show large grains; cross-sections of these coins do not show any constraints (they do not show any twin or strain lines), nor do they show a dendritic structure, both of which are signs that these coins were allowed to cool slowly. Signs of constraint only appear on the upper part of these coins, where the movement of the die during the striking process deformed the surface layer.

Some coins made of a copper alloy show a very low amount of tin (below 5%) and a high amount of lead (Fig. 6). Because it is not possible to strike coins consisting of more than 30% lead, these coins (beginning as blanks) must have been molded using the lost-wax technique. Experiments shown that if the percentage of lead is too high in the blank (for lead is not miscible in alloy form), the coin breaks

²⁹ SCOTT 1991: 2–6.

during the process of striking (because of the difference between the hard copper-tin alloy and the soft lead).

EXPERIMENTAL ARCHAEOLOGY³⁰

We can learn a great deal about the minting process from careful examination of all the aspects of a coin. Nevertheless, some of these answers are only theoretical. Certain hypotheses that have been made in the numismatic literature – like the possibility of the moneyers directly pouring the metal on a marble table – also need to be verified in practice. Experimental archaeology attempts to offer a series of answers to these questions. Of course, choices have to be made, and, even after long-term experiments repeated over and over, it is impossible to test all the possibilities, simply because the amount of unknown data is too large.

The results presented here were obtained after several rounds of experiments held between 2006 and 2011 as part of the “Plateforme des Arts du Feu” in Melle (France).³¹ F. Téreygeol runs this platform, which is dedicated to experimental archaeology in the fields of metal mineralurgy and metallurgy.³²

For financial reasons, these experiments were limited to silver and copper-alloy coinage. While the experiments covered all the aspects of the minting process – from the melting of the blanks to the striking of the coins – these experiments were oriented towards studying the behavior of the dies, a subject that will not be discussed here. It was the investigators’ goal to provide information about how the blanks were used.

Nevertheless, some of the results obtained during these experiments make it possible for us to confirm – or to discard – some of the hypotheses that are based on investigations of these coins. The experiments indicate how different the metallurgies of silver and copper alloys are. While the melting of silver (under 1000° C) does not require specific skills or structures, the melting of bronze is different. It is both more time-consuming (as a result of which it also consumes more fuel) and harder to obtain. Fluidity and “pourability” are essential questions when it comes to bronzes, especially when blanks are cast in molds.

1. *Silver*

Contrary to what we observed for copper alloys, one of the main characteristics of precious coinage is the consistency in weights. Without entering into a debate over

³⁰ It is my pleasure here to thank all the people who participated in these long and tiring tests over the years. The results obtained would not have been possible without them.

³¹ See: FAUCHER et AL 2013; FAUCHER et AL 2009.

³² To see different aspects of this research: TEREYGEOL 2012.

how precise ancient moneyers were (a difference of 1 grain of 0.02–0.03 grams?), it is a fact that most of the coins struck in a single issue were of the same weight with a low standard deviation. Of course, this consistency was due to the fact that the value of the coin was correlated to its intrinsic worth. In the production of blanks during our experiments, we first used an open mold (in sand) into which to pour the melted metal. After numerous attempts, we realized that it was both time-consuming and imprecise when we proceed in this way. The blanks were of uneven weight, and it was difficult to produce a large series of blanks from the crucible, for the silver cooled and solidified in a short period of time. Of course, more practice would have led to an approach that was both more accurate and faster, but it seems impossible to reach consistent weights simply by pouring metal into single cavities. A second technique was used in order to produce a larger quantity of blanks: we connected the cavities by channels in order for the metal to spread into the next cavity, making the pouring of the metal faster and more consistent (despite the fact that no runners or traces of runners appear on most Ptolemaic coins). However, while this method allows more blanks to be produced, the weights remained inconsistent; also, this approach required a large amount of extra work in the form of clipping and trimming the blanks from the chapelets.

