AMERICAN JOURNAL OF NUMISMATICS

25

Second Series, continuing
The American Numismatic Society Museum Notes

THE AMERICAN NUMISMATIC SOCIETY
NEW YORK
2013

© 2013 The American Numismatic Society

ISSN: 1053-8356
ISBN 10: 0-89722-324-1
ISBN 13: 978-0-89722-324-9

Printed in China

Contents

American Journal of Numismatics

Andrew R. Meadows
Editor

Oliver D. Hoover
Managing Editor

Editorial Committee

John W. Adams
Boston, Massachusetts

Jere L. Bacharach
University of Washington

Gilles Bransbourg
American Numismatic Society

Andrew Burnett
British Museum

Evridiki Georganteli
Harvard University

Kenneth W. Harl
Tulane University

Paul T. Keyser
IBM T. J. Watson Research Center

John M. Kleeberg
New York, New York

John H. Kroll
Oxford, England

Eric P. Newman
St. Louis, Missouri

Ira Rezak
Stony Brook, New York

Stephen K. Scher
New York, New York

Stuart D. Sears
Westport, Massachusetts

Peter van Alfen
American Numismatic Society

Bernhard Weisser
Münzkabinett
Staatliche Museen zu Berlin

AJN Second Series 25 (2013) pp. 49–118
© 2013 The American Numismatic Society

A Metrological Survey of Ptolemaic Bronze Coins

Daniel Wolf*

Analysis of many Ptolemaic bronze coins clarified relationships between their weights and values during the reigns of Ptolemy I–IV. Two aggregate bronze weight standards came to light for time periods before and after a coinage reform *c.* 265–260 BC. Analyses of the new empirical data showed that previous theoretical Ptolemaic bronze weight standards were incorrect. Large samples gave more confident estimates for the weight standards, the relationship between them, and the value structures of denomination series. The data also revealed some previously unrecognized denominations. The analyses provided reliable mean weight values for many coin types to replace conflated approximations found in preceding literature. Statistical and graphical comparisons of data for individual types and value series showed that post-reform minting technology permitted weight-to-value relationships that were highly conserved and faithfully executed for half a century at Alexandria and provincial mints.

Bronze coins of the Ptolemaic empire comprise numerous and varied types that were most completely catalogued by J. N. Svoronos.[1] Within the framework of the types and catalogue entries enumerated by Svoronos and subsequent scholars,[2]

* ptolemy@megagem.com.

1 Svoronos 1904–1908. References to Svoronos's catalogue types are abbreviated: e.g. Sv 965 for Svoronos catalogue number 965.

2 Kromann and Mørkholm 1978; Weiser 1995; Pitchfork 2000; Noeske 2000.

the study of values and denominations for Ptolemaic bronze coinage has always faced a refractory conundrum. Some Ptolemaic bronze coin types with unique combinations of design and controls, e.g. Sv 412, vary in weight. Sv 412 is listed in Svoronos's catalogue from 74 g to 105 g. Its magnitude and design uniqueness imply it nevertheless expresses one denomination (value). Other types catalogued as separate denominations are less easily distinguished because they share identical designs (e.g. Sv 1005–1009) and/or controls (e.g. Sv 964–967). Different size ranges and denominations were produced during different time periods. Prior to *c.* 260 BC the maximum weight is about 16 g; thereafter up to about 100 g.

A Metrological Approach

Quantitative analysis of coin weights spanning a long period of time may clarify relationships among Ptolemaic bronze coin values and sizes. Statistical tests might distinguish types that differ only in size and weight and inform comparisons of similarly-sized coins of different mints or time periods. Quantitative study could apply to various measurable attributes: diameter, weight, thickness, alloy composition. This survey focuses solely on weight because it is easy to measure (unlike alloy composition), unequivocal, and verifiable within the small range of error of weighing instruments.[3]

The purpose of this survey is to examine enough recorded specimen weights to address three goals:

1. Obtain confident weight distributions and statistics (e.g. mean, range, etc.) for unambiguously specific types (e.g. Sv 412) and apply statistical comparisons to types potentially conflated by similarity of design and controls (e.g. Sv 964 vs. Sv 965).

2. Illuminate a larger context of weight standards by comparing individual types and denominations across different emission series, mints, and time periods. A weight standard implies that weight ratios are uniformly related to monetary value (denomination) ratios, e.g. that if diobol coins weigh twice as much as obols then obols also weigh twice as much as hemiobols, that there is a unit of value with a specific weight. A goal of this survey is to explore large numbers of specimens to learn confidently whether Ptolemaic bronze coins, with large individual weight variation, do manifest weight standards.

3. Address the questions of putative ideal weight raised by earlier scholars and the fiduciary vs. intrinsic nature of Ptolemaic bronze coinage that is obscured by their great variability.

3 For a recent metrological study of small Judaean bronze coins, also focused solely on weights of many specimens for coin types that individually vary and for which diameter measurement is likewise potentially equivocal, see Hendin 2009.

Precedents

The Ptolemaic bronze coin metrology begun by H. Brugsch (1889), nearly contemporary with the first systematic catalogue of Ptolemaic coinage by R. S. Poole (1882), tabulated an almost bewildering volume of theoretical exchange values calculated to a precision of five significant figures. He posited relationships of pre-coinage Egyptian weight standards (e.g. magnitudes of *mine*, *deben*, *kite*, etc.) to the Ptolemaic coin weights. Similar exchange theories of F. Hultsch (1903) were even incorporated directly into Svoronos's four-volume work of 1904–1908. Hultsch calculated exchange values between bronze, silver, and gold coinage of different ancient weight standards (Ptolemaic vs. Demotic or Phoenician, etc.). He also proposed exact theoretical weights, namely a bronze drachm of 106.8 g (30 silver drachms) preceding the reform (*c.* 260 BC) and 71.2 g (20 silver drachms) after the reform. Both values presumed bronze coins weighed exact decimal multiples of a 3.56 g Ptolemaic silver drachm. The early metrological work's importance is that it was contemporary to (even incorporated within) other early studies of Ptolemaic coins. Its weakness is that the little empirical data Hultsch cites is relegated to footnotes. While many attributions of the pioneering scholars have improved in light of modern discoveries the early theoretical bronze coin weight standards remain largely untested.

In 1988, V. Van Driessche presented a modern empirical Ptolemaic coin metrology, albeit partly within the context of Hultsch's theoretical constructs. She demonstrated the problem of large bronze coin weight ranges and the unsatisfactory state of Ptolemaic bronze coin metrology compared to better-studied precious metal coinage. Her histograms and sample modes are based on the weights of many coins and results differ from Hultsch's predictions, yet her important paper does not fully break with his ideas to place Ptolemaic bronze metrology on a strictly empirical footing.

Wolfram Weiser (1995) also reprised, without reference or quantitative justification, Hultsch's 30- and 20-drachm weight standards (106.8 and 71.2 g). Lorber (2000, 2005) gave convenient estimates and ratios of ideal weights for specific denominations and types based on Van Driessche's ideal denominational weight tables.

Catalogues and Ptolemaic coin references prior to Weiser's largely expressed bronze coin denominations as size or weight 'modules' without monetary values (e.g. drachm, hemidrachm, etc.). Svoronos gave alphabetic denomination lists in order of decreasing diameter despite lacking data for individual coin diameters. Van Driessche enumerated denominations in order of decreasing ideal weights. Weiser gave two monetary values for each type: drachm, obol, etc., and another value in decimal units.

Most recently, Picard and Faucher (2012) assigned a monetary value system to Ptolemaic bronzes, largely adopted here. This study expands on the empirical metrology of Van Driessche, for more types over a longer period to show relationships among Ptolemaic bronze coins within contemporary series (horizontally) and across different series, times, and locations (vertically).

Type Definitions, Grouping and Methodological Limitations

Coin types and series here are largely as defined by Svoronos's catalogue, refined and improved by Lorber (forthcoming). Picard and Faucher (2012) have proposed a modern organization of Ptolemaic bronze coins into series of related types with denomination values. Aggregation of comparable denomination coin types from those various series are mostly according to shared design elements and other subordinate features (e.g. controls, mint marks, regnal symbols, etc.). For example, Svoronos 562, 582 , 602, and 625 were grouped (Series 2H) because they differ only in secondary controls. Each catalogued type is listed individually for clarity. Subjectivity of some aggregations and comparisons is acknowledged and others may explore alternatives because all the data used here are freely available. A few specimens are not from published catalogues or reference books and grouped based on my best judgement. This survey includes Ptolemaic coinage produced from *c.* 305 to *c.* 205 BC. A major reform of the Ptolemaic monetary system, especially for the bronze coins, took place about 260 BC and is widely recognized in the scholarship of Ptolemaic coinage.[4] This study includes the period preceding *c.* 260 BC, referred to as 'pre-reform.' The subsequent period is called 'post-reform.'

Data and Sources

A total of 1,582 pre-reform and 4,036 post-reform coin weights are organized in digital databases from traceable sources. About half are from institutional collections and reference catalogues (e.g. Svoronos, Danish National Museum, British Museum, American Numismatic Society) and half from published hoard finds, private collections, and traceable commercial sale and auction records. The metrology of the coinage of Ptolemy Philadelphus minted in Sicily has been published elsewhere.[5]

Data Quality and Precision

Most types are accepted as identified and weights as stated in their source publications without photographic or physical verification. For Svoronos's catalogue and the ANS collection database many cannot be photographically verified. Care was taken to avoid duplication or repetition of data. Sometimes Svoronos or other catalogue specimens are duplicated in other publications (e.g. Svoronos includes some coins also listed in other collections such as those of the Danish National Museum and the British Museum). Most commercial sale

4 Lorber 2012.
5 Wolf and Lorber 2011.

and auction records used here are from 2000–2013 to avoid recording coins that may have appeared in commerce more than once. Almost all coin data are from traceable sources.

The British Museum provided a modern database with more recent and accurate weight records (in grams) than were published by Poole (measured in grains). Some of their data were directly verified. Precision of weighing varies for different sources, with values usually reported in one hundredths (0.01) of a gram but in some cases either in tenths (0.1) or thousandths (0.001) of a gram. Manual data entry was performed cautiously but errors of transcription cannot be excluded. Corrections are solicited.

Small measurement or typographical errors in published reports probably have negligible effect for large samples from many sources. Many data from many sources may best produce convincing average coin weights and comparisons. All data for this study are freely available so that opportunities for corrections and alternate interpretations are open to others.

Approximate Type Identifications

Some coins are recorded with the notation 'cf' that have a close resemblance to, but cannot be precisely identified with, a single Svoronos catalogue number. This may be due to wear or strike quality making a control symbol unreadable. Sometimes a design or legend variation excludes exact identification despite similarity to a specific catalogue-numbered type. These approximations are noted in the databases and are included in groupings or aggregations where that is justifiable, even if the specific catalogue-numbered type cannot be recognized. It is only important that a coin belongs to the group, irrespective of its exact catalogue number, when averaging weights of related types.

Broken, severely damaged (e.g. holed), or badly corroded coins cannot contribute useful quantitative information and were excluded. Weights that seem low or high were not, per se, grounds to exclude recognizable coins or coins listed in scholarly publications. A uniform method was applied to exclude 'outliers' (extremely high or low values) from comparisons but 'outlier' coin weights are not excluded, per se, from the database.[6] Large weight ranges are actually one rationale for these analyses. Potentially conflation of types sharing similar designs, that differ only in size and weight, is another rationale for statistical analysis that may better clarify relationships.

