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QUANTIFYING MONETARY SUPPLIES IN GRECO-ROMAN TIMES

François de Callataÿ (ed.)

OFF PRINT

EDIPUGLIA
Bari 2011

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FOREWORD

The 18 papers published in this book form the proceedings of the Third Francqui Conference, hosted in Rome both by the Academia Belgica and the Istituto Italiano di Numismatica on the theme “Quantifying monetary supplies in Greco-Roman times” (September 2008, 29th-30th). It is a consequence of the Francqui Prize attributed in 2007 to François de Callataÿ.

The editor wishes to express his gratitude to the institutions which made this conference possible: first and foremost, the *Francqui Foundation*, and especially its president Vicount Eyskens, former Prime-Minister of Belgium, who opened the conference (the day the largest Belgian bank was destroyed), the Academia Belgica, its director, M. Walter Geerts and all his dedicated staff, the *Istituto italiano di Numismatica*, and its director, Professoressa Sara Sorda, who welcomed the participants in the illustrious Palazzo Barberini, the Royal Library of Belgium as well as the Belgian Science Policy which provided great support to this event. More personally our warm thanks go also to Cécile Arnould who carried out brilliantly as the secretary of the conference and to Valentina Natali who, along with the editors, took on the publishing of the proceedings.

Clive Stannard

EVALUATING THE MONETARY SUPPLY: WERE DIES REPRODUCED MECHANICALLY IN ANTIQUITY?

For the numismatists north of the Alps
from whom I learned much

The possible use of mechanically reproduced dies in antiquity is of basic importance for the die-studies on which most attempts to evaluate ancient monetary supply are based, because, in theory, the nigh perfect mechanical reproduction of dies could make it impossible, or at least hazardous, to attempt to quantify emissions. The question has been hotly debated for nearly a century, since George Hill, in 1922, argued that the Greeks used hubs to strike working dies.[1]

I use the following conventions for clarity:

"hub" means a tool in positive, with a whole coin design, used to sink a die;[2]
"patrix" means an intermediate tool in positive, with a whole design;
"matrix" means an intermediate tool in negative, with a whole design;
"piece punch" means a tool in positive, with a part design. A piece punch matrix is a negative from which piece punches can be raised. Piece punches can range from minor design elements, to nearly complete designs, such as the halfpenny punch in figure 1.

One of the key arguments of proponents of hubbing is from presumed utility, namely that the use of hubs (or piece punches) would have speeded up and im-

I thank, in particular, Barry Cook, Suzanne Frey-Kupper, Markus Peter, Lucia Travaini, Rick Witschonke, Bernhard Woytek and Bernward Ziegaus, for their advice and help.

[1] Hill 1922, 19-22 and 37-38.

[2] The *Oxford English Dictionary* defines a hub as "a cylindrical piece of steel on which the design for a coin is engraved in relief". It gives the first use as 1851, in the *Illustrated Catalogue of the Great Exhibition*. The origin of the word is uncertain. It probably derives from "boss", in the sense of a (rounded) protuberance. Cooper 1988 uses the variants, "hob" and "hobbing".

proved the production of dies.[3] We have, however, no idea of how ancient mints might have perceived such utility, and should guard against reading back into the ancient world the utility that current mint practice derives from hubbing. There is a history of technological and social development behind the modern hub that has few parallels in the ancient world.

The coinages of Greece and Rome until about the fourth century AD were relatively thick, with images in high relief. Perhaps because of this, there seems to have been no clipping – which plagued mediaeval and early modern coinage, and drove die-making technology in Middle Ages – until the thinner coinages of the late empire arrived.[4]

There was less pressure for uniformity of design and fabric in ancient coinage than later.[5] In contrast, medieval coinage tended to be very thin, with rudimentary images in low relief. Mints increasingly sought regularity of design not only against counterfeiting, but also against clipping.[6]

Iron – or rather steel-capped iron dies – replaced the high-tin bronze dies, common in antiquity.[7] The steel faces of die blanks were worked in an annealed state, before tempering for use. Facilitated by the low relief of the designs, the classical practice of hand engraving with scorpers and drills progressively gave way to the use of piece punches, to emboss shallow elements of the design.[8]

[3] The classical formulation is David Sellwood's: «It seems to me that the advantages [of hubbing] are too great for the Greeks not to have resorted to it» (Sellwood 1962, 221).

[4] It also seems that culling of heavier coin from circulation was not the significant factor it was later. As I noted in showing that many issues of Republican *denarii* were adjusted *al marco* rather than *al peso* (that is, that a tale of flans was brought to a certain weight, without too much care expended on the weight of individual flans), the wide range of weights that characterises adjustment *al marco* does not seem to have resulted in heavy coins being picked out for melting or hoarding in the ancient world (Stannard 1993, 50).

[5] «The Cosa hoard sample is a witness: although largely a savings hoard, there is no sign that its owner had successfully picked out heavier pieces, as the mean is at the theoretical standard and weights range widely. Moreover, the willingness to accept gouged denarii with what looked like a chunk of metal missing must be related to the fact that Republican denarii do not seem ever to have been clipped, or had silver removed fraudulently, which is most surprising, given the frequency of plating, and the ceaseless struggle against it to which the test-marks on the coins testify» (Stannard 1993, 50.)

[6] «While clipping would not be an issue in the case of those coins that circulated by weight, such as the ducat, the lower denominations were commonly counted in transactions. By trimming a bit of metal off the edge, a clipper could then spend the coin itself at full value and melt the scraps for a profit. One such individual in 1366 bought Venetian *soldini* for clipping in batches of 100,000 coins at a time – when arrested he had enough clippings to make more than 35,000 new coins. The first line of defence against clipping was the minting of coins with dotted borders on the perimeter of each face to indicate their prescribed edgea» (Stahl 2004, 193-194).

[7] Travaini 2007, 29-30.

[8] «Dies were no longer manufactured with the skill and care exercised in classical times, perhaps through ignorance, and many of the minting practices became relatively crude. It is believed that designs were often obtained by setting them out diagrammatically on the plain working surface of the

Precisely when piece punches came to dominate is unclear.[9] Lucia Travaini suggests the 12th century.[10] The first use of piece punches for larger, more complex images seems be have been in Bohemia in the 12th century,[11] with Venice soon following.[12] Although the images may often appear rudimentary, the metalworking technologies involved were increasingly complex, and probably beyond the skills of most ancient mints.[13] By Renaissance times, piece punches for major elements of the overall design were regularly employed, for example for the portrait bust of Queen Elizabeth I of England.[14]

Mints developed extensive repertoires of piece punches, which sometimes remained in use for years, as the tool-lists of the mint of Massa di Lunigiana, drawn up on various occasions between 1585 and some time after 1603, show: four punches, for example, "con l'effigie di S. Ecc.a", reappear in all of them.[15]

die and then using several small, positive piece punches to engrave a crude portrait or inscription. Such punches continued to be used, albeit in improved form, for many centuries … Unfortunately such piece punches have not survived so that we know very little concerning their manufacture» (Cooper 1988, 19).

[9] Vanhoudt 1986 publishes a Merovingian triens, where double striking appears to show the use of a piece punch for the letter, O, but this seems unlikely, as no other letter or design element suggests the use of a piece punch.

[10] She notes the use of piece punches for the lettering of British pennies, for the coins of Venice, and for Denari Terzoli of Milan, all in the 12th century (personal communication, 28 May 2008).

[11] Karras 1985.