82 During further sessions, other techniques were used to improve the quality of the blanks and especially the consistency of the weights. After some tests done on a small scale, we were able to produce blanks of very regular weights. First, molds were prepared. In this case, we used litharge molds that we prepared ourselves, mostly because this technique existed in the past and because it is possible for these molds to be reused. The exact weight of the silver – in the forms of grains – was poured into the molds in a solid state.³³ These molds were placed in large furnaces until the silver melted. This technique produced blanks of precise and regular weight, with only a slight loss in weight which never exceeded 0.08 g (0.4% of the total weight). The most time-consuming part of this technique is the preparation of the molds in which the silver has to be weighed and poured.

2. *Bronze*

After two long-term experiments on silver minting, the team proceeded to bronze. The bronze experiments were easier in the sense that archaeological evidence reduces the spectrum of possibilities. Our experiments focused on the most common techniques used by the Ptolemies, that is, the production of blanks in chapelet molds.

³³ These grains are easy to produce. First, put any amount of silver in a crucible. After the metal has melted, pour it into another crucible, one which has holes in the bottom. This strainer has to be placed over a big basin of water. When the silver touches the water, it solidifies and forms small grains.

We did not try the technique which makes use of bronze bars.³⁴ For obvious reasons, only molds in limestone have been preserved; evidence for clay molds is almost nonexistent for the period. All the experiments were made with a “good bronze” consisting of 88% copper and 12% tin.³⁵ The first experiments using limestone molds were unsuccessful. If the result was of fair quality, our molds were greatly affected by the heat and most of the sharp edges of the cavities were damaged after the first cast, which made the molds unusable a second time. The reason the initial experiments were unsuccessful mainly lies in the quality of the limestone we used: it was simply unsuitable for heating. We therefore turned to molds made from foundry sand. This technique allowed the team to produce blanks in great numbers (up to several hundred a day). After few days of practice, the results were very satisfying and very close to the examples found during excavations. The hardest part of the process in making the blanks was to control the furnace well enough to have a good melting temperature. A temperature that was too low, even if the alloy was melted, resulted in a thick substance which was difficult to pour into the molds. It caused the metal to solidify too quickly and prevented the mold from being fully filled.³⁶

In this technique, the most time-consuming part is the treatment of the blanks after their production. When the blanks are taken out of the mold, they are in the form of a chapelet of several units. They need, then, to be separated. Metallographic investigations have shown that they were cut with a chisel.³⁷ After this operation, the edges of each blank needed to be filed down individually.³⁸ Moreover, the blanks had to be polished, on both sides, in order to ensure that a good impression would result from the strike. Experiments have shown that if the blanks were not adequately polished, even a good blow of the hammer was not sufficient to correctly print the engravings of the dies. These mis-strikes appear on ancient coins, even on some *fleur de coin*.³⁹

3. The striking process

The striking of bronze coins proved to be much more difficult than the striking of silver ones. Even a blow of mid-range force was enough to deform a blank

³⁴ We only conducted experiments on the blanks in order to study the deformation of the metal during the hammering and annealing and to compare it to the metal structures of ancient Ptolemaic coins (see below).

³⁵ Some attempts were nevertheless made with different amounts of lead (10%, 20%, and 30% lead) in order to look at the effects on the melting point, the degree to which it was possible to pour the melted metal, and the malleability of the blanks.

³⁶ Of course, these problems could be circumvented with the experience of knowledgeable workers.

³⁷ FAUCHER 2013: 239–241.

³⁸ Depending on the period, this operation was more or less well executed.

³⁹ FAUCHER 2016: 74, pl. 20. I do not mention here the central cavities that occur on Ptolemaic bronzes and that are part of the polishing process. For details, see: FAUCHER 2013: 242–257.

made of silver. For silver, the deformation was in general quite substantial. Hence, for a blank with a diameter of 20 mm, and averaging 17.2 g, the diameter of the coins after striking was on average about 22 mm. For bronze blanks, almost no deformation was recorded. These coins required the very strong blow of the same hammer (we invariably used a hammer that weighed 10 lbs) by an experienced worker. The difference in force that was required meant that the dies used for bronze deteriorated at a much faster rate than the dies that were used to produce silver coins.