Groups of Related Coin Types

Tables 1, 2, 3, and 4 (see Appendix 1) present the data for individually catalogued coin types as well as grouped summaries for relevant combinations. Table 1 covers Series 1 and 2, Table 2 covers Series 3, Table 3 covers Series 4, and Table 4 covers

6 Tukey's criterion identifies outliers as those data more than 1.5 times the interquartile range above the third quartile or below the first quartile, respectively.

Series 5. Each coin type is represented by a row with twelve columns:

1. Svoronos catalogue number
2. Series and sub-series identification code
3. Value (denomination in *chalkoi*)
4. Number of specimens confidently identified for the specific catalogue number
5. Mean weight
6. Standard deviation
7. Gaussian distribution fit estimate (see Appendix 1)
8. Number of additional approximate-identification ('cf') specimens
9. Number of 'outliers' (according to Tukey criterion, see Appendix 1)
10. Adjusted number of specimens (including 'cf' and excluding outliers) for grouped totals
11. Mean weight of specimens as adjusted to include 'cf' and exclude outliers for grouped totals
12. Gaussian distribution for the adjusted specimens (see Appendix 1) for grouped totals
13. Calculated mean unit (*chalkous*) weight for the adjusted group of specimens (adjusted mean divided by the number of *chalkoi*) for grouped totals

Rows in bold type are aggregate totals for each denomination in a series or sub-series. Most rows for totals (bold type) aggregate multiple catalogue types of a single denomination for a particular series. Occasionally only individual catalogue types exist for certain denominations so those aggregate (bold type) rows reflect only that one catalog type. A few catalog types are not included here because there are no available recorded weights of even a single specimen.

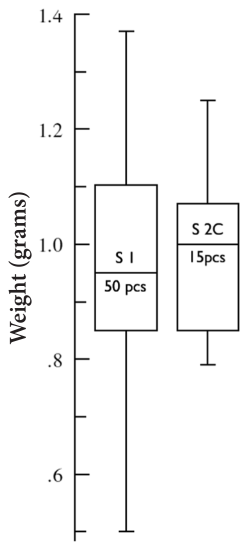
A. Pre-Reform Coinage

Table 1 includes the individual type and group summaries for weight data of Series 1 and 2, the coinage preceding the coinage reform of *c.* 260 BC. We can address weight standards best after learning how the groups, identified by numismatic criteria, are related according to weight.

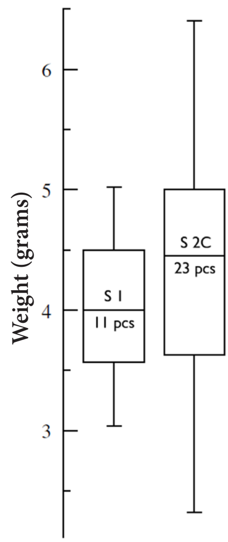
Alexandria issues are subdivided based on control configurations and shared designs. The Alexandria issues of Series 1–2C comprise only small coins and two obverse portraits while Series 2D introduced new larger sizes and new designs. Nomenclature here is largely based on that of Picard and Faucher (2012) with a few additional divisions of Alexandrian Series 2D (2E–2H).

Series 1 through 2C

Alexandrian one-*chalkous* types occur in Series 1 and Series 2C. Their mean weights are (excluding one outlier specimen) 0.987 and 0.957 g, a difference of about 3%, suggesting they are similar. Graph 1 box-plots (see Appendix 2) also



Graph 1. Box plot comparison of Series 1 and Series 2C one-*chalkous* groups.



Graph 2. Box plot comparison of Series 1 and Series 2C hemiobol groups.

show the weight ranges. *Chalkoi* of Series 1 and 2C share weight properties which may exemplify systematic *chalkous* production in both coinages. The overall mean weight of all 65 one-*chalkous* specimens taken together is 0.964, a first step toward estimating a weight standard. Statistical comparison test results (Mann-Whitney U test and Kolmogorov-Smirnov test) for Series 1, 2A, 2B, and 2C are summarized in Table 5.

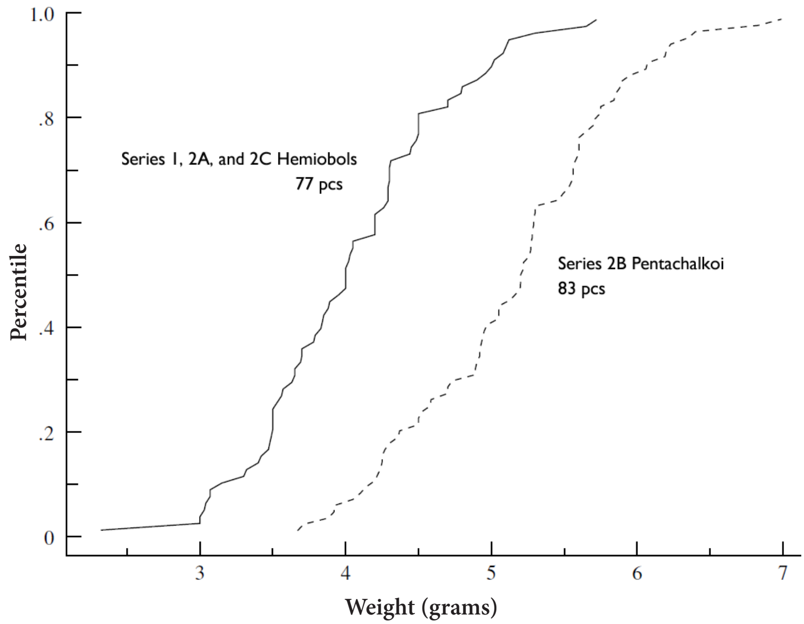
Table 5. Series 1–2C weight distribution comparisons.

Size	**Series (#)**	**KSTest**	**UTest 2-tailed**
Chalkous	1 (50) and 2C (15)	0.809	0.63 similar*
Hemiobol	1 (11) and 2A(44)	0.576	0.40 similar*
Hemiobol	1+2A+2C (77) and 2B (83)	0.000	0.00 different

*Values over 0.05 indicate similarity.

The larger coins of the same two series may be compared in a similar fashion. The mean values are 4.073 and 4.368, their box plots shown in Graph 2. Comparison tests show the distributions are similar, like the corresponding one-*chalkous* types.

To visualize all the data values (outliers excluded) of Series 1 and 2C we plot weights (grams) on the Y-axis against denominations (*chalkoi*) on the X-axis. The least-squares (regression) method generates a best estimate linear equation for all the data values. Its slope (grams per *chalkous*) estimates a weight standard that fits all the plotted data. In this case applying the least squares method to 99 data of



Graph 3. Kolmogorov-Smirnov test percentile graph comparison of Series 1, 2A, and 2C hemiobols (left) and Series 2B p*entachalka* (right).

Series 1 and 2C together (65 *chalkoi* and 34 hemiobols) yields a best-fit line with slope of 1.10 g per *chalkous*.

Hemiobols of Series 2A are also comparable to those of Series 1. A combined regression plot for all coin weights of Series 1, 2A, and 2C (a single 6.4 g outlier excluded) is shown in Graph 4 (below) with a slope of 1.02 g per *chalkous*.

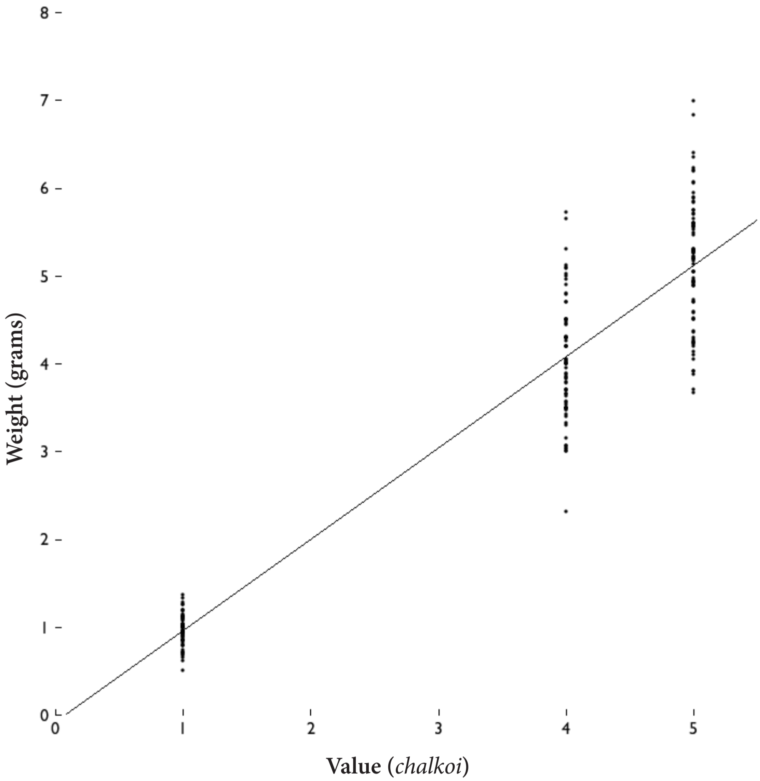
Series 2B stands out with a mean weight of 5.137 g, about 25% greater than hemiobols of Series 1, 2A, and 2C (4.06 g). Percentile plots of both groups, showing distinct and uniform separation, are seen together in Graph 3. Although major design elements are shared among all four groups, Series 2B coins with the aphlaston mark are heavier and those groups clearly differ.

Series 2B coins differ from the hemiobol data sets. They are:

a. either hemiobols with a weight approximately 25% greater (for no apparent reason) than the other six data sets of Series 1, 2A, and 2C

b. or a different denomination, perhaps 5-*chalkoi* (*pentachalkon*)

Only the second hypothesis (b.) can be tested. Graph 4 is a regression plot for all the data of Series 1, 2A, 2B, and 2C treating 2B coins as 5 *chalkous*. Its slope of 1.040 is approximately the same as the previous regression plot slopes. Given the fairly

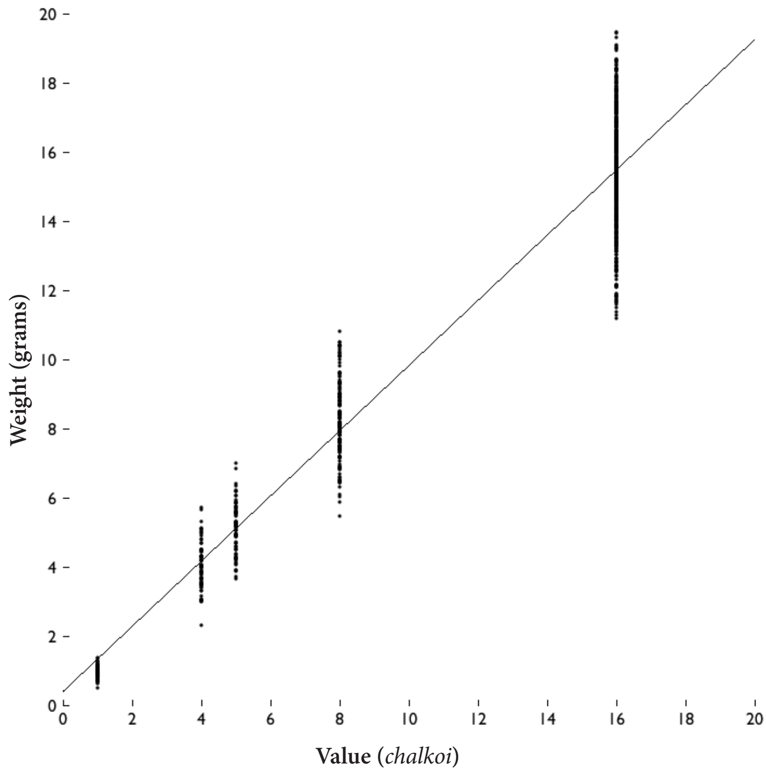


Graph 4. Series 1–2C regression plot.

large sample for Series 2B (83 specimens) it is difficult to avoid the conclusion that these coins represent a *pentachalkon* denomination.