[12] «In the late Greek and Roman period, each die is hand carved, so variations from die to die were inevitable; and imitations could be distinguished from genuine mint products only on the subjective grounds of the style of the die carving. It was the medieval use of punches in the carving of dies that introduced an objective criterion for the recognition of good issues; the Venetian mint was among the leaders in the systematic application of punches to the die-making procedure. Though small punches shaped as wedges, crescents, and dots had been part of the engraver's tool kit since at least Carolingian times, the use of punches containing larger, complex images has been recognized first in the coinage of twelfth-century Bohemia [citing Karras 1985, 179-210], where it probably served to speed up the production of dies for the large coinages minted there by allowing dozens of dies to be mechanically engraved with the same image. By the beginning of the thirteenth century, Venice had adapted the process to production of its new basic coin, the *grosso*, on which separate punches were used for the heads of the doge and Saint Mark, on the obverse, and Christ on the reverse. By the end of the fourteenth century, these head punches had become so distinctive that the use of one with the recognizable likeness of doge Antonio Venier resulted in the first true example of portraiture on a European medieval coin» (Stahl 2004, 192-193).

[13] See Archibald, Lang & Milne 1995 for a description of the complex process needed to purify the iron, make the steel for the caps, and weld the steel cap to the wrought iron or mild steel shafts, for dies of Cnut, William I, Henry I and Stephen of England. Elements of technology advanced at different paces in different mints: for example, Venice was still striking by hand at the end of the Republic, in 1797, when the rest of Europe had gone over to mechanical presses.

[14] Brown & Comber 1988.

[15] «Si noterà la notevole quantità di punzoni elencati e come in più di trent'anni di attività molti di essi come i quattro 'con l'effigie di S.E. fossero' ancora in buono stato e così gli alfabeti che in questo lasso di tempo quasi raddopiano. Il consumo delle attrezzature sembra riguardare quasi esclusivamente i coni» (Finetti 1987, 71-73, drawing on Giampaoli 1917, 363-365).

The use of such piece punches does not make die-studies impossible, because different piece punches were used from die to die, because they were not always placed in precisely the same relationship to each other, and because they often suffered recognisable individual damage.[16]

The use of piece punches increasingly accustomed mints to working tools both in the positive (piece punches) and in the negative (the dies themselves).[17] It becomes increasingly the practice to sink negative tools from positives, and raise positive tools from negatives: this is central to modern die-making. Softened metal is struck into hardened metal and the result then hardened. There are, however, advantages in working certain steps in positive or negative. In particular, small details that are intended to stand proud and relatively high on the positive are best sunk into a negative. This is the case of lettering, which is most easily cut or punched into the die itself, or into a matrix from which a hub can be raised, because to cut letters directly in positive is clumsy, and would mean removing masses of metal and difficult finishing of the angle between field and letter.

«At the beginning of the 17th century [in the British Mint], dies, whether intended for hand or mechanical striking of coins, seem to have been sunk with hand-cut piece punches that were driven manually by blows of the hammer into the softened faces of the die blank», but, at some point between 1668 and 1678, the screw press was put to use in sinking punches into die blanks, as well as striking coin.[18] New techniques were tried: «counterpuncheons» seems to have been used with the screw press in Scotland at about this time: these carried the design in negative between raised lines. The counterpuncheon served as a matrix, but considerable remaining metal had then to be cut from the face of the punch, around the resulting positive elements in the design.[19] This seems to have be a transitional stage, until more powerful presses became available. At the Paris Mint in 1692, major-element piece punches themselves were being reproduced mechanically, from a hand-cut positive master, to a struck negative, to struck positive working punches.[20]

[16] Cf. North 1990 and 1992, and Harris 1995.

[17] This distinction is not absolute: piece punches could themselves be raised from negatives (matrixes). Cooper 1988, 80, fig. 84, illustrates "an engraver's Matrix Plate" for piece punch manufacture.

[18] Gaspar 1993, 134.

[19] «An important feature of these tools is that their shape reveals them to have been used with a screw press, and hence they represent an early example of the *mechanical* raising of punches» (*Ibidem,* 135).

[20] «The 1692 Paris account explicitly states that a master punch, e.g., for the King's bust, was hand engraved and hand-hammered into the soft block of steel that, when hardened, served as a matrix for raising duplicate working punches. It is not clear, however, whether these working punches were raised by hand hammering a soft punch blank into a matrix, or instead were raised with the aid of a press. Certainly the hand-raising of punches was a practical possibility for small punches carrying individual letters and design elements» (*Ibidem*, 135).

Fig. 2. - Dies for the 1794 halfpenny, with lettering and beading, made with the piece punch in figure 1 (on display in the British Museum).

Fig. 1. - Screw press piece punch for the reverse of the 1754 half-penny (on display in the British Museum).

In the early 18th century, sinking a complete design was still not the rule: after impressing the bust of the monarch (or the main elements of the reverse design, as in figure 1), the engraver still had to "add details such as letters and beads by hand to each die", [21] as can be seen from figures 2 and 3. The transition to lettered punches (that is, for the first time, a complete hub) occurred only in the 1780s, and greatly reduced the workload. [22] The main elements of modern hubbing had now been brought together.

Further developments in the 19th century turn on Boulton's application of steam power, and the use for dies and die-making tools of Huntsman's new crucible steel, soft and malleable in the annealed state, but extremely hard when tempered. It was now possible to take systematic advantage of moving back and forwards between negative and positive, for example, changing a date by stoning it off a patrix, sinking a new matrix, punching a new date into that, and raising new patrixes from the result. It is interesting to note – with the possible use of hubs in ancient coinages in mind – that Boulton's master was worked not in positive but in negative. [23]

[21] Dyer 1993, 160.

[22] «In the six years from January 1772 to December 1777 nearly 200 dies were sunk for guineas alone and getting on for 5000 altogether. The labour of lettering and beading so many dies may be imagined and the introduction of lettered punches must have been desired for the considerable saving of time it would achieve» (*Ibidem*, 163).

[23] «The master, known as a 'matrix', was cut in a block of new steel, hardened, and placed in a more powerful and larger screw, or hobbing press; here it was used as a die to cold-forge its impression onto the polished coned surface of a similar piece of steel known as a 'patrix' or working punch. This punch was hardened and then used for striking production dies in negative … the engravers often touched up the patrix, so that small variations occurred … Striking punches from matrices, and dies from punches, involved much heavier blows than those needed for striking the coins of the same design. The steel die blank needed two or three times the force required for striking

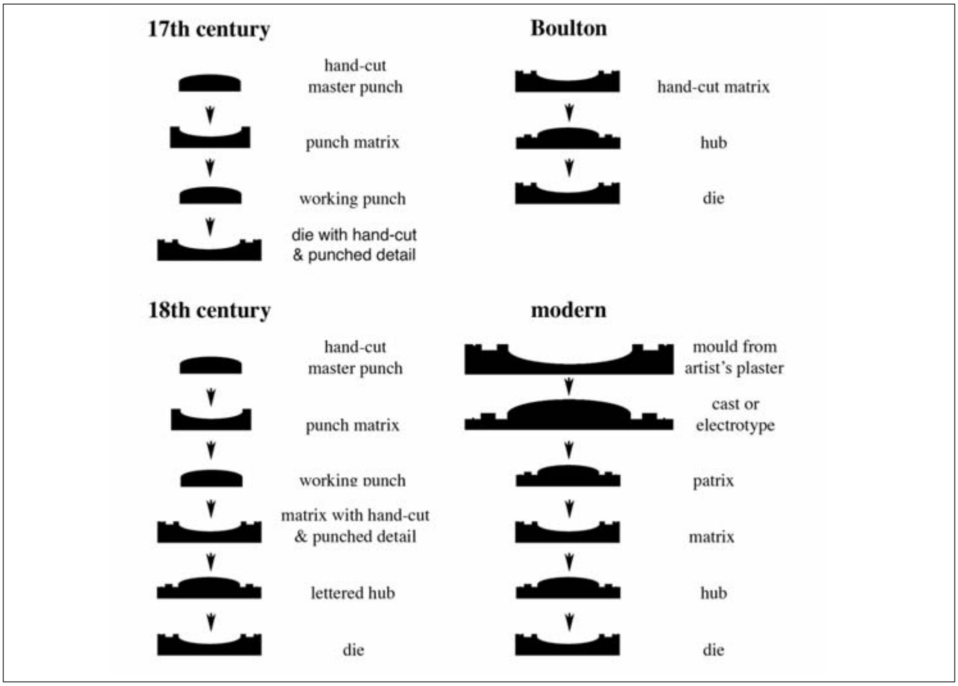

Fig. 3. - Modern piece punching and hubbing practices.