4. *Hot or cold striking?*

This question appears quite often in the literature on ancient minting techniques. The experiments that we conducted on silver showed that it was not necessary for the blank to be hot in order for the die to make a good print (even on our rather large Attic-weight tetradrachms). Therefore, we do not see any good reason why the ancients would have heated the blank prior to striking. The question is more pertinent to bronze coinage because of its hardness (see above). Having some experience, we discovered that it is possible to make a perfect print on a 20 mm coin of “good” bronze. It is not possible to be certain about which type of striking was used for larger denominations, especially for the very large coins struck by the Ptolemies during the 3rd century BC (the heaviest of which reached almost 100 g). However, several indications point toward cold-striking being used even for larger coins. First of all, large Ptolemaic coins often show signs of coins that were double struck or mis-struck, signs that workers met with great difficulty in striking them. Secondly, hot-striking produces severe problems in the management and organization of the work. Hot-striking is simply hard to do. If hot-striking is to occur, a furnace or other hot place to anneal the blanks is needed in the workspace.⁴⁰ Other problems also occur. The most severe, in my opinion, is the fact that during annealing (the blanks have to be hot enough in order to have any effect on the striking), the blank is attacked by corrosion, resulting in a black layer on it, which destroys all the effects of the polishing and alters the nice gold-like color of the bronze. Such coins would have needed to be cleaned with chemicals after striking, which would be both complicated and time-consuming. Hot-striking would also have an effect on the dies during the striking. A hot blank would transfer energy to the dies, and this would result in heavier wear and distortion of the dies during the striking. This would greatly affect the lifetime of the dies. Finally, annealing would affect the microstructure of the coins, resulting in the creation of smaller grains; but except for the blanks made from bars, we did not see any evidence of that sort on the coins

⁴⁰ Further research leads us to propose that the production of blanks and the striking process were accomplished in distinct locations (FAUCHER 2013: 101–105).

we studied. In conclusion, we do not see any decisive arguments that would prove that hot-striking was used during antiquity, at the very least for Ptolemaic coins.

5. Metallography following the experiments

The experiments make it possible to sample the results, to conduct elemental and metallographic analysis. After investigating ancient Ptolemaic coins, several questions arise: What does the microstructure look like after casting? What does the microstructure look like after the annealing and/or hammering process? How deeply was the microstructure affected by the striking?

This metallographic study confirms almost systematically the observations and shows that the results obtained by the experiments are very close to phenomena observed on ancient coins, for example the structure of annealed and hammered blanks (Fig. 7, for the experiments, compared to Fig. 5).

CONCLUSION

Experimental archaeology is undoubtedly one way to explore numismatics. With regards to a topic on which textual evidence is almost nonexistent and where archaeology has only left faint traces, recreating the whole process of minting can provide us with answers about the feasibility of certain operations and help us to understand where moneyers struggled. We must not expect experiments to give us straightforward results and accurate numbers. The unknowns are too numerous to expect that all the possibilities will be covered. Whatever their training, the teams of people engaging in these experiments will never match the skills developed by ancient craftsmen. But experimentation can definitely provide us with responses to questions that have not yet been answered. It can also confirm or dismiss theories or hypotheses which have never been tested.