That Series 2B metrologically indicates a *pentachalkon* denomination does not speak to its meaning and Svoronos, noting early hemiobols of 17 and 22 mm, did not propose a *pentachalkon* denomination. Hultsch (1903: 19) mentions a *pentachalkon* symbol without identifying a coin type for that value. This evidence for a *pentachalkon* is persuasive because it includes several catalogued types all with the aphlaston mark and a fairly large sample size. The ratio of mean weights between 2B coins and related coins that lack the aphlaston mark is also very nearly 5:4. Potential identification of a *pentachalkon* denomination is metrologically justified, novel, and merits further study.

Overall we note a range of unit weights of groups in Series 1, 2A, 2B, and 2C from 0.957 to 1.027 g per *chalkous* and the combined regression (Graph 4) suggests a unit weight of 1.040 g per *chalkous*.



Graph 5. Alexandrian Series 1–2H regression plot.

Series 2D–2H

Series 2D–2H have more designs, larger denominations, and many more catalogued types (distinguished by many control symbols) than Series 1 through 2C. Series 2D–2H also are abundantly represented, about 40% of the entire data set of pre-reform coins. The majority of those (about 550) are laureate Zeus diobols that are segregated by configurations of controls and symbols on the reverses into seven sub-series: 2Di, 2Dii, 2Diii, 2E, 2F, 2G, and 2H.

Smaller denominations of Series 2D, found only in Sub-series 2Di, are difficult to interpret. Sv 238 and 239 share a single design with overlapping weight distributions, yet they are recorded as *dichalkon* and hemiobol denominations. This ambiguity is magnified by a hitherto uncatalogued type sharing their HP monogram but with a portrait of short-haired Alexander, recorded as a single *chalkous* denomination, but with weights similar to Sv 238 and 239. The denominations of Sv 238, 239, and the short-hair type are unclear and, while they will benefit from additional analysis, they are excluded from this discussion.

The larger denomination bearing the portrait of Ptolemy I, putative triobols of Series 2D, are so few and so inconsistent that they also cannot contribute to this metrological analysis.

Diobols dominate the Series 2D–2H data; the seven sub-series having mean weights from 14.3 to 16.0 g (~12% range). Sub-series 2Di, 2Dii, and 2Diii share related controls and control configurations and, combined, are 249 values (excluding two outliers) with mean weight of 15.71 g. A second large group of diobols is sub-series 2F, comprising 179 specimens (excluding four outliers) with mean weight of 15.77 g. These two largest diobol groups are similar (U-test P>0.50, KS P=0.586), implying uniformity for a large majority of Series 2D–2H diobols. The mean weight of this combined majority of Series 2D and 2F diobols (2Di, Dii, Diii, and 2F) is 15.74 g or about 0.98 g per *chalkous*.

Sub-series 2H diobols, marked with the ⳩ monogram under the Galatian shield, has the lowest sub-series mean weight, 14.3 g. This is about a 10% lower mean weight compared to the majority of related coins and merits further study. The difference is statistically significant but lies within the range of variation seen in other pre-reform Ptolemaic bronzes. Its meaning is unclear but the reduced weight compared to the preceding majority is large enough—based on over 100 specimens—to suggest additional research to understand the substantially lower weight.

Sub-series 2E is only a single catalogued diobol type, Sv 550, represented here by just 17 specimens, so its relatively low mean weight of 14.4 g is difficult to interpret. Series 2E also includes a larger denomination (Sv 549) known by only two specimens and therefore not helpful in this study. Sub-series 2G, with ΣΙ below the shield, has mean weight of 14.98 g but is also associated with only two catalogued types (Sv 554 and 564), represented here by only 11 specimens, making its metrology difficult to interpret separately.

Only three of the seven diobol sub-groups also have obol denominations in Series 2D–2H, ranging from 7.526 to 8.367 g mean weight. The 11% range is similar to that observed for the corresponding diobols.

Graph 5 is a regression plot for 948 Alexandrian pre-reform bronzes (Series 1 through 2C and the obols and diobols of Series 2D–2H, outliers excluded) with a slope (weight standard estimate) of 0.943 g per *chalkous*. Sub-series 2Di, 2Dii, 2Diii, and 2F comprise over 400 of those 948 data points. Another estimate is calculated by dividing each coin's weight by its denomination to obtain a mean 'per coin' unit weight. The pre-reform Alexandria mean unit (one-*chalkous*) weight of 934 coins (28 outliers excluded) is 0.981 g.

Table 6 (below) presents some group summaries of pre-reform coins, the first portion of which is the Series 1–2H coins of Alexandria presented above.

Table 6. Summary of mean weights, ranges, confidence limits, and related calculations for pre-reform Series and Sub-series (outliers removed) of at least 5 specimens. Outliers excluded, 'cf' coins included.

Mint/Series	*Chalkous*	*Dichalkon*	**Hemiobol**	*Pentachalkon*	**Obol**	**Diobol**
			Alexandrian Series			
Alex 1	0.957		4.073			
Alex 2A			3.902			
Alex 2B				5.137		
Alex 2C	0.987		4.368			
Alex 2Di		??	??		8.368	15.39
Alex 2Dii						15.53
Alex 2Diii						16.00
Alex 2E						14.44
Alex 2F					7.998	15.77
Alex 2G						14.98
Alex 2H					7.526	14.31
Mean (coins)	**0.964**	—	**4.033**	**5.137**	**8.277**	**15.43**
# specimens	**65**	—	**77**	**83**	**165**	**558**
Gaussian	**0.72**	—	**0.41**	**0.79**	**0.60**	**0.32**
Minimum wt	**0.500**		**2.32**	**3.670**	**5.460**	**11.20**
Maximum wt	**1.370**		**5.72**	**6.990**	**10.80**	**19.47**
95% con. min	**0.920**	—	**3.883**	**4.980**	**8.104**	**15.30**
95% con. max	**1.008**	—	**4.184**	**5.295**	**8.450**	**15.57**
Mean g/*ch*	**0.964**		**1.008**	**1.027**	**1.035**	**0.964**
			Non-Alexandrian Series			
Byzantion		1.924				
Cyprus	1.130		4.190		8.258	
Cyrene			3.571			
Magas			4.317		7.433	
Ceraunus			4.026		7.785	
Mint 22					7.315	13.32
Mint 26					7.627	
Mint 7	1.140					
Mint 9					8.214	
Mint 10					7.836	

Tyre–Ptol I			3.846			
Tyre–Ptol II			3.679			
Mean (coins)	1.135	1.924	3.874	—	7.994	13.32
# specimens	18	61	138	—	295	16
Gaussian	0.94	0.69	0.48	—	0.60	0.54
Minimum wt	0.94	1.05	2.57		6.00	8.940
Maximum wt	1.31	3.08	5.13		10.10	17.70
95% con. min	1.077	1.806	3.782		7.897	12.16
95% con. max	1.193	2.042	3.966		8.091	14.48
Mean g/*ch*	1.135	0.962	0.969		0.999	0.833
Both Series						
Mean (coins)	1.007	1.924	3.928	5.137	8.084	15.39
# Specimens	82	61	215	83	458	574
Gaussian Fit	0.86	0.69	0.29	0.79	0.08	0.26
Minimum wt	0.620	1.05	2.440	3.670	5.75	11.08
Maximum wt	1.370	3.08	5.326	6.990	10.42	19.47
95% con. min	0.9693	1.806	3.850	4.980	7.997	15.26
95% con. max	1.045	2.042	4.006	5.295	8.172	15.53
Mean g/*ch*	1.007	0.962	0.982	1.027	1.011	0.962

Series 2 Coinage of Other Mints

The remaining pre-reform types are associated with mints of Tyre, several unknown mint locations in Thrace and Macedonia (issues of Ptolemy Ceraunus) and Cyprus, as well as Cyrene, Byzantion, and Sicily.

With the exception of Mint 22[7] diobols' very low mean weight of 13.32 g (0.83 g per *chalkous*), these provincial mint unit weights range from 0.89 to 1.14 g, similar to those of Alexandria.

Further analyses exclude data for a few types or groups with less than five specimens. Those types are:

Cyrene, *chalkous*, Sv 72—4 coins

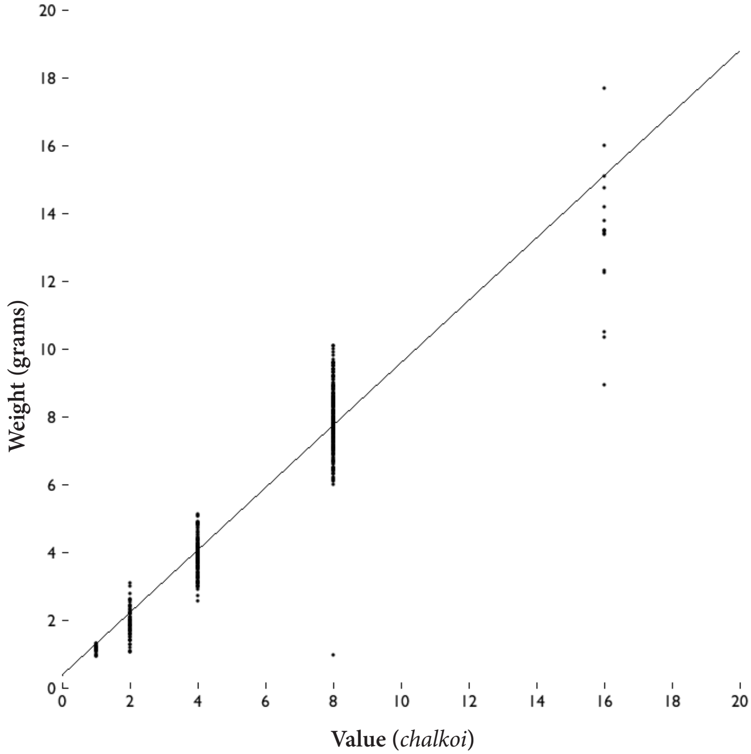
Ceraunus, *dichalkon*—1 coin

Cyrene, *dichalkon*, Sv 69—1 coin

Tyre, *dichalkon*, Sv 217—4 coins

Mint 9, *chalkous*—2 coins

7 Unknown and letter mint designations follow Lorber (forthcoming).

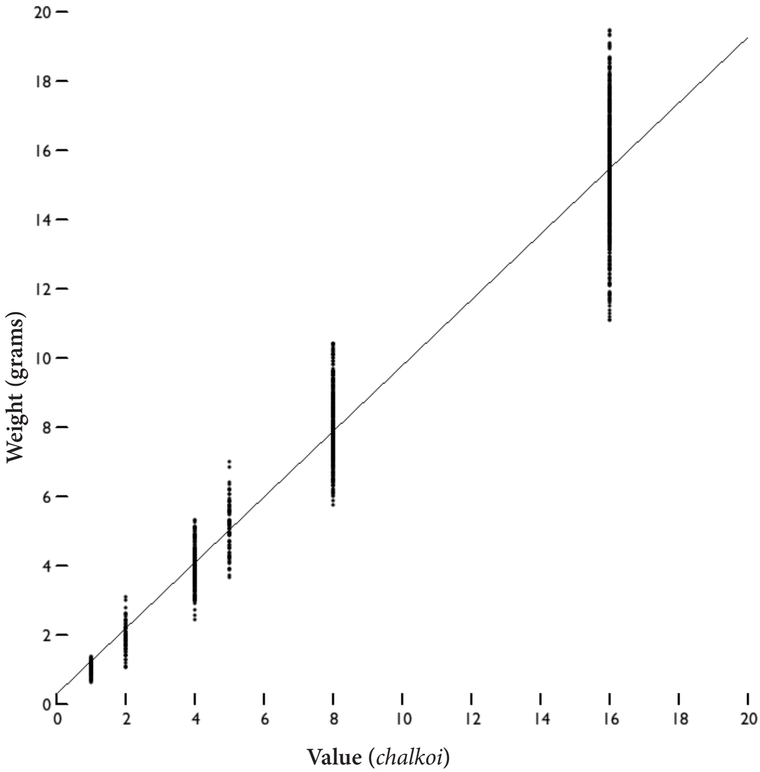


Graph 6. Non-Alexandrian pre-reform regression plot.