The utility sought by mediaeval and later mints is therefore much more complex than that posited for Greek and Roman mints, and includes – in addition to speedy preparation of a die – the ability to create much greater numbers of dies annually than were needed in most ancient emissions, greater regularity of design and manufacture, as a deterrent to forgers, clippers and cullers,[24] and the technical advantages of working backwards and forwards between positive and negative.

With the introduction of the pantograph, from the late 18th century, it became

a coin of similar size, and all but the very smallest dies were struck with a number of blows» (Cooper 1988, 160).

[24] There was always an economic trade-off between quality and production cost, particularly for low value pieces: Stahl notes that workers in the Venetian mint striking *grossi* were paid twice as much as those striking *soldini*, which defined the quality standards that could be maintained (Stahl 2004, 194). «The quandary for the mint in the case of the *soldino* is illustrated in a series of deliberations of the Senate in 1391. Noting that the coins leaving the mint were so uneven in weight that they were commonly culled with a resultant lowering of the aggregate value of those that remained in circulation, the Senate ordered that *soldini* be minted to a remedy, or tolerance, of 1.7%, which was five times as much variation as allowed for the larger silver *grosso* … Workers were offered a small raise to compensate for their extra work in meeting the new tolerances. The raise turned out not to be enough to cover the extra effort of the tightened remedy, and the Senate was soon informed that the workers refused to work on *soldini*. The Senate relented and set a wider absolute tolerance for individual pieces, while demanding that the aggregate weight of the coinage as a whole fall within the original weight of variation. Again the workers rebelled and finally the Senate set the allowance for individual coins at a liberal 7.6%, with a narrower tolerance for the aggregate mean weight of the issue» (*Ibidem*, 195).

possible to work from artists' plaster casts, make a metal cast or galvano of these, and cut a patrix at the size needed for the coin in question. (This, of course, has no bearing on antiquity).

The number of dies used in coinages in early modern Europe, when piece punches were evolving from minor into major elements of coin types, was often orders of magnitude greater than the numbers used in most ancient emissions, with the implication that the utility of creating a hub would not have been great in antiquity. Between January 1772 and December 1777, the British Mint used some 5,000 dies.[25] For comparison, the very prolific *hektai* mint of Mytilene used at least 438 obverse and 512 reverse dies between *c*. 521 and *c*. 326 BC, or some five dies a year (though allowance must be made for an extremely fluctuating volume of issues).[26] All the incuse reverse staters of Metapontum used 200 recorded and 263.4 ± 7.7 estimated obverse dies between *c*. 530 and *c*. 480 BC, or some 5.27 estimated dies a year.[27] Of the 246 emissions assembled by de Callataÿ for the archaic and classical Greek coinages, only 18 use more than 100 recorded dies, and 6 more than 200, over differing periods of time.[28] The total die-set of all denominations of all Spanish mints has been estimated as 41.87 a year under Augustus, 63.74 under Tiberius and 76.75 under Caligula, for a total in this period of 3,622.3 ± 128.2.[29] Some issues reach greater numbers: under the Roman Republic, in the case of *RRC* 361/1, P·CREPVSI, 82 BC, "the number of obverse dies is very likely to be 475 ± 10 and the number of reverse dies is 510 ± 15, struck in a period of 127 ± 10 days … or probably 1520 ± 120 hours".[30]

This issue provides a useful measure of the time required to sink a die of the size and complexity of a denarius. … «Since only two engravers were used to prepare essentially all the Crepusius dies, then:

$$\frac{127 \text{ days} \cdot 12 \text{ hrs/day} \bullet}{985 \text{ dies (obverse and reverse)}} \quad = 3.1 \text{ engraver-hours/die»}$$
$$2 \text{ engravers}$$ [31]

«Evidently it was a relatively easy job for a good engraver to make a die, and

[25] Dyer 1993, 163.

[26] Healy 1993, 13, citing Bodensted 1981.

[27] De Callataÿ 2003, 1-2.

[28] *Ibidem*, 239-246.

[29] By statistical methods, paralleling known die-numbers in certain mints with the rarity of coins in *Roman Provincial Coins* (which represents a compendium of museum holdings). This proves to be significant. «It is as well to remind the reader that the results given here are estimations whose purpose is to quantify their magnitude only approximately. The authors do not claim an absolute certainty for these estimations and ask that this should always be born in mind» (Ripollès, Muñoz & Llorens 1992).

[30] Carter & Carter 1983, 41, based on Buttrey 1976.

[31] *Ibidem*, 41.

Fig. 4. - Piece punches from the Kleinsorheim find (photo: M. Eberlein, Archäologische Staatssammlung München).

… one engraver could produce enough dies for 7 or 8 anvils working full time».[32] Even in such a massive issue, then, the utility of using large-element piece punches, or hubbing, would not have been that great.[33]

Much of the discussion around the possible use of hubs has really concerned piece punches – usually the major shape of the main type – with the assumption that the die needed to be completed and substantially reworked by hand.[34] It follows logically that it is difficult, or impossible, to identify their use, and the argument is without relevance to the evaluation of the monetary supply. Gerin suggests – because of the regularity of size and shape – that the obverse heads of Pan on a series of 3rd century BC Arcadian League obols were punched in and finished by hand. She recognises that «no proof can be offered for the use of hubs nor could it be. All I hope to have shown is that there were cases (probably mainly limited to issues of fractions) where recutting alone cannot account for the extremely close resemblance of dies, when in addition the dies were close together on the anvil and striking was very hurried».[35] Healy illustrates an obverse die for the *hektai* of Mytilene as being an "unfinished anvil-die, itself a product of hubbing": it is clearly

[32] Carter 1981, 203.

[33] The time taken to cut large piece punches for 17th century dies was surprisingly long. «There is ... the statement of Sir Isaac Newton [then Master of the Mint] in 1717 that an embossment and a punch for a halfpenny would take the engraver about six weeks ... [However,] it may be assumed that in a crisis an ordinary die might serve as a matrix and be used to raise a replacement punch» (Dyer 1993, 162). Clearly, there were differences in ancient and modern working methods, materials and products, that counsel against simple comparisons and conclusions.

[34] «I have the impression (but not more) that hubs, if used at all, were resorted to in order to 'block out' the main part of a design on the die – details such as hair and lettering would not be on the hub and would be added on the die after 'hubbing'» (Sellwood in his postscript to Schwabacher 1966).

[35] Gerin 1993, 22.