REFERENCES

- ARIEL, D.T. 2012. "Judean Perspectives of Ancient Mints and Minting Technology", *INJ* 7: 43–80.
- ARLES, A. 2009. *Entre monnayage officiel et faux-monnayage. La fabrication de la monnaie au marteau en France (XIIIe–XVIIe siècles). Approche physico-chimique, expérimentale et historique*, PhD dissertation defended at Orléans, February (online: <https://halshs.archives-ouvertes.fr/tel-00418642/>).
- ARLES, A. and TEREYGEOL, F. 2011. "Études des structures et des objets liés à la fabrication de la monnaie". In P. MILLE (ed.), *L'atelier monétaire royal de La Rochelle, La place de Verdun, archéologie d'un espace urbain*, Rennes: 83–135.
- BLET-LEMARQUAND, M., NIETO-PELLETIER, S. and SARAH, G. 2014. "L'or et l'argent monnayés". In Ph. DILLMANN and L. BELLOT-GURLET (eds.), *Circulation et provenance des matériaux dans les sociétés anciennes*, Paris: 133–159.

- BLET-LEMARQUAND, M., GRATUZE, B. and BARRANDON, J. 2014. "L'analyse élémentaire des monnaies: Adéquation entre les problématiques envisagées, les alliages étudiés et les méthodes utilisées". In H. DERSCHKA, S. FREY-KUPPER and R. CUNZ (eds.), *Selbstwahrnehmung und Fremdwahrnehmung in der Fundmünzenbearbeitung. Bilanz und Perspektiven am Beginn des 21. Jahrhunderts*, II. Reflexionen, Lausanne: 121–146.
- BLET-LEMARQUAND, M. 2013. "Les analyses élémentaires de monnaies de bronze grecques réalisées au Centre Ernest-Babelon de l'IRAMAT: méthode, résultats, synthèse". In C. GRAND-JEAN and A. MOUSTAKA (eds.), *Aux origines de la monnaie fiduciaire. Traditions métallurgiques et innovations numismatiques. Actes de l'atelier international des 16 et 17 novembre 2012 à Tours*, Bordeaux: 39–56.
- BUTCHER, K. and PONTING, M. 2014. *The Metallurgy of Roman Silver Coinage: from the Reforms of Nero to the Reform of Trajan*, Cambridge.
- CACCAMO-CALTABIANO, M. 2001. "L'Argyrokopeion nelle testimonianze archeologiche e letterarie". In *Luoghi della moneta: le sedi delle zecche dall'antichità all'età moderna*, Milan: 19–28.
- CHAMAY, J. 2002. "La frappe de la monnaie". In – A. J. CLARK and J. GAUNT (eds.), *Essays in honor of Dietrich von Bothmer*, Allard Pierson Series 14, Amsterdam: 69–72.
- CHEVILLON, J.-A. 2010. "Un atelier monétaire hellénistique découvert à Marseille", *Infonumis* 48: 3–4.
- CHEVILLON, J.-A. 2011. "Marseille grecque: un atelier monétaire hellénistique mis à jour", *Provence Numismatique, Bulletin de liaison des associations* 114, Nice: 20.
- DASZEWSKI, W.A. 1972. "Polish Excavations at Kato (Nea) Paphos in 1970 and 1971", *Report of the Department of Antiquities. Cyprus*: 204–236.
- DUYRAT, F. and OLIVIER, J. 2010. "Deux politiques de l'or. Séleucides et Lagides au III^e siècle avant J.-C.", *RN* 166: 71–94.
- FAUCHER, T. 2016. "EH 173. Le trésor de Touna el-Gebel, 1962? (CH 10.448)". In T. FAUCHER, A. MEADOWS, and C. LORBER (eds.), *Egyptian Hoards I: The Ptolemies*: 64–75.
- FAUCHER, T. 2015. "Les monnaies égyptiennes en or de Nectanébo II", *BSFN* 70: 278–283.
- FAUCHER, T. 2013. *Frappier monnaie: la fabrication des monnaies de bronze à Alexandrie sous les Ptolémées*, *Etudes Alexandrines* 27, Alexandrie.
- FAUCHER, T. BROUSSEAU, L. and OLIVIER, J. 2013. "Expérimentations sur la technique de fabrication des monnaies grecques: approches, réalisation, perspectives". In F. TEREYGEOL (ed.), *Comprendre les savoir-faire métallurgiques antiques et médiévaux l'expérimentation archéologique et archéométrique sur la plate-forme expérimentale de Melle*, Paris: 71–99.
- FAUCHER, T. COULON, L. FRANGIN E. and GIORGI, C. 2012. "Un atelier monétaire à Karnak au II^e s. av. J.-C.", *BIFAO* 111: 146–166.
- FAUCHER, T. TEREYGEOL, F. BROUSSEAU, L. and ARLES, A. 2009. "À la recherche des ateliers monétaires grecs: l'apport de l'expérimentation", *RN*: 43–80.
- HACKENS, T. and KONSOLAKI, H. 1980. "Un atelier monétaire dans un temple argien?", *Bulletin de correspondance hellénique. Supplément* 6: 279–294.
- HAZZARD, R.A. 1990. "The composition of Ptolemaic silver", *Journal of the Society for the Study of Egyptian Antiquities* 20: 89–99.
- HILL, G.F. 1922. "Ancient methods of coining", *NC* ser. 5, 2: 1–42.
- HOLLARD, D. 2014. "L'outillage monétaire gaulois de Valempoulières (Jura), témoin d'une production tardive de quinaires de ΚΑΛΕΤΕΔΟΥ", *Cahiers numismatiques* 51: 11–25.
- JUNGFLEISCH, M. and SCHWARTZ, J. "Jetons de faïence et moules à monnaies ptolémaïques", *ASAE* 53: 209–219.
- LA NIECE, S. 1998. "Metallography in Numismatics". In W.A. ODDY and M.R. COWELL (eds.), *Metallurgy in Numismatic*, RNS, Special publication 30, London: 227–236.