The data are available for others but rarity and small sizes preclude a meaningful contribution in this context.

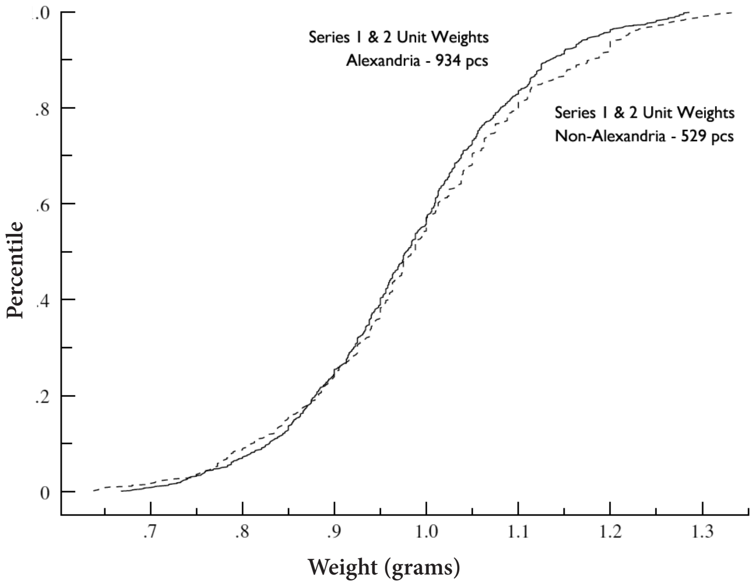
Graph 6 is a regression fit for 528 non-Alexandrian pre-reform coins and has a slope (estimated unit weight) of 0.921 g per *chalkous*, slightly lower than the slope of 0.943 obtained (above) for Alexandrian types (Series 1 through 2D, Graph 5). A regression plot for 1,473 pre-reform coins, Alexandrian and non-Alexandrian issues taken together (Graph 7, below) has a slope of 0.949 g per *chalkous*.

The set of mean unit weights for all the individual non-Alexandrian coins is 529 values (22 outliers removed) with a mean of 0.989 g per *chalkous*, within 1% of the corresponding figure of 0.981 for 934 Alexandrian coins. The distributions are alike to a high degree of confidence (U test P > 0.5 KS Test P = 0.27). The two distributions' percentile graphs are shown together in Graph 8 (below). Large-scale comparisons of unit weight distributions masking distinctions of type, mint, denomination, etc. illustrate a simple similarity between Alexandrian and non-Alexandrian coins.



Graph 7. All pre-reform coins regression plot.

These large-scale comparisons show that the average metal amount corresponding to one *chalkous* of value is approximately uniform over the range of denominations and throughout the empire. A weight standard is suggested by similarity of the regression graph slopes and the per coin unit weight estimates over many coinage series and a long period of time. Variation of mean denominational weights and differences between weight and denomination ratios (e.g. Alexandrian diobols : obols ratio of about 1.85 rather than 2.0) suggests either a modest imprecision or a seignorage for the largest value coins. Linear relations with high correlations and the uniformity of the two large distributions of 'per *chalkous*' weights shows these coinages systematically express a relationship between value and metal content. The regressions and consolidated distributions suggest together an estimate of about 0.96 g per *chalkous*.



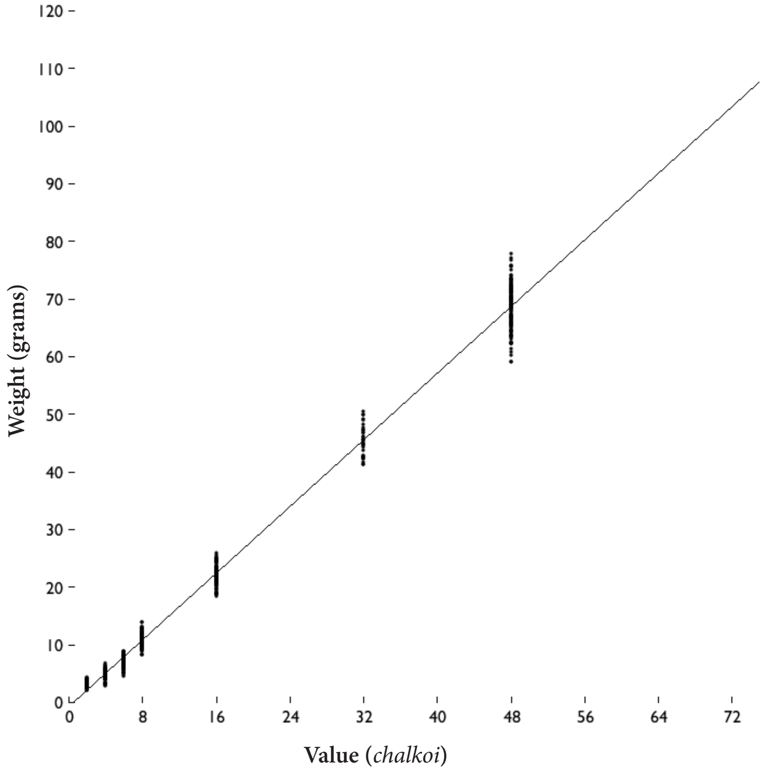
Graph 8. Kolmogorov-Smirnov test percentile graph comparison of Alexandrian Series 1 and 2 (left) and non-Alexandrian (right) unit weights.

B. POST-REFORM COINAGE

Series 3

This earliest post-reform bronze coinage includes the first impressively large and heavy coins, as well as other new denominations, and expresses a new weight standard. There are also clear contributions from three provincial mints and some coin denominations from multiple mints sharing almost precisely congruent designs. Alexandrian issues span seven denominations.[8] The largest are valued by Picard and Faucher as drachm and tetrobol. They bear a new Zeus Ammon obverse while the diobol and obol reprise obverse designs from immediately before the reform: Laureate Zeus and Alexander in elephant skin, respectively. Many Alexandria issues also manifest the novel use of various control letters between the eagle's legs seen also on subsequent coin series (e.g. Series 4 and 5). The congruent-design Alexandrian and non-Alexandrian issues (of three mints) allow unequivocal comparisons, as the provincial issues also carry consistent secondary marks. Some small denominations are only from Alexandria. The four largest denominations

8 Picard and Faucher (2012: 35) tabulate six denominations for Series 3; I treat all the largest (*c.* 90 g) coins within Series 4, but add two further denominations unrecognized by them (the *dichalkon* and *hexachalkon*). Hence Series 3 is defined here by seven denominations.



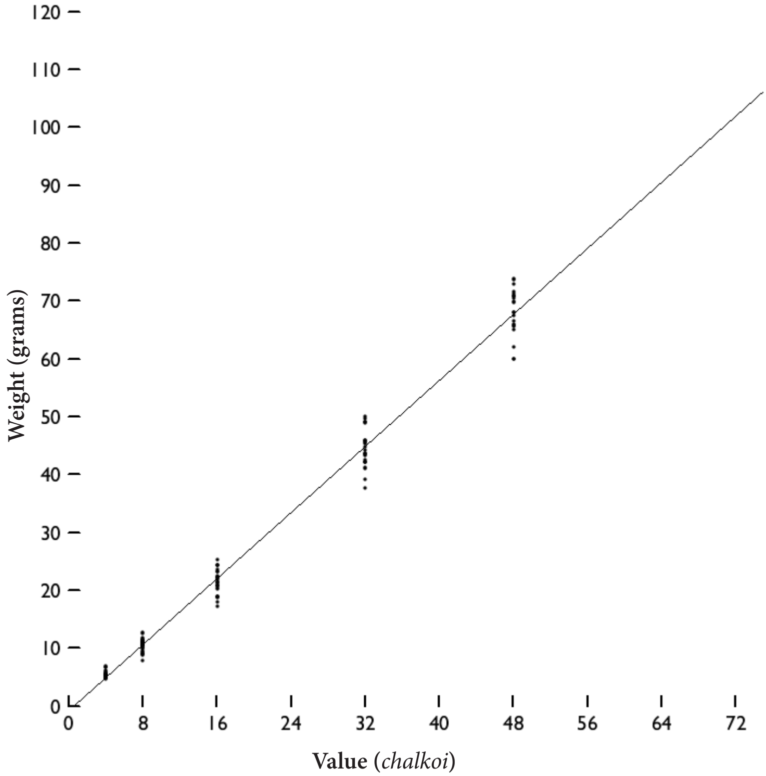
Graph 9. Series 3 Alexandria regression plot.

are common to all four mints and like denominations are metrologically similar (Appendix 1, Table 2).

The regression plot for all seven Alexandrian denominations (Graph 9, 610 coins) has a slope of 1.446 g per *chalkous*. The non-Alexandrian regression plot (Graph 10 [below], 121 coins) slope is 1.428.

Graph 11 (below) shows percentile graphs of Alexandrian and non-Alexandrian aggregated individual coin unit weight distributions and the KS test for those distributions shows that they are alike (P = 0.26). Series 3 shows precise allocation of bronze to the production of different denominations at all the mints. Variations between Alexandrian and non-Alexandrian mean weights are within about 5% for the denominations common to all four mints.