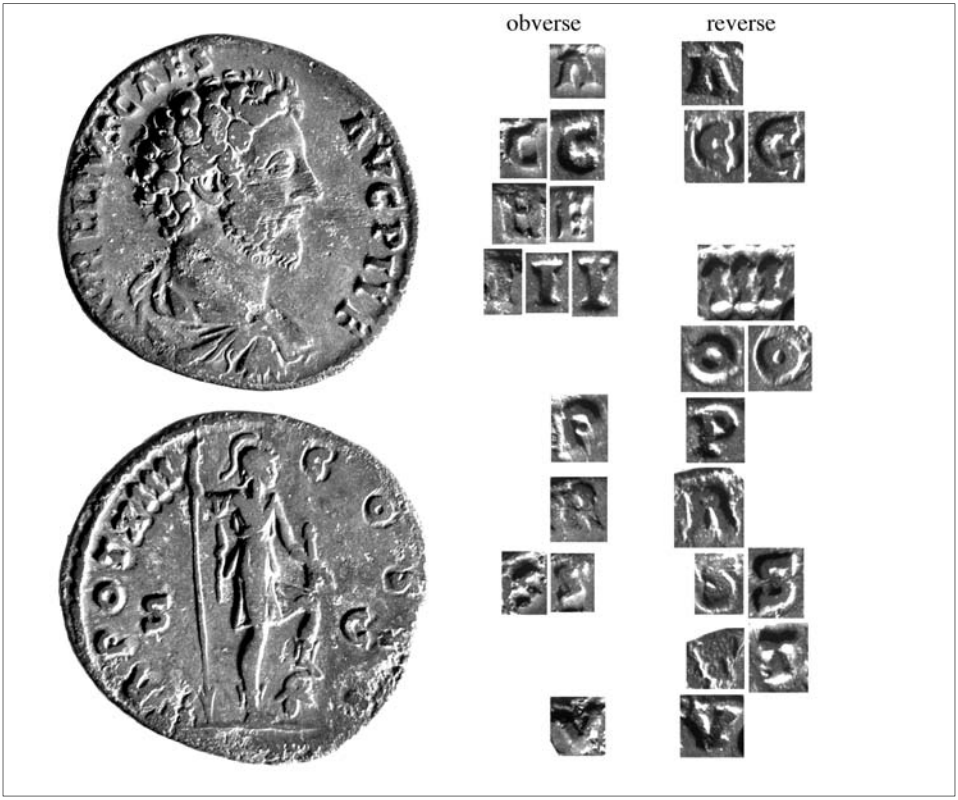

Fig. 5. - A sestertius of Marcus Aurelius, with "troughs' around the letters.

unfinished, but there is no proof that it results from the use of a piece punch.[36] In the coinage of the ancient Mediterranean world, there seems to be no sure example of the use of major-element piece punches,[37] although, as figure 8 shows, we have been able to identify the use of a few minor-element piece punches at Sybaris.

In northern Swabia, however, whole die-sinkers' tool-bags of the time of the late Republic and early Empire have come to light, which include – in addition to hammers, anvils, iron dies, and high-tin bronze hubs – minor-element piece punches, such as curves, points and lines.[38] Figure 4 shows the punches from the Klein-

[36] Healy 1993, 15 and pl. 1, 10 and 11.

[37] Schwarz 2000 makes the most extensive argument for the use of major-element piece punches, at the Roman provincial mint of Tyana. She argues in some detail that die-sinking was a complex, time-consuming and expensive process, and that it was difficult to copy portraits accurately. The utility of using piece punches is urged. A general punch for animals' forms, or for heads, is considered possible, it being necessary to retouch to the extent that a great number of variants can be generated from a single piece punch. A number of coins are then analysed, and the use of punches, produced by casting in clay moulds, is posited. It is suggested that cities bought imperial portrait punches, even perhaps whole dies, to which they then added their legend. I am unconvinced by the argument, or by the examples.

[38] Ziegaus 1998 and 2002: he is preparing a corpus of western Celtic dies.

Fig. 6. - "ROMA" cut in relief on quadrigatus dies.

sorheim find.[39] One may speculate that the stylised, repetitive elements of Celtic design favoured the use of punches. The Celts were advanced iron-smiths for their time, and this too may be in play, as iron replaced the high-tin bronzes used for most earlier dies.[40] The cyclic passage between positive and negative is a metal technology, and perhaps was not attempted in Greek and Roman mints, because gem-stone engraving was the parent technology of die-sinking, and relied on tools, such as drills, that cut in negative.[41] These influences probably did not constrain Celtic mint technology.

Here, too, the use of piece punches does not make die-studies impossible.

The existence of "troughs" around elements of a coin design may appear to be a diagnostic feature of punching, because of a lifting of the metal around the impression.[42] However, figure 5 analyses such a piece,[43] and shows that each letter is unique: letter punches were not used. A trough also outlines the helmet-crest on the reverse, the engraving of which appears to have been started with a drill, and not punched in. I suspect such troughs are an artefact of metal-flow.

Figure 6 shows the exergual legends of a number of Roman quadrigati, as an example of the difficulties of cutting features such as letters in relief. On these coins, "ROMA" is in incuse on a relief tablet, which was cut in negative into the die, leaving the letters standing proud. The clumsy, imperfect quality of this lettering must be seen against the overall beauty and workmanship of incuse-legend quadrigati. It suggests, I think, that hubs with lettering in relief were never cut in positive in any ancient coinage, but could only have been reproduced mechanically from a die, or from the impression of a coin. There are similarly very few examples, such as in the case of these quadrigati, where letters were cut in relief on a die.

It is clear, nonetheless, that Greek mints did sometimes prepare dies with the

[39] Ziegaus 2008, fig. 4. I thank him for this image.

[40] For a listing of known dies and associated tools from the beginning of coinage to *c*. 1350 AD, with many Celtic entries, see Malkmus 2007.

[41] Grierson 1956, 485.

[42] In describing 18th century punching, Cooper notes that «the metal [of the die] surrounding the impression lifted, and was then filed level» (Cooper 1988, 80).

[43] Peter 1996, 487 and pl. 27, 283. I thank him for having brought the piece to my notice, and for the photograph.

Fig. 7. Incuse reverses in Magna Graecia.
No. 1: Bruttium, Kroton; AR stater (8.13g), *c*. 480-430 BC; cf. SNG ANS 265, Freeman and Sear Mail Bid Sale 15, 19. No. 2: Bruttium, Kroton; AR stater (7.82g), *c*. 480-430 BC; HN Italy 2001, 2108, BMC 10; Freeman and Sear Mail Bid Sale 15, 20. No. 3: Lucania, Poseidonia; AR stater (7.46g), *c*. 530-500 BC; Maison Palombo Auction 5, 10.

design in relief (cut directly), in order to strike negative impressions on the coins themselves. Examples are the *hektai* of Mytilene,[44] the Etruscan incuse reverse bronze issues,[45] and, above all, the early silver issues of Magna Graecia, where negative reverses mirror positive obverses. Such reverse dies could easily have been pressed into service as piece punches to sink at least the major design elements on the obverse die,[46] but there is no convincing proof of this having occurred.

Noe, in studying Metapontum, argued from presumed utility that hubs were used to sink not obverses, but reverses.

> To cut the reverse die directly, the die-cutter would have had to remove the entire surface of the die, with the exception of the ear itself and the rim, and he would have had to cut to a depth equal to the relief of the highest point of the [corn-]ear. In other words, about three-quarters of the surface to a uniform depth of nearly 4 mm would have to be removed and all the delicate portions of the relief would have to be left untouched, including the rim as well as the awns. This feat is not impossible, but that it could have been carried out for so extended a coinage without having left some traces is almost inconceivable… All these difficulties would be eliminated,

[44] Cf. Healy 1993, pl. 1.

[45] *HN Italy* 2001, 27-28.

[46] «It seems to me that the principle of hubbing may have commenced with the earliest, incuse reverse coins of Magna Graecia. Here there had to be a good alignment between the dies. What easier way than by using the relief trussel to 'mark out' the main part of the design by hubbing?» (Sellwood 1962, 222). Sellwood did not attempt to document his suggestion.