- MALKMUS, W. 1989–1993. “Addenda to Vermeule’s catalogue of Ancient coin dies, parts 1, 2, 3, 4 et 5”, *SAN* XVII–XVIII = MALKMUS, W. 2008, “Ancient and medieval coin dies: catalogue and notes”. In: L. TRAVAINI and A. BOLIS (eds.), *Conii e scene di coniazione*, Rome: 75–240.
- META, A. 2015. *Le monnayage en argent de Dyrrachion (375-60/55 av. J.-C.)*, Athens.
- MASTER, P. 1958. “Frappe défectueuse de monnaies classiques de Sicile”, *RBN* 104: 149–153.
- NICOLAOU, I. 1990. *Paphos II: The Coins from the House of Dionysos*, Nicosia.
- NICOLAOU, K. 1972. “Découverte d’un Hôtel des Monnaies de l’époque ptolémaïque à Paphos, Chypre”, *BSFN* 27: 310–315.
- OLIVIER, J. and FAUCHER, T. Forthcoming. “From owls to eagles. Metallic composition of Egyptian coinage (5th–1st c. BC)”. In: K. BUTCHER (ed.), *Debasement: Manipulation of Coin Standards in Pre-Modern Monetary Systems*.
- OLIVIER, J. 2012. *Archè et Chrèmata en Égypte au IIe siècle avant J.-C. (204-81 av. J.-C.). Étude de numismatique et d’histoire*, PhD dissertation at the University of Orléans.
- PICARD, O. 2016. “L’atelier monétaire dans les cités grecques”. In: F. BLONDE (ed.), *L’artisanat en Grèce ancienne. Filières de production : bilans, méthodes et perspectives*, Athens: 207–224.
- PICARD, O. and FAUCHER, T. 2012. “Les monnaies lagides”. In: O. PICARD et AL (ed.), *Les monnaies de fouilles du Centre d’Études Alexandrines. Les monnayages de bronze à Alexandrie de la conquête d’Alexandre à l’Égypte moderne*, Alexandria: 17–108.
- PICON, M. et AL. 1966. “Recherches techniques sur des bronzes de Gaule romaine”, *Gallia* 24, 1: 189–215.
- PONTING, M. 2012. “The Substance of Coinage: The Role of Scientific Analysis in Ancient Numismatics”. In: W.E. METCALF (ed.), *The Oxford Handbook of Greek and Roman Coinage*, Oxford: 12–30.
- SCOTT, D.A. 1991. *Metallography and Microstructure of Ancient and Historic Metals*, Marina del Rey.
- TEREYGEOLF. (ed.). 2012. *Comprendre les savoir-faire métallurgiques antiques et médiévaux*, Paris.
- DE VILLENOSY, F. 1900. “De la fabrication des monnaies antiques”, *Congrès international de numismatique*, Paris: 51–62.
- WATELET, C.-H., LEVESQUE, P.-C. and VIDAUD, D.L.T. 1788. *Encyclopédie Méthodique*, Liège.
- WOYTEK, B. 2013. “Signatores in der römischen Münzstätte: CIL VI 44 und die numismatische Evidenz”, *Chiron* 43: 243–284.