With observed drachm mean weight of 68.5 g, the expected and observed weights of smaller sizes, and their ratios to the drachm, are in Table 7 (below). Variability of individual coin weights conceals this nearly precisely proportional relationship, an unmistakably close connection between mean weights and



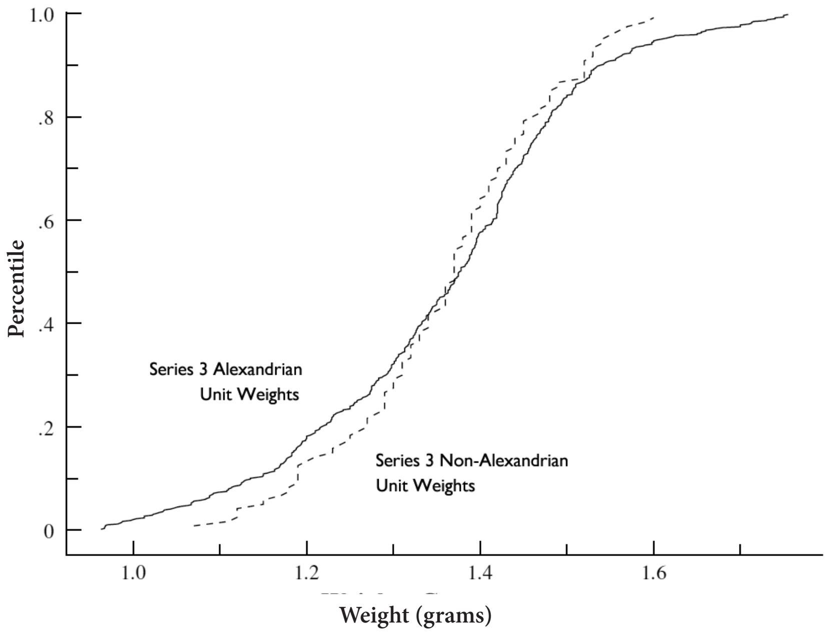
Graph 10. Series 3 non-Alexandrian regression plot.

denomination value. The production of these coins according to an aggregate weight standard was precise and systematic.

Table 7. Expected and observed weights of Series 3.

Denomination	Expected weight	Observed weight
Drachm		68.5 (1.000)
Tetrobol	45.6 (0.666 x 68.5)	45.0 (0.657)
Diobol	22.8 (0.333 x 68.5)	21.8 (0.318)
Obol	11.4 (0.166 x 68.5)	11.0 (0.161)

The smaller denominations are slightly lighter than expected for exact proportionality to the drachm. The average calculated 'per *chalkous*' weight of all Series 3 coins taken together (1.36 g) is likewise slightly less than the regression graph slope because the fractions are slightly lighter than expected. This small discrepancy from equality of weight ratios to denomination ratios can be checked



Graph 11. Kolmogorov-Smirnov test percentile graph comparison of Series 3 Alexandrian (smooth) and non-Alexandrian (dotted) unit weights.

in Series 4 and 5, below. It suggests a slightly larger fraction of metal wasted (casting sprues, surface smoothing losses, etc.) in production of smaller sizes. Another explanation for slightly lower-than-expected weights of the smaller sizes might be that some production costs were fixed regardless of the coin size and their recovery could affect smaller coin types more than large coins. The largest coin is the most reliable basis for the aggregate weight standard of approximately 1.43 g per *chalkous* for Series 3 (68.5 g per drachm / 48 *chalkoi* per drachm).

The ratio of Series 3 unit weight (1.43) to Series 2 unit weight (0.96 for the average of Series 2D diobols) is so nearly equal to the simple ratio of 1.5 to 1 that it expresses a straightforward quantitative impact of the reform. The reform reduced the value of bronze by one third (i.e. Series 3 obols are 50% heavier than Series 2 obols). The bronze devaluation increased bronze coinage cost to the Ptolemaic treasury. A persuasive explanation for this large devaluation of bronze and vastly increased coin weights is outside the scope of this survey.

Series 4

Most Series 4 coins were minted at Alexandria and those are the focus of this discussion. Series 4 has no contribution from the three provincial mints (Tyre, Mint 27, and Ake-Ptolemaïs) that issued Series 3 coins closely congruent to

Alexandria's Series 3 types. Small contributions to Series 4 are attributed to Ras Ibn Hani, Kyrene, and a few rare types of Cyprus which are set aside for future study, as their denominations and types are not clearly congruent to the Alexandrian issues of Series 4. Alexandrian Series 4 spans seven denominations including the largest Ptolemaic bronzes, octobols. While two rare octobol types have sometimes been assigned with Series 3, they are treated here as Series 4 for consistency of metrological interpretation. Table 3 of Appendix 1 summarizes the Alexandrian issues of Series 4.

The middle fractions of Series 4 (tetrobol, diobol, and obol) are extended with the same obverse designs from Series 3 and we can test if the weights of those denominations also continue from Series 3 (Table 8).

Table 8. Middle fraction weight comparison between Series 3 and 4.

Denomination	**Series 3**	**Series 4**	**U-Test**
Tetrobol	45.028 (54 coins)	44.472 (442 coins)	0.33 similar*
Diobol	21.877 (123 coins)	21.246 (11 coins)	0.25 similar*
Obol	10.804 (146 coins)	10.348 (89 coins)	0.01

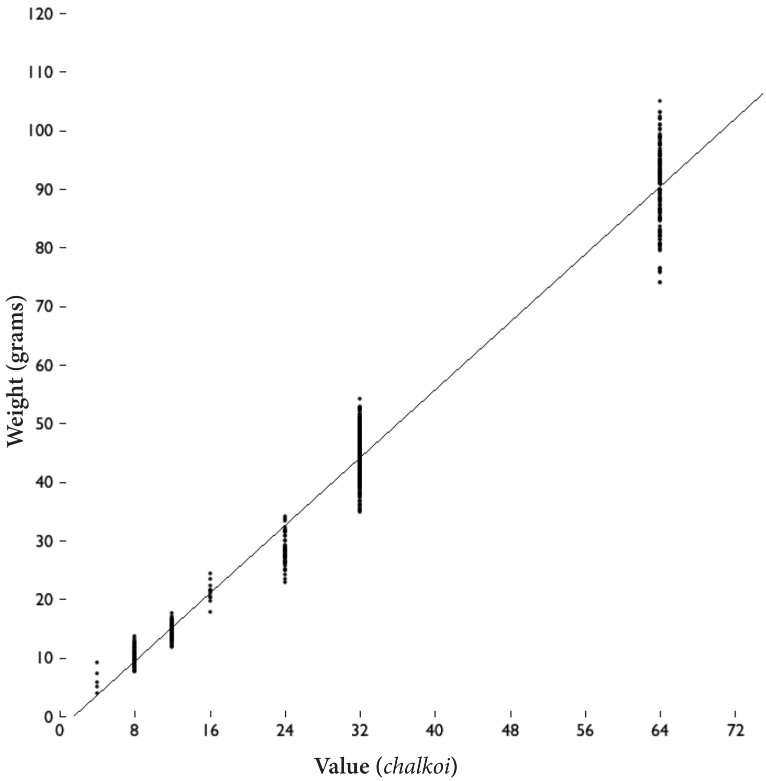
*Values over 0.05 indicate similarity.

There is a small but significant difference between the obols of Series 3 and 4, while the weights of tetrobols and diobols span both series. Series 3 and 4 share one weight standard.

In addition to the huge octobols, Series 4 introduces another new denomination between tetrobol and diobol, represented by Sv 1167 with Λ control and an issue with E control that was listed only in the Addendum to Svoronos's catalogue without a separate catalogue number (given here, using Svoronos's designation, as 974a). This coin type (with E control) should not be confused with the very plentiful tetrobol, Sv974. The type is described as a triobol (hemidrachm or 24 *chalkoi*) in Picard and Faucher (2012: 44 and 46). Its 28.3 g mean weight, however, suggests its value is equal to 20 *chalkoi* (an *eikosichalkon* or 2.5 obols) rather than a hemidrachm (~ 33–34 g). Its mean weight (fifty specimens, one outlier removed) is much lower, by about 15%, than expected for a hemidrachm.

A graphical 'experiment' sheds more light on the possibilities for this type, namely hemidrachm or 20-*chalkoi* values. Regression plots of Series 4 show this type positioned as hemidrachm and 20 *chalkoi* in Graphs 12 and 13 to help visualize its value in context. Note the obviously correct graphical fit of the 20-*chalkous* value (Graph 13, below) in the full context of Series 4. Metrological data alone persuasively identify this type as a previously unrecognized decimal denomination.

An appealing explanation for the 2.5-obol denomination lies in documented exchanges of bronze and silver. When payment was made using bronze for transactions ordinarily specified to be in silver (transactions said to be *pros*



Graph 12. Series 4 Alexandrian regression plot—Sv 1167 as hemidrachm.

argyrion), an additional fee of 2.5 obols per tetradrachm was required; one silver tetradrachm equivalent required four bronze drachms plus and additional 20 *chalkoi*.[9]

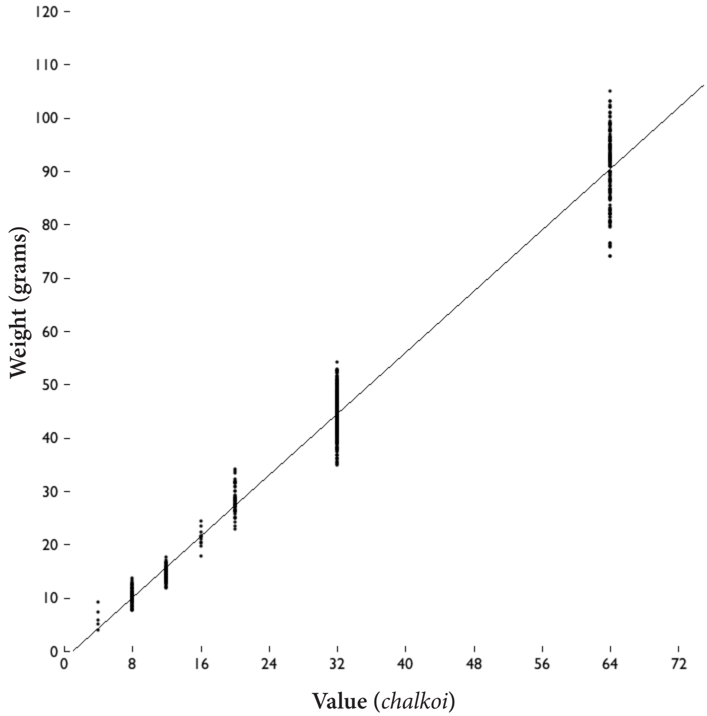
One alternative explanation is based on a few papyrological references to transactions in the amount of 20 *chalkoi*[10] and another by comparisons with the anomalous Attic-weight precious metal coins of Ptolemy III that were produced in some decimal base denominations such as the 2.5-drachm, pentadrachm, and dekadrachm. Several scholars interpreted this enigmatic precious metal coinage as simultaneously valued in both Attic and Ptolemaic systems.[11] This raises potential parallels for the Series 4 bronze coinage best addressed by future studies.[12]

9 Hazzard 1995: 78; Maresch 1996: 80-90.

10 Muhs 2011.

11 Newell 1927: 8-12; Naville 1951: 105; Olivier 2006: 121.

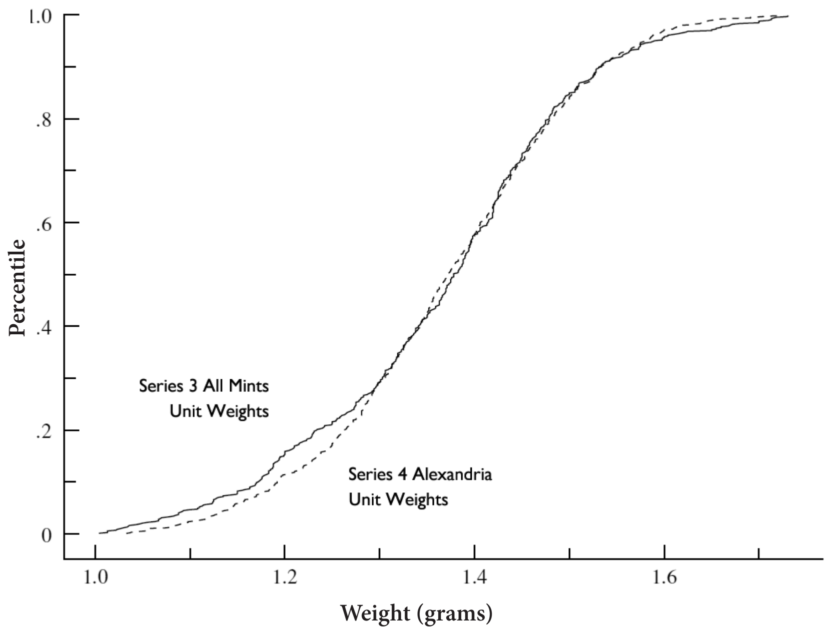
12 These data persuasively support a 20-*chalkous* denomination but are insufficient to reliably distinguish whether other small denominations of Series 4 can be best interpreted



Graph 13. Series 4 Alexandrian regression plot—Sv 1167 as *eikosichalkon*.