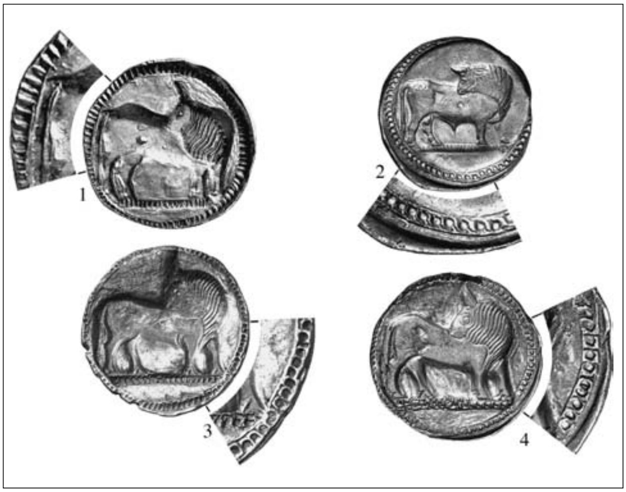

Fig. 8. - Incuse reverse borders on staters of Sybaris. No. 1: AR stater (8.43g), *c*. 550-510 BC; HN Italy 2001, 1729; Künker Auction 100, 5. No. 2: AR stater (8.03g), *c*. 530-510 BC; HN Italy 2001, 1730 var.; Numismatica Ars Classica Auction 25, 33. No. 3: AR stater (7.55g), *c*. 550-510 BC; HN Italy 2001, 1729; Lanz Auction 135, 46.No. 4: AR stater (7.97g), *c*. 550-510 BC; HN Italy 2001, 1729; Numismatica Ars Classica Auction 25, 31.

however, if what is known as a "hub" in the making of modern medals were used.[47]

Separate hubs, and not reverse dies, were, he thought, used for this purpose, because «if a reverse die was forced into a 'steel hub' in a heated state it would have 'drawn the temper of that hub'; that is, its heated condition would have burnt out the carbon of the hub and softened it. Unless the ancients had a knowledge of retempering such a hub, it could not have been used again.[48] The reverse dies are fully as numerous as the obverse ones and no evidence for re-using these hubs has been found.» He therefore postulated a separate hub for each reverse die. He argued further that «the bungling nature of the modelling [of a number of ugly reverses dies] could have been due to nothing else than an attempt to cut the die directly and the contrast of this crudity with more usual finish of the other dies supports the position that hubs were customary».[49]

The contortion in these arguments show the perils of arguing from presumed utility alone, and they can more parsimoniously be turned on their head: if in a coinage such as Metapontum – where reverse dies could so easily have served as hubs – they were not so used, then how much less likely it is that piece punches or hubs were used in other series.

Figure 7 shows the difficulties of cutting detail in positive, on a die or on a hub: The main elements of the reverse design stood proud on these dies, but the details (the eagle's feathers, the handles of the tripod and the legend, on the Krotoniate coins; Poseidon's hair, the trident, the *chlamys*, and the legend on the Poseidonian

[47] Noe 1984, 3.
[48] The argument is poor: they almost certainly did.
[49] *Ibidem*, 4.

Fig. 9. - Geto-Dacian transfer dies.

coin; and the border in all cases) are cut in negative.

A close look at some of the incuse reverse dies of Sybaris in figure 8 shows the difficulties die-sinkers faced in working small details on dies in positive. One of the most finicky tasks was to cut an incuse reverse mirror image of the obverse border of dots on the incuse reverses. Sometimes, as in no. 1, the die-cutter simply gave up, and instead cut a series of lines radiating from the centre. In no. 2, he cut a series of reversed-S-shapes through a raised circular band on the die, leaving an incuse central dot. (This technique can be compared with that of the obverse border of figure 7, no. 3, where the S-shapes have been complemented by a dot sunk into the die in the area left between the S-shapes.) Nos 3 and 4 show a rare use of a piece punches. The piece punch of no. 3 has a flat top, with a hole drilled into it, and the edges have been almost rounded, from a square original. The piece punch of no. 4 has a square, flat top, with a small bead on relief left on it. (The bead is not round, as would be the case if it had been made in negative with a drill, but lozenge-shaped.) These are the only sure uses of piece punches in a Greek mint that I have found. They do not mean that the overall design, or the major design elements, were hubbed, and pose no problems for die-identification.

It is, however, undoubtedly the case that dies were mechanically reproduced in antiquity, under certain circumstances. Forgers – presumably in the very cities and states they were forging – did so to make plated coins: Crawford, for example, has

> draw[n] attention to two coins in Hannover, one silver and one plated, which at first sight come from the same dies, but which display evidence of different and incompatible die-breaks. The only likely explanation of the phenomenon is that the dies used for the plated piece were mechanically copied from a pure silver piece, which has been struck from the same dies as the pure silver piece illustrated here before the appearance of some die-breaks. These derivative dies then acquired in use die-breaks of their own. [50]

Dies were also mechanically reproduced in frontier communities, where there was a dearth of official small change, and the coins they produced cannot all be classed as deliberately fraudulent, in the same way. [51] The iron-core, copper-plated

[50] Crawford 1974, 561 and pl. LXV, 1 and 2.

[51] For discussion of the role of informal coinages in such circumstances, see Peter 2004, 21-22, Wigg-Wolf 2004, and Pfisterer 2007a. Silver coins of good metal were not deliberately fraudulent, but plated pieces probably were.

copies of Roman *aes* coinage from Noricum and Pannonia are a good example.[52] In addition to the mechanical reproduction of dies, coins themselves were mechanically reproduced – for example, at Augusta Raurica – by casting.[53]

The mechanical reproduction of Republican *denarius* dies, and the striking of good silver coins from them, in the Geto-Dacian area, mainly in the late first century BC, is a separate phenomenon.[54] Figure 9 shows one such piece.[55] It is a hybrid with the obverse of *RRC* 410/5, Q·POMPONI MVSA of 66 BC and the reverse of *RRC* 382/1, C·NAE BALB of 79 BC, created with "transfer dies" made from actual coins. The edges of these are visible on both faces. On the reverse, the serrated edge of the model has been carried over onto the transfer die, off which a cud of metal has then broken at 5 o'clock. *Denarii* were also copied in the Geto-Dacian area by casting.[56] By statistical analysis of the metal of *denarii* in a sample of Romanian hoards, Lockyear tentatively suggests that between perhaps about 14%-30% of the coins were either struck or cast copies.[57]

[52] Pfisterer 2007b and Pfisterer & Traum 2005.

[53] «Ob es sich bei den gegossenen Denaren um Fälschungen, eine Art Notgeld, ein Denarsurrogat in Zeiten mangelhafter Münzversorgung oder gar einen Kleingeldersatz mit einem weit unter dem Denar liegenden Nominalwert handelt, ist nicht völlig klar. Wahrscheinlich lässt sich diese Frage mit modernen Begriffskategorien und -abgrenzungen gar nicht befriedigend lösen. Fest steht jedenfalls, dass es sich nicht lediglich um Fälschungen von Privaten handelt, da man in diesem Falle mit einer reichsweit regelmässigeren räumlichen Verbreitung des Phänomens - vergleichbar den subaeraten Prägungen - rechnen müsste; ferner weisen die bisher gefundenen Werkstätten keine Anzeichen einer versteckten Tätigkeit auf. Ich bin aber davon überzeugt, dass die gegossenen Denare in aller Regel hergestellt werden, um gleichwertig, also nicht als Denarfraktion bzw. Kleingeld, neben echten Münzen in Umlauf gebracht zu werden. Dies wird auch nicht nur durch die oft täuschende Qualität bezeugt, sondern auch durch das vereinzelte Auftauchen in Denarfunden» (Peter 2001, 244-245).

[54] Lockyear reviews the evidence for the copying of coins, both by striking – including with transfer dies – and casting, in what is now Romania (Lockyear (forthcoming), in particular the 12th and 14th pages of the article and Table 2.)

[55] No. HT3 on www.rrimitations.ancients.info, downloaded on 2 August 2008. I thank Phil Davis for allowing me to use this illustration.

[56] «During the preparation of the Bucuresti lot [122 coins from the Breaza hoard] it was noticed that some coins are identical to each other—not only is the type identical, as might be explained by the use of the same dies, but the shape of the flan, the position of the design and the position of the countermarks are also identical. (Poenaru Bordea and Ştirbu 1971). There is only one possible explanation: these coins must have been cast, almost certainly using a genuine coin to make the moulds. Five separate issues were cast with a total of 11 coins being identified. The dates of the issues copied range from 85-41 BC (Crawford's chronology)» (Lockyear (forthcoming), 9th page of article).