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PLATE 1

Fig. 1. Silver tetradrachm of Cleopatra VII, showing diametrically signs on edges

Fig. 2. Edge of a bronze hemiobol of series 02

Fig. 3. Cross section of a lightweight tetradrachm struck by Cleopatra VII

Fig. 4. Cross section of a bronze large horn of Ammon of Series 06,
showing the dendritic structure

PLATE 2

Fig. 5. Cross section of a bronze hemiobol of series 02, with strain and twin lines

Fig. 6. Cross section of a 40-units bronze coin of series 09, showing nodules of lead

Fig. 7. Cross section of a bronze blank (after annealing and hammering),
showing small grains



1



2



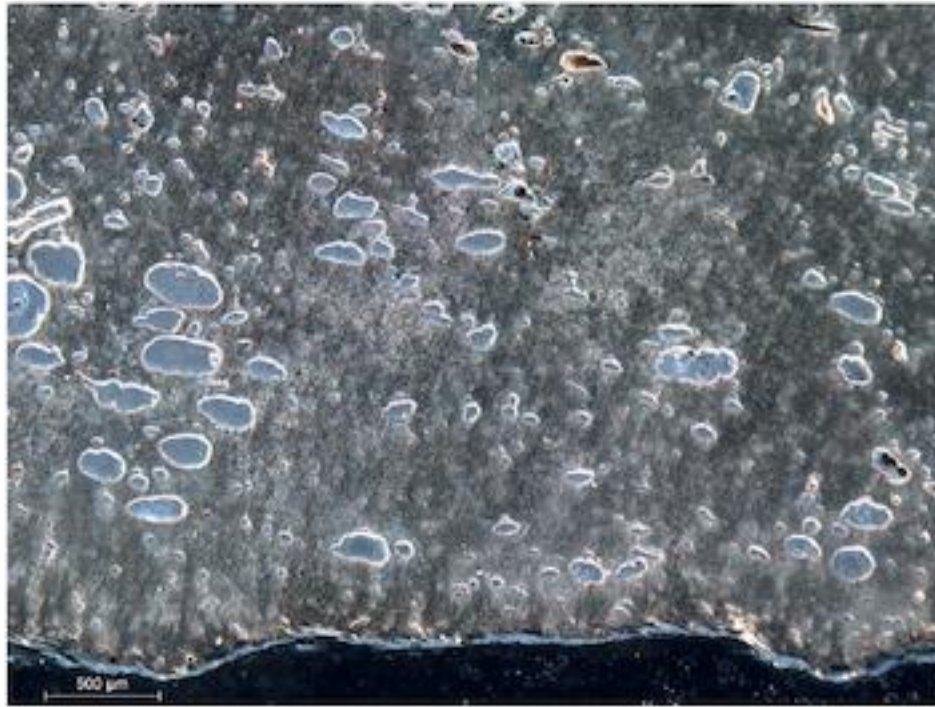
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6



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