Recognizing the new 20-*chalkous* coin value does not appreciably affect the overall weight standard estimate for Series 4 because coins of this denomination represent only a small fraction (50 of about 840 coins) of the Series 4 data set. The hemidrachm-valued regression plot (Graph 12) has a slope of 1.446 and the corrected plot with the 20-*chalkoi* value has a slope of 1.436 (Graph 13). The similarity of Series 3 and 4 is graphically exemplified by percentile plots of the unit weight distributions in Graph 14 that nearly merge over much of the ranges. These plots use the 20-*chalkoi* value for Sv 1167. The mean unit weight for Series

also as decimal (10-, 7.5-, 5-*chalkoi*) rather than obol-based (12, 8, 4) values. Those hypothetical values might be tested with large data sets. Weight ratios of Series 4 admit both decimal and sexagesimal interpretations that may not be quantitatively distinguishable. Series 4, with its novel ratios and denominations (octobol and *eikosichalkon*), produced during the reign of Ptolemy III, suggests possible broader comparisons with Ptolemy III's multi-valued Attic coinage.



Graph 14. Kolmogorov-Smirnov test percentile graph comparison of all Series 3 (smooth) and Series 4 Alexandrian (dotted) unit weights.

3 is 1.365 (665 coins of all of Series 3) and for Series 4 is 1.370 (842 coins) with a KS test P value of 0.23.

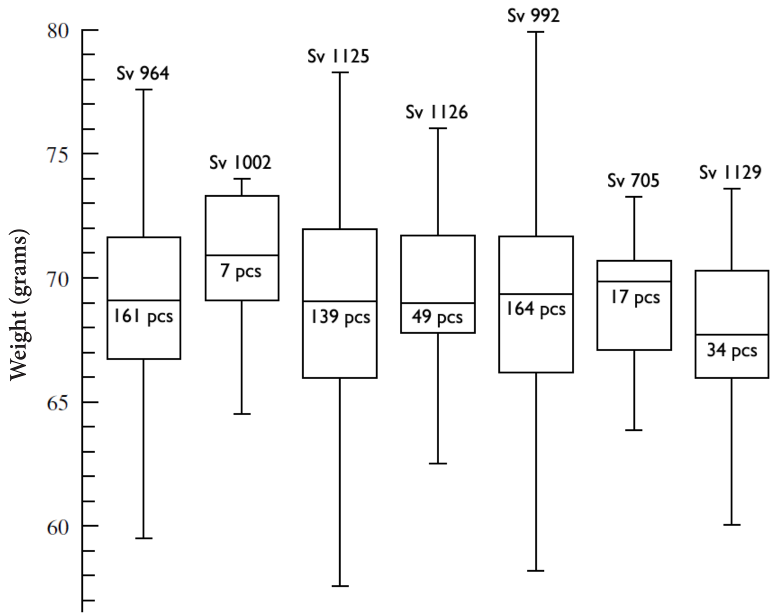
Series 5

Table 4 of Appendix 1 summarizes the weight data for coins of Series 5.

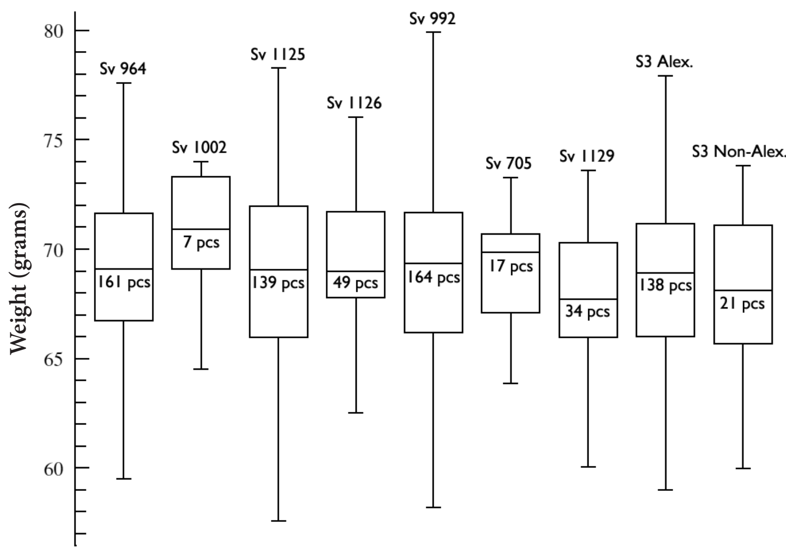
Longitudinal Analyses

The last series examined here has more denominations and mints than Series 3 or 4. The large denomination of Series 5 reprises the drachm of Series 3:[13] five types of Alexandria (Svoronos 964, 1002, 1125, 1126, and 992) and two of Tyre (Svoronos 705 and 1129). Graph 15 (below) shows adjacent box plots of those seven types and the ANOVA (P = 0.42) indicates all seven types share a common weight distribution. Graph 16 (below) extends these results with Series 3 Alexandrian- and Phoenician-mint bronze drachms. The ANOVA P = 0.39 indicates that all drachms of Series 3 and 5 share a single weight distribution. The amount of metal used to produce large numbers of coins of this denomination was very precisely

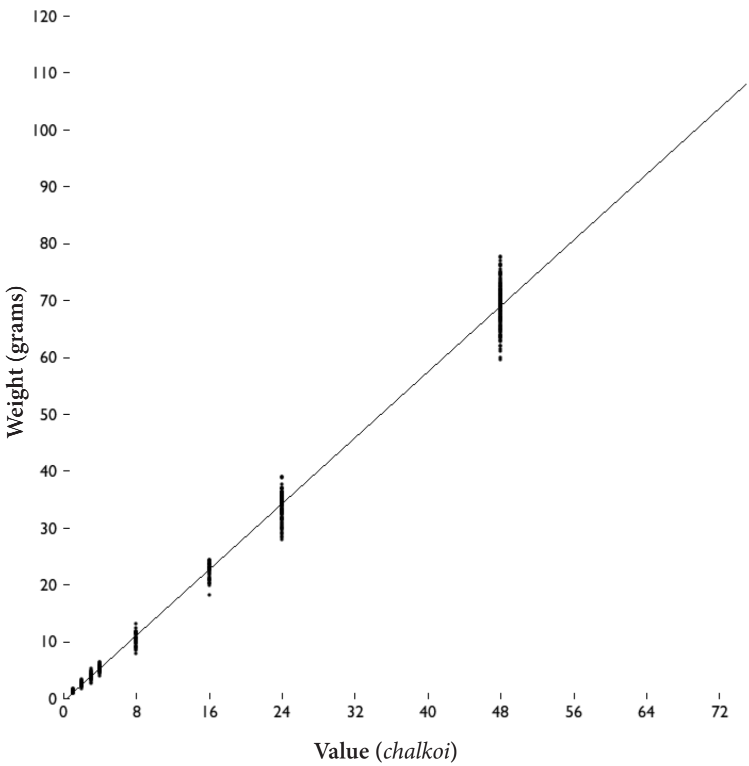
13 Excepting an extremely rare octobol of Cyprus control linked to Series 5 Alexandria and Tyre issues (ΛΙ),



Graph 15. ANOVA box plot comparison of Series 5 drachms (seven types).



Graph 16. ANOVA box plot comparison of Series 5 (seven types) and Series 3 drachms.

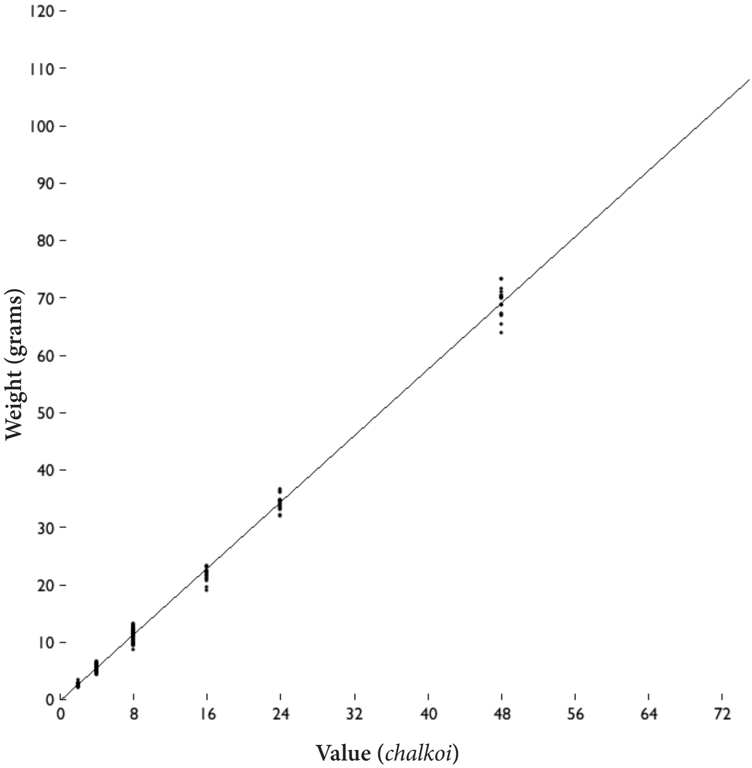


Graph 17. Series 5 Alexandrian regression plot (Sv 964–971).

uniform over a long period of time and among widely distant mint locations. Series 3 and 5 drachm coins combined (727, outliers removed) have mean weight of approximately 68.9 g. This is the empirical weight value for post-reform bronze drachm coins.

Uniformity of the post-reform bronze weight standard is supported by similar ANOVA comparisons for tetrobol and diobol denominations that are common to all three post-reform series. ANOVA comparison of Series 3 to Series 5 drachms (nine types of coins, see Graph 16) shows they are all quite similar (P ~ 0.39).

Series 3, 4, and 5 tetrobols (three groups of coins) are also alike (ANOVA P ~ 0.53). The diobols of Series 3, 4, and 5 (three groups of coins) are also similar (ANOVA P ~ 0.50). These statistics reflect the data of Tables 2–4 of Appendix 1 but the result for drachm sizes comparing nine different groups is perhaps the most revealing. Graph 16 illustrates the geographic and temporal precision of the post-reform bronze weight standard.