[57] «The metallurgical results have proved a difficult data set to analyse with many problems and pitfalls. The above estimates all have rather wide confidence limits and thus the exact proportion of copied coins in the hoards is still extremely unsure. […] We can be confident that there were more copies in the Breaza and Poroschia hoards than Chiţescu or Crawford had allowed for, and there is good reason to believe that there are copies in the Poiana, Stăncuţa and Şeica Mică hoards; the Zătreni hoard remains a marginal case. It would appear that the level of copying is around 30% taking a cautious line, or about 14% taking an ultra-conservative line. Obviously, extrapolating to the entire

Fig. 10. - Barbarian copies of denarii made with transfer dies, reworked both in the positive on the hub, and in the negative on the die itself.

The Geto-Dacian imitations are best seen as wealth objects in a pre-monetary society. [58] A similar phenomenon occurs, *c*. 225-250 AD, when Roman denarii were copied, probably in modern Hungary, and circulated into Poland, North Germany and Scandinavia, [59] again as wealth objects. [60] Figure 10 seems to show that hubs were cast from *denarii*, and were reworked in the positive, to cut away elements of the design. The hubbed dies themselves were reworked in the negative, to "strengthen" the lettering: [61] the artisan was obviously illiterate, because the resulting legend is gibberish. [62]

Forgeries from mechanically reproduced dies and barbarian transfer die issues, as

Dacian corpus from a small number of hoards is not ideal, and a further programme of analysis is needed to improve upon our estimates» (Lockyear (forthcoming), 24th page of article).

[58] «Coinage is to be envisaged as for the most part a fashionable form in which to hold and display wealth, alongside jewellery and other forms of mobile riches; the origin of the fashion perhaps lies in the perception of the power of money in the civilised and fascinating Greco-Macedonian Mediterranean world; there of course the power derived from a real economic function. Nor is there any reason to suppose that any change took place when Republican *denarii* replaced the assortment of Greek and native issues available earlier» (Crawford 1985, 229).

[59] Stribrny 2003, 51-62, 66-67 and 91-100.

[60] «Zunehmend wird in der Forschung einer Form des Austauschs auf der Ebene sarmatisch-germanischer Kontakte Aufmerksamkeit geschenkt, die als Gabentausch unter kriegerischen Eliten beschrieben wird. Die Träger des Tauschs werden als Elite angesprochen, da die hochwertigen Gaben in einer entsprechenden sozialen Schicht angesiedelt werden müssen … Die wichtigste, aus der Aufzählung des Parallelfundguts zu gewinnende Erkenntnis ist, dass die barbarisierten, barbarischen Denare nicht alleine in der Fundlandschaft stehen, sondern sich anderem Material in der Zeitstellung und Verbreitung an die Seite stellen lassen. Die Untersuchung der stempelverbundenen Gruppen zeigte, dass die Produzenten gezielt auf die Herstellung einer Wertsache in Form von Münzkomplexen hinarbeiteten» (*ibidem*, 99-100). This pattern of use of silver, probably by weight, continues amongst the Germanic peoples into the Viking age, including for Wergeld ("man-money") in feuds.

[61] For reworking of the hub, *ibidem*, 139, pl. 7, where the altar with snake, and the globe and rudder, are cut off the image of SALVS AVGVSTI. For strengthened letters, see 140, pl. 8.

[62] *Pace* Crawford (forthcoming; I thank him for having given me a sight of the draft): «Why would the producer(s) of these coins convert a correct legend into gibberish? For the thesis to be convincing, one would need the heads on the coins in question to be shown to be mechanical copies of heads on official Roman *denarii*». The process, as I have analysed it, shows how a fine mechanically reproduced portrait may be combined with a gibberish legend.

well as cast coins, if we do not recognise them, could in theory complicate certain methods for evaluating the monetary supply (for example, by extrapolating from the relative frequency of coin types in finds). However, this is more a theoretical than a practical problem. Plated forgeries are identifiable, and barbarian transfer die issues are geographically constrained, often identifiable, and limited in number.

What technologies were used to reproduce mechanically dies that included all elements of the design, in particular the lettering and beading? Mints were aware that it was possible to sink a negative image from a coin, even in the same metal and without specific hardening treatments, as brockages occurred in both bronze and silver. Figure 11 shows three *denarius* brockages. (I have chosen the examples to show the spreading that however occurred with repeated strikes, by 36% in the case of the Trajan piece).[63] To make a positive hub containing all design-elements directly, it would have been necessary to raise it from a completed negative die, but we do not have any indication that this was done, perhaps because it is more difficult to strike from the negative than from the positive,[64] perhaps because there was little utility to be gained, when few dies were needed. Most dies in the ancient world were made of high-tin bronze, an excellent metal for casting, which could be hardened and softened as needed by heat treatment.[65] Hubs could be made indirectly, by pressing a coin into clay, and casting a short bronze rod onto this. One example is the *victoriatus* hub from Ancient Spain, published as an official mint tool, but undoubtedly the work of a forger.[66] It would also have been possible, by one means or another, to cast negatives directly in bronze, and use these as dies: I do know of any such case. Bronze was used for cast hubs, because iron could not be cast with the precision of bronze.

Another method involved forcing a coin into a heat-softened die blank. Pfisterer and Traum have demonstrated the ease with which this can be done, in discussing iron-core, copper-plated *limes* copies of Roman *aes*, made with such transfer dies.[67]

[63] Spreading is also a phenomenon of modern hubbing, in 19th century practice by perhaps 0.1% radially for each progressive step. (Cooper 1988, 160-161.) If the same rate of spreading occurred, the *denarius* stuck to the upper die would have struck about 360 pieces by this stage.

[64] «It was more difficult to strike the positive punch from the negative matrix than the negative die from the punch. (It is easier to drive the upstanding positive design down into the surface of the die blank than to force the metal up into the incuse negative design)» (Cooper 1988, 162).

[65] Malkmus 2007, 139, die no. V-37 appears to be an iron reverse die for a Tiberian PONTIF MAXIM denarius or aureus. A similar icon die was found in 2004, in a layer datable to AD45, under amilitary officer's house, in *Vindonissa,* Switzerland (Doppler Pauli - Gabi & Peter 2005). The two finds are liked by the fact that the belt ornaments in both burials were made from the same matrix. These dies - both from military contexts - are the first examples of early (pre-fourth-century) Roman iron-dies for precious-metal coinage.

[66] García-Bellido 1986, commented on in Stannard 1988.

[67] Pfisterer & Traum 2005.

Fig. 11. - Brockages, showing spreading of the design. No. 1, RRC 287/1, Anonymous, c. 115-115 BC; NAC Auction 29, 304; 3.96g. No. 2, RRC 13/1, L.CASSIVS LONGINVS, c. 63 BC; Tkalek Auction 2008, 320; 3.96g. No. 3, Trajan, RIC 91ff; Gorny and Mosch Auction 130, 2113; 3.40g.