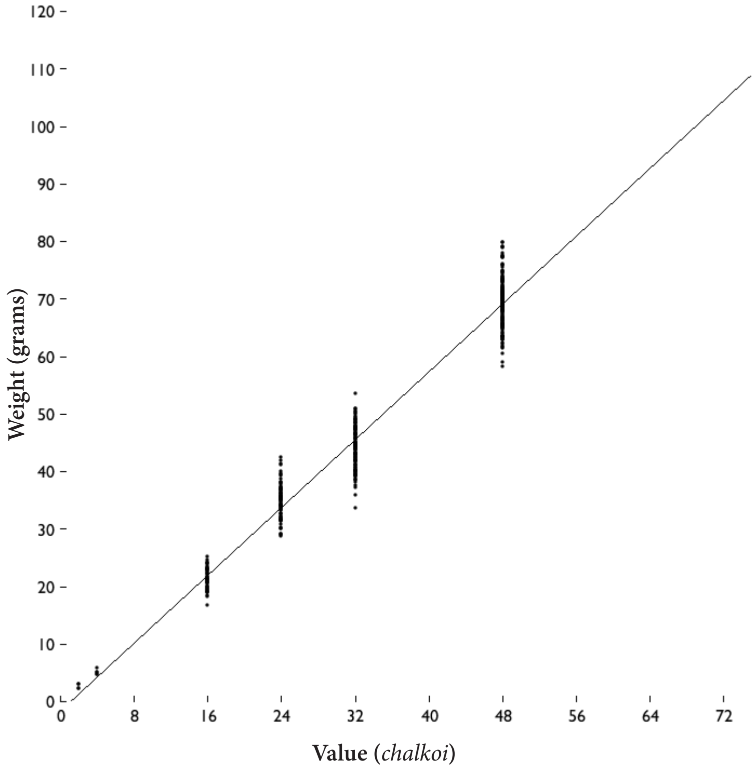
Graph 18. Series 5 Tyre regression plot (Sv 705–711).

Intra-series Analyses

Two sub-series from Alexandria (marked ⳩ and Σ/ΣE,[14] with cornucopia), Tyre (unmarked, with club) and Cyprus (with Aphrodite statue) have five to eight denominations so regression graphs help estimate weight standards for them. Graph 17 shows the best-represented Alexandrian issue of Series 5, the eight denominations of Svoronos 964–971 (with ⳩ mark) with a slope of 1.4505 g *chalkous*. The unit-weight mean for all ⳩ coins is 1.398 for 448 coins (outliers removed).

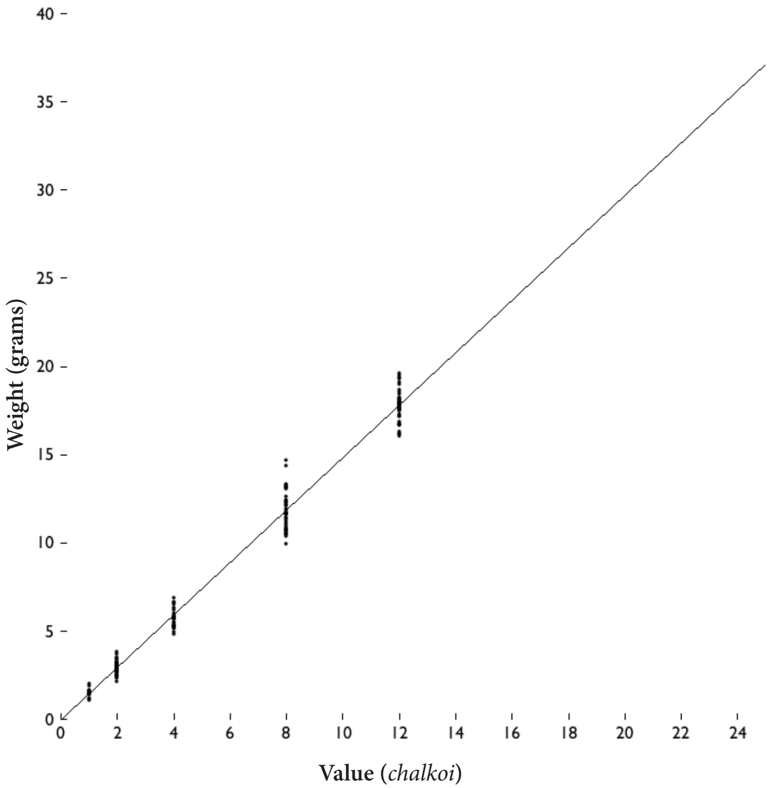
Graph 18 is the corresponding regression plot for the unmarked Tyre sub-series, Svoronos 705–711. Parallels between the Alexandrian ⳩ series and the unmarked Tyre series are clear, but it is likely that the Tyre series is represented by six, rather than eight, denominations. The ⳩ series consists of exactly congruent designs for the drachm, hemidrachm, diobol, and obol (Svoronos 964, 965, 966,

14 ΣE appears as separate letters and as the monogram ⋿.



Graph 19. Series 5 Alexandria regression plot (Sv 992).

967) and likewise the unmarked Tyre series (Svoronos 705, 706, 707, and 708). The smallest four of the ☧ series, however, have varying obverses and reverses that distinguish them from one another even with overlapping weight variations, while the Tyre series has no corresponding obverse or reverse design differences that distinguish any of the coin sizes. Svoronos catalogued seven Tyre denominations from drachm through dichalkon all of exactly congruent designs. It appears, rather, that two small sizes issued at Alexandria with different obverses than the rest were just not issued at Tyre at all. This observation is also supported by the paucity of specimens reported as Svoronos 710 in our data set, within a series for which the other small sizes are very plentiful. The sub-obol denominations at Tyre, expressed by the hemiobol and dichalkon, differ enough in visual size to be practically distinguished, absent different designs. Graph 18 is a regression plot for the Tyre unmarked series adapted to six, rather than seven, denominations. The slope is 1.444 (grams per *chalkous*), close to that of the ☧ series. The mean unit weight for this series is 1.393 g per *chalkous* (171 coins with outliers removed), in

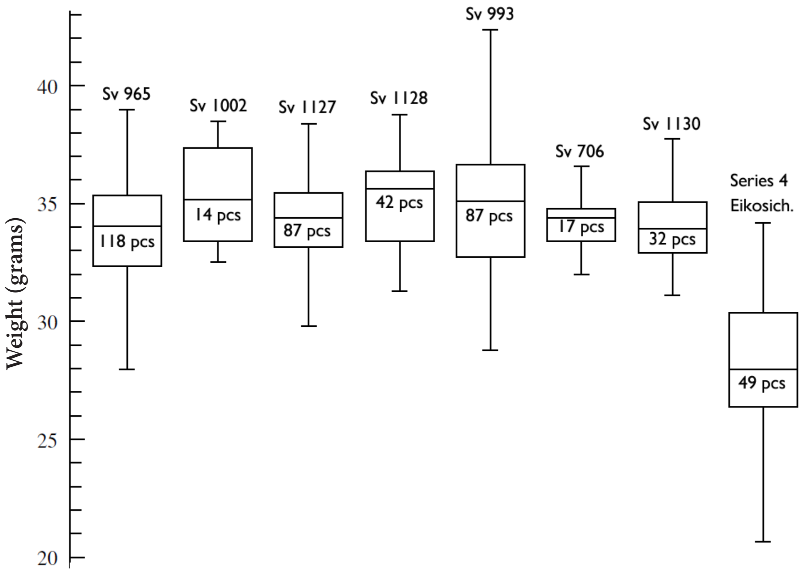


Graph 20. Series 5 Cyprus regression plot (Sv 1005–1009).

close agreement with the ⁎ series, and U-test comparison shows they are alike (P ~ 0.53).

Graph 19 is the regression plot of four catalogued denominations bearing Σ/ΣE controls with a few coins of smaller denominations (hemiobol and dichalkon) not previously catalogued. Its slope is 1.475 g per *chalkous*, slightly greater than for the ⁎ and Tyre sub-series. Mean unit weight for this group of 452 coins (13 outliers removed) is 1.41 g.

The Cypriot Aphrodite statue series of five small denominations (Svoronos 1005–1009) yields Graph 20 with a slightly higher slope value of 1.4867 (grams per *chalkous*) than for the ⁎ and unmarked Tyre groups. The coinage is highly regular with an exactly congruent design on all sizes. The Aphrodite statue series has no types larger than a trihemiobol. The unit weight of this series, 1.452 g per *chalkous* (151 coins, outliers removed), is also about 4% greater than the ⁎ and Tyre's unmarked coinage and that difference is statistically significant (U test of Cyprus vs. ⁎ yields P < 0.001) The importance of this small significant difference



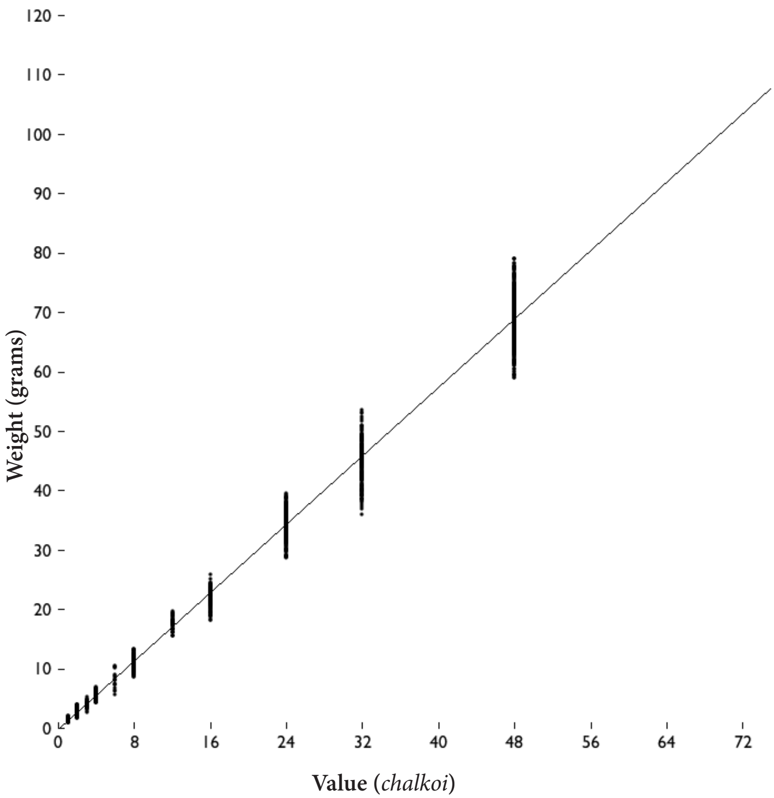
Graph 21. ANOVA box plot comparison of Series 5 hemidrachms (seven types) and Series for *eikosichalkon*.

is unclear, perhaps due to the limited denomination range or potential conflation of adjacent denominations of exactly congruent coin types.

Issues marked with ΔI and ΛI are also well-represented for both Alexandria (Svoronos 1125, 1126, 1127, 1128) and Tyre (Svoronos 1129, 1130) but with few denominations.

The only Series 5 large types of Cyprus are rare tetrobols and octobols, indicating that Cyprus's coin series structure diverged from the other mints during the time of their issue. Regression graph slopes representing only two denominations are not useful here. The mean unit weights of these sub-series are, however, consistent with other Series 5 groups (Table 9).