Peter has also shown experimentally that a silver denarius can be driven into heated iron, to make a die.[68]

In all probability, both bronze and iron dies could have been made either with a cast bronze hub, or by forcing a coin into them directly.[69] It would be nearly impossible to tell from the finished die. I suspect, however, that the direct impression method was easier with thicker coins (such as *aes*),[70] and that hubs were used with thinner coins, which were more likely to deform under direct hammering. A cast hub would provide a rod, which could more safely be struck with a hammer. Stribrny believes that the dies for the coin illustrated in figure 10 were made by the direct impression of coins. I interpret them as made with cast hubs, because of these reasons, but also because of the elements cut off the reverse design, which must have been done

[68] «Markus Peter, Basel, hat experimentell die Machbarkeit dieses Vorgehens überprüft. Da der Versuch bisher nicht publiziert wurde, erlaube ich mir aus seinem Brief (21.8.1995) zu zitieren: "daß man eine Münze auf einen erhitzen Metallzylinder schlagen kann und dadurch einen fertigen Stempel erhält, habe ich bei einen traditionell arbeitenden Schmied im Experiment nachvollzogen. Mit einer Bronzelegierung sei dies ohnehin kein Problem, ..., deshalb haben wir es gleich mit einem Eisenzylinder versucht. Diesen haben wir auf ca. 800°C erhitzt, einen römischen Denar draufgelegt und sofort mit einem kräftigen Hammerschlag 'geprägt'. Die Münze sprang weg (und zeigte danach erstaunlicherweise nur geringe Beschädigungen) und hinterließ einen deutlichen Negativabdruck. Auf ein anschließendes Härten des Zylinders haben wir verzichtet, und sind danach an das Prägen von Denaren gegangen. Das Ganze funktioniert also, lediglich mit der Versinterung der Oberfläche gab es Probleme, die sich aber umgehen lassen» (Stribrny 2003, 63-64).

[69] Pfisterer 2007b, 641, fig. 10.3, illustrates just such a forger's die in the form of a flat tablet, with a coin image pressed deep into the surface.

[70] See the problems that arose, even with a Roman Provincial bronze piece: «Das Stempeleisen wurde hellrot-orange geglüht, die Münze daraufgelegt und sofort mit einem langstieligen 5-kg-Hammer von über dem Kopf aus zugeschlagen. Dieser erste Versuch misslang völlig, da die Münze unter dem Prägeschlag explosionsartig zersplitterte und zudem kaum einen Abdruck im Eisen hinterliess. Aufgrund dieser negativen Erfahrung entschlossen wir uns, das Verfahren umzukehren und die nächste Münze nach unten zu legen, das glühende Stempeleisen daraufzusetzen und auf dieses zu schlagen ... Dieses Mal gelang der Versuch schon wesentlich besser, da zumindest ein Abdruck entstand und die Vorbildmünze den Schlag nahezu unbeschadet überlebte» (Pfisterer & Traum 2005, 130-131).

in positive, either from the coin itself or from a hub. It seems unlikely that the coin itself was recut, but rather that a cast hub was doctored.

In any case, there were shortcomings in all such dies, in particular the risk of carrying over the flan shape of the model, often with incomplete or off-centre images, lettering and beading. It is therefore implausible that they were used in the mints of the issues copied. They were rather made by those who lacked the technical or artistic skills to cut dies, that is, forgers, or peoples from other artistic traditions. Crawford has identified the specific Republican die that was mechanically reproduced by one forger, to make plated *denarii*.[71] A good number of Geto-Dacian transfer dies have been found.[72] (Geto-Dacian denarii were also made with fresh-cut dies, and in this case, often deviate wildly from the style of the originals.) To conclude, there is no convincing use of hubs by official Greek and Roman mints, in ways that might compromise die-studies and attempts to evaluate coin-production production from die numbers.[73] There is no sure sign of the use of major-element piece punches, and the evidence for the use of minor-element piece punches is very limited. Arguments from perceived utility are simplistic, and have little to offer. A key to understanding the role of hubbing lies in the distinction between working in the positive and working in the negative: ancient hubs, with lettering and beading, were not raised from dies or matrixes, but were cast in bronze from actual coins, with all the defects this involved. Alternatively, coins might be forced directly into heat-softened die blanks. Such tools were used only by forgers, frontier communities without official mints, and peoples beyond the frontiers. Celtic communities seem to have developed distinct and different minting practices, with superior iron-working technologies that included the use of piece punches and iron dies.

Bibliography

M. Amandry 1991, *Les coins,* in B. Françoise and H. Chew 1991, *Masques de fer. Un officier romain du temps de Caligula,* Paris, 185-191.

M. M. Archibald, J. R. S. Lang and G. Milne 1995, *Four early medieval coin dies from the London waterfront*, NC, 155, 163-200.

F. Bodenstedt 1981, *Die Elektronmünzen von Phokaia und Mytilene*, Tübingen.

I. D. Brown and C. H. Comber 1988, *Portrait punches used on the hammered coinage of Queen Elizabeth I*, BNJ, 58, 90-95.

[71] Crawford 1975, 561 and pl. LXV, 3 and 4, referring to Lupu 1976, 101.

[72] E.g. Lupu 1967. See also (Lockyear [forthcoming], 13th-14th page of article, Table 2).

[73] Bernhard Woytek informs me that he has looked closely at the dies for some periods of Trajan's coinage, using images of more than 40,000 coins: «I have found no evidence whatsoever for the mechanical reproduction of dies; all the dies are more or less easily distinguishable, and none of them was used to strike a disproportionately large number of coins: so probably no hubbing was involved in Rome in that period» (Personal communication, 29 July 2008).

Th. V. Buttrey 1967, *The denarii of P. Crepusius and Roman mint organization*, ANSMN, 21, 67-108.

G. F. Carter 1981, *Die-link statistics for Crepusius denarii and calculations of the total number of dies*, in Ch. Carcassonne and T. Hakens (eds.), *Statistique et Numismatique* (PACT 5), Strasbourg, 193-203.

G. F. Carter and B. G. Carter 1983, *Simulation of a Roman mint by computer*, in A. Aspinall and S. E. Warren (eds.), *Proceedings of the 22nd International Symposium on Archaeometry, University of Bradford, UK. 30 March-3 April 1982*, Bradford, 38-46.

D. R. Cooper 1988, *The art and craft of coinmaking: a history of minting technology*, London.

M. H. Crawford 1974, *Roman Republican Coinage*, Cambridge.

M. H. Crawford 1985, *Coinage and money under the Roman Republic*, Cambridge.

M. H. Crawford (forthcoming), *Review of Stribrny 2003*, Gnomon.

Fr. de Callataÿ 1997, *Receuil quantitatif des émissions monétaires hellénistiques*, Wetteren.

Fr. de Callataÿ 2003, *Receuil quantitatif des émissions monétaires archaïques et classique*s, Wetteren.

H.W. Doppler, T. Pauli - Gabi and M. Peter 2005, *Der Münzstempel von Vindonissia,* Gesellschaft Pro Vindonissa. Jahresbericht 2004, 41-49.

G. P. Dyer 1993, *Punches and dies in the 18th century*, in M. M. Archibald and M. R. Cowell (eds.), *Metallurgy in numismatics*, vol. 3, London, 160-168.

A. Finetti 1987, *Numismatica e tecnologia. Produzione e valutazione della moneta nelle società del passato*, Rome.

M. P. García-Bellido 1986, *A hub from ancient Spain*, NC, 146, 76-84.

P. P. Gaspar 1993, *Coining and die-making techniques in the 17th century*, in M. M. Archibald and M. R. Cowell (eds.), *Metallurgy in numismatics*, vol. 3, London, 130-142.

D. Gerin 1993, *Techniques of die-engraving : some reflections on obols of the Arcadian League in the 3rd century B.C*, in M. M. Archibald and M. R. Cowell (eds.), *Metallurgy in numismatics*, vol. 3, London, 20-25.

U. Giampaoli 1917, *Contributo alla storia della Zecca di Massa di Lunigiana. Origine della zecca e valore delle monete Massesi*, RIN, 311-365.

Ph. Grierson 1956, *Note on stamping of coins and other objects*, in Ch. Singer *et al*. (eds.), *A history of technology*, vol. 2, London, 485-292.

E. J. Harris 1990, *The repeated use of a faulty punch on some Henry V dies*, Seaby's Coin and Medal Bulletin, 850 (May), 107-108.

J. H. Healy 1993, *Techniques of die-engraving: evidence for the use of hubs*, in M. M. Archibald and M. R. Cowell (eds.), *Metallurgy in numismatics*, vol. 3, London, 7-19.

G. F. Hill 1922, *Ancient Methods of Coining*, NC, 5 (2), 1-42, pl. 1.

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

R. M. Karras 1985, *Early twelfth-century Bohemian coinage in the light of a hoard of Vladislav I*, ANSMN, 30, 179-210.

K. Lockyear (forthcoming; at http://eprints.ucl.ac.uk/4832/1/4832.pdf), *Aspects of Roman Republican coins found in Late Iron Age Daci*a, in *Miscellanea numismatica Antiquitatis. In honorem septagenarii magistri Virgilii Mihailescu-Bîrliba oblate*, Bucarest, 2008 (at http://eprints.ucl.ac.uk/4832/1/4832.pdf;).

N. Lupu 1967, *Aspekte des Münzumlaufs im vorrömischen Dakien*, JNG, 17, 101-121.

W. Malkmus 2007, *Ancient and medieval coin dies*, in L. Travaini and A. Bolis (eds.), *Conii e scene di coniazione*, Rome, 75-240.

S. P. Noe 1984 (with additions and corrections by Ann Johnston), *The Coinage of Metapontum, Parts 1 and 2*, New York.

J. J. North 1995, *A broken crown punch in class 3g of Edward I*, NumCirc, 103 (3), 89.

J. J. North 1992, *A short-lived letter punch of Edward I*, NumCirc, 100 (1), 9.

J. J. North 1988, *A re-examination of classes 7 and 8 of the short cross coinage*, BNJ, 58, 25-39.

M. Peter 2004, *Imitation und Fälschung in römischer Zeit*, in A.-F. Auberson, H. R. Derschka and S. Frey-Kupper (eds.), *Faux—contrefaçons—imitations. Actes du quatrième colloque international du Groupe suisse pour l'étude des trouvailles monétaires* (*Martigny, 1er-2 mars 2002*). *Fälschungen—Nachahmungen—Imitationen. Sitzungsbericht des vierten internationalen Kolloquiums der Schweizerischen Arbeitsgemeinschaft für Fundmünzen (Martigny, 1.–2. März 2002), Untersuchungen zu Numismatik und Geldgeschichte* 5, Lausanne, 19-30.

M. Peter 2001, *Untersuchungen zu den Fundmünzen aus Augst und Kaiseraugst* (Studien zu Fundmünzen der Antike 17), Berlin.

M. Peter 2000, *Die "Falschmünzerförmchen": ein Vorbericht*, Jahresberichte aus Augst und Kaiseraugst, 21, 61.

M. Peter 1996, *Augusta Raurica I. Augst 1949-1972* (Inventar der Fundmünzen der Schweiz 3), Lausanne.

M. Pfisterer 2007a, *Falschgeld und Beischläge der Prinzipatszeit in Carnuntum—Ein Überblick*, in M. Alram and F. Schmidt-Dick (eds.), *Numismata Carnuntina—Forschungen und Material, Die Fundmünzen der römischen Zeit in Österreich Abteilung III: Niederösterreich, Band 2: Die antiken Fundmünzen im Museum Carnuntinum*, Vienna, 635-642.

M. Pfisterer 2007b, *Limesfalsa und Eisenmünzen – Römisches Ersatzkleingeld am Donaulimes*, in M. Alram and F. Schmidt-Dick (eds.), *Numismata Carnuntina—Forschungen und Material, Die Fundmünzen der römischen Zeit in Österreich Abteilung III: Niederösterreich, Band 2: Die antiken Fundmünzen im Museum Carnuntinum*, Vienna, 643-764.

M. Pfisterer and R. Traum 2005, *Der Herstellungstechnik subferrater Kopien römischer Buntmetallmünzen: ein praktisches Experiment*, SNR, 84, 125-140.

Gh. Poenaru Bordea and C. Ştirbu 1971. *Tezaurul de denari romani republicani şi de la începutul principatului descoperit la Breaza, comuna Lisa (jud. Bra¸sov)*, Studii şi Cercetări de Numismatică, 5, 265-282.

P. P. Ripollès, J. Muñoz and M. M. Llorens 1992, *The original number of dies used in the Roman provincial coinage of Spain*, in *Proceedings of the XIth International Numismatic Congress*, vol. 1, Louvain-la-Neuve.

RRC (see above, M. H. Crawford 1974, *Roman Republican Coinage*, Cambridge).

W. Schwabacher 1966, *The production of hubs reconsidered*, NC, 7 (6), 41-45.

H. Schwarz 2000, *Die Herstellung von Münzbildern: Einsichten in die Stempelproduktion kaiserzeitlicher Stadtmünzen anhand tyanitischer Prägungen*, in D. Berges and J. Nollé (eds.), *Tyana: archäologisch-historische Untersuchungen zum südwestlichen Kappadokien*, Bonn, 343-356.

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

A. M. Stahl 2004, *Technological Innovation and Control at the Medieval Venetian Mint*, in M.-T Zenner (ed.), *Villard's Legacy: Studies in Medieval Technology, Science and Art in Memory of Jean Gimpel (Avista Studies in the History of Medieval Science, Technology and Art)*, Aldershot (UK) and Burlington (USA), 189-196.

C. Stannard 1988, *The hub from ancient Spain reconsidered*, NC, 148, 141-143.

C. Stannard 1993, *The adjustment al marco of the weight of Roman Republican denarii* *blanks by gouging*, in M. M. Archibald and M. R. Cowell (eds.), *Metallurgy in Numismatics*, vol. 3, London, 45-70.

K. Stribrny 2003, with contributions by H.-G. Bachmann and P. Hammer, *Funktionsanalyse barbarisierter, barbarischer Denare mittels numismatischer und metallurgischer Methoden* (Studien zu Fundmünzen der Antike 18), Mainz am Rhein.

L. Travaini 2007, *I conii e le zecche*, in L. Travaini and A. Bolis (eds.), *Conii e scene di coniazione*, Rome, 25-64.

H. Vanhoudt 1986, *De Merovingische munttechniek: het gebruik van een patrijs*, RBN, 132, 157-158.

D. Wigg-Wolf 2004, *Zur Interpretation und Bedeutung der "Barbarisierungen" der römischen Kaiserzeit*, in A.-F. Auberson, H. R. Derschka and S. Frey-Kupper (eds.), *Faux-contrefaçons-imitations, Actes du quatrième colloque international du Groupe suisse pour l'étude des trouvailles monétaires (Martigny, 1er-2 mars 2002). Études de numismatique et d'histoire monétaire 5. Fälschungen-Nachahmungen-Imitationen. Sitzungsbericht des vierten internationalen Kolloquiums der Schweizerischen Arbeitsgemeinschaft für Fundmünzen (Martigny, 2.3. März 2002), Untersuchungen zu Numismatik und Geldgeschichte* 5, Lausanne, 55-75.

B. Ziegaus 2008, *Keltische Münzwerkzeuge aus dem Nördlinger Ries: ein Vorbericht*, in R. Cunz, U. Dräger and M. Lücke (eds.), *Interdisziplinäre Tagung zur Geschichte der neuzeitlichen Metallgeldproduktion. Stolberg 2. April bis 4. April 2006. Teil 1 veranstaltet von der Numismatischen Kommission der Länder in der Bundesrepublik Deutschland und der Braunschweigischen Wissenschaftlichen Gesellschaft* (Abhandl. Braunschweigischen Wiss. Ges. 60), Braunschweig, 115-129

B. Ziegaus 2002, *Ein neuer keltischer Müzstempelfund aus dem Nördlinger Ries (Schwaben),* International Numismatic Newsletter, 39 (Spring/Summer), 3-5.

B. Ziegaus 1998, *Keltisches Werkzeugdepot eines Münzmeisters und Toreuten aus Schwaben*, International Numismatic Newsletter, 32 (Autumn/Winter), 2-3.