A few specimens, some unknown to Svoronos, also show that Tyre issued coins parallel to Alexandria's Sv 993, 994, etc., but only in small sizes of obol, hemiobol (Svoronos 1153), and *dichalkon* denominations. Althhough they unequivocally exist and show that Tyre minted yet another Series 5 group in parallel to Alexandria, the quantities of the small denomination Tyre Σ-types are too few to contribute meaningfully to this survey.



Graph 22. Series 5 regression plot (all coins).

Table 9. Unit weights of Alexandrian and Tyre Series 5 issues of Ptolemy IV.

Alexandria	Delta Iota	Sv 1125 and 1127	1.433 (225 coins, 11 outliers removed)
Alexandria	Lamda Iota	Sv 1126 and 1128	1.447 (94 coins, 3 outliers removed)
Tyre	Both	Sv 1129 and 1130	1.417 (66 coins, 4 outliers removed)

As seen in Series 3, the fractions are slightly lighter than expected. Since drachm, tetrobol, and diobol weights are strongly conserved across Series 3, 4, and 5 (see above), the reason fractions weigh slightly less than their proportional values is unexplained. The short weight of fractions persists through the post-reform period of these three series.

Series 5 introduces seven types of bronze hemidrachms (Sv 1003, 965, 1127, 1128, 706, 1130). Unlike drachm coins, they vary enough that they do not share a single weight distribution (ANOVA P = 0.003). Nevertheless Series 5 hemidrachm mean weights range from 33.7–35.3 g (overall mean weight of 395 coins = 34.25 g, very nearly one half of the drachm mean weight) and Svoronos 1167 (of Series 4) at 28.32 g is clearly far below that range, supporting the conclusion (see Series 4, above) that Sv 1167 is a 20-*chalkous* coin, not a hemidrachm. Hemidrachm coins thus make their first appearances in Series 5. Box plots of Series 5 hemidrachms, with Sv 1167 added at the far right for comparison, are shown in Graph 21.

Corinth mint issues uniquely bearing the portrait of Ptolemy III are catalogued as four types, Svoronos 997, 998, 999, and 1000. The 998 type is reported for only two coins in this data set with weights similar to the 15 specimens of 999 so that those two Sv 998 data are treated here as *hexachalkon* types along with Sv 999. The mean unit weight for 85 Corinth mint specimens (outliers removed) is 1.391, similar to the values obtained for the ⚹ (1.398) and Tyre, unmarked (1.393) groups.

Svoronos assigned two small denominations marked with harpa symbols to Joppa, three small denominations with trident marks to Berytos, and three small denominations with tripod marks to Ake-Ptolemaïs. While modern scholarship has left the Joppa mint attribution unchanged, reports on museum collections in southwest Turkey by Ashton (2002) and Konuk (2004) led to Lorber's relocation of the mints for the tripod types to Telmessus and the trident types to Caunus, respectively.[15]

The issues of Joppa (harpa mintmark), Caunus (trident mintmark), and Telmessus (tripod mintmark) are only known in obol and smaller fraction denominations. Their mean unit weights are consistent with the range observed for coins from other mints in Series 5.

Joppa mean unit weight = 1.380 (47, 1 outlier removed).

Caunus mean unit weight = 1.376 (74, no outliers).

Telmessus mean unit weight = 1.498 (119, 8 outliers removed).

The coins assigned here to Telmessus include Svoronos 791, 792, and 793. Until 2012 only a single specimen of Sv 792 was known and more of them appeared in commerce. The mark at the right of the eagle on this one type led Svoronos to assign all three types to Ake-Ptolemaïs because they share the tripod mintmark, yet all the known specimens of Sv 792 lack the central depression seen on Sv 791 and Sv 793. Sv 791 and 793 are plentiful in the Turkish museum collection examined by Ashton so it may well be that Sv 792 needs a separate consideration. I note that the mean unit weight of the Telmessus coins, reflecting all three types, is 4–7% greater than most other groups of Series 5 coins.

The Berenike portrait bronzes of Ras Ibn Hani are also limited to small denominations and lack the central depressions typical of post-reform bronze coins.[16] The meaning of their observed lighter mean unit weight (1.326 g/*chalkous*

15 Lorber (forthcoming).

16 Lorber 2007.

for 86 specimens, 5 outliers removed) is unclear and it suggests a need for further study of those types. Series 5 coins in this data set ascribed to Cyrene are also excluded from further comment, subject to future analysis.

Series 5 types included here, comprising many denominations, mints, and control-linked types, largely express a regular mean coin-weight standard. Graph 22 is a regression plot for the types and mints of the entire Series 5 (excluding Ras Ibn Hani and Cyrene) representing a total of 2,046 coins from seven mints. The slope is 1.44 g per *chalkous*, providing a good estimate for the bronze weight standard of Series 5 as a whole and almost exactly equal to those of Series 3 and 4.

Conclusion

In pre- and post-reform Ptolemaic bronze coinage there are systematic weight standards, in spite of wide individual coin weight variations, that apply in aggregate, i.e. to average weights of large numbers of coins. In addition to the *al marco*[17] production of individual coin types of various denominations, weight standards are reflected in denomination weight ratios that emerge clearly from mean weights of many specimens. Ratios of mean weights of large denomination coins to mean weights of smaller denominations are approximately equal to their value ratios. The degree to which ratios of value agree with weight ratios varies somewhat in the pre-reform coinage (Series 1–2D) but regression plots of many coins show a high correlation between weight and denomination. Regression plots also reveal a previously unrecognized 5-*chalkous* denomination comprising Series 2B, marked with an aphlaston symbol.

Most mean unit-weights of pre-reform types (Series 1–2D, Table 1) are in the range of 0.9 to 1.0 g per *chalkous*. Given approximately equal ratios of weights and ratios of denominations the slope of the regression graph for 1,473 pre-reform coins (by denomination, with outliers excluded) slope of 0.95 g per *chalkous* is a justifiable estimate for the pre-reform weight standard. The largest contributors to the pre-reform data set are Series 2D diobols (about 1/3 of the pre-reform data set), with a mean weight of 15.4 g (0.96 g per *chalkous*). The pre-reform coinage weight standard is approximately 0.95 g per *chalkous*.

Post-reform coinage denominations and weights are also parallel, but with even greater precision spanning many types, values, and mints. Regression plot slopes of Series 3 Alexandrian, Series 3 non-Alexandrian, Series 4 Alexandrian, and combined Series 5 issues of 7 mints are all in very close agreement (1.43–1.45 g per *chalkous*). The mean weights of 9 drachm groups of Series 3 and 5 are virtually identical. Tetrobols and diobols spanning all three post-reform series (3, 4, and 5) also share mean weights and weight distributions. Variability of individual coin weights cannot obscure very clear precision, scope, and duration over Series 3, 4 and 5 of the weight standard of approximately 1.44 g per *chalkous*. The observed

17 Consistent aggregate weight totals despite variations in individual coin weight.

ratio of post-reform to pre-reform bronze values is so nearly 1.5 to 1 as to suggest that this is the quantitative meaning of the bronze coinage reform.

With weight to value estimates based on large samples and a range of types, we can confidently reject the weight standards proposed by Hultsch. No coin type observed in this large data set corresponds to Hultsch's proposed 106.8 g bronze drachm standard (the so-called '30-drachm standard' based on a multiple of 30 silver 3.56 g drachms). The mean weight of a large sample of the largest bronze coins (Series 4) is actually 90.3 g. The empirical mean weight of over 700 Series 3 and 5 drachms is 68.9 g, not Hultsch's ideal proposed value of 71.2 g.

The fact that Hultsch's theoretical ideal post-reform bronze drachm weight of 71.2 g is within a few percent of the observed value of 68.9 deserves comment. It might appear that Hultsch arrived at a value that is approximately correct because his theoretical concept is correct or perhaps that a 'wear-adjustment' of the observed value would conform with Hultsch's theory. It is tempting to ascribe a prescience to Hultsch's work, but it is unwise for several reasons:

1. The 'ideal' 71.2 gram drachm weight Hultsch proposed is part of a theory of silver-to-bronze exchange ratios based on a silver drachm 'ideal' weight of 3.56 g, for which weight Hultsch provides little or no empirical support.

2. The same exchange ratio theory, based on the same 'ideal' 3.56 g silver drachm, yields other 'ideal' bronze coin weights (e.g. the 106.8 g '30-drachm' standard) that greatly diverge from any known empirical Ptolemaic bronze coin weights.

3. It is also noteworthy that the pre-reform '30-drachm' (106.8 g) standard is 50% heavier than the post-reform '20-drachm' (71.2 g) standard, the opposite of the relationship found here. That casts additional doubt on the theory itself.

4. Any casual observer can estimate that the weight of the post-reform Ptolemaic bronze drachm is approximately 70 g. Such approximations do not substitute for quantitative analyses that reveal extensive temporal and geographic consistency of the coinage.

While the 71.2 g value is (nearly but) not correct, some future empirical study of contemporary silver coins may tell us whether Hultsch was correct in his belief in simple weight ratios of exchange between bronze and silver Ptolemaic coins.

Van Driessche (1988) began an empirical metrology of Ptolemaic bronze coins independent of the 'fantastical' theoretical constructs of Hultsch. Nevertheless her conclusions were biased by a subsequent theoretical adjustment for wear, uniformly adding 10% to all the empirical coin weights. Uniform wear by 10% for all Ptolemaic bronze coins would imply most worn so smooth as to be unidentifiable because they are struck in fairly low relief. Wear doubtless plays some role in the observed coin weights but there is no convincing justification for applying any arbitrary 'wear factor' to increase them. The data here are insufficient to estimate the degree to which observed weight distributions differ from 'as struck' weight distributions. Van Driessche's ideal weights arbitrarily exceed the empirical mean weights found in this larger survey.[18] I cannot attribute the differences between Hultsch's and Van Driessche's ideal weights (71.2 and 72 g, respectively) and the empirical value of (68.9 g) to wear, as Hultsch's 'ideal' weight estimate lacks a convincing empirical basis and Van Driessche's adjustment of 10% would increase the (observed) drachm weight to a value somewhat greater than either earlier 'ideal'. Regression plots for post-reform coins here have a range of slopes and offsets (Y axis intercepts) which do not suggest any obvious departure from some unknown 'ideal'. We do best to allow these thousands of coins to speak for themselves.

Van Driessche also discussed the likely intent of post-reform bronze types and their weights as a basis for easy of exchange between bronze and silver. The refutation of her ideal weights calls that interpretation into question. Van Driessche's wear adjustment also led to an erroneous conflation of her Denomination 5 (18 g, purported trihemiobol) with bronzes now known to have been minted on Sicily to the local weight standard of ~17.1 g.[19] The quarter-drachm (trihemiobol) denomination plays only a minor role in the post-reform coinage, solely in Series 5 (Cyprus issue Svoronos 1005 and Corinth Svoronos 997) and it weighs less than the 18 g Van Driessche calculated from erroneous ideal weights. The hypothesis that an 18 g Ptolemaic bronze denomination circulated both within and outside the empire, as an intermediary between silver and bronze, is not supported.

Sicilian Ptolemaic bronze coins of *c.* 265 BC, struck in a single denomination, were local Sicilian issues that do not appear to have circulated elsewhere.[20] Those Sicilian bronzes of ~ 17.1 g minted by Ptolemy II on Sicily (and imitated by Hieron II) are indeed approximately half the weight of Series 5 hemidrachms (34.28 g, mean of 395 specimens of Series 5). The hypothesis that the Egyptian post-reform standard purposely integrated the 17.1 g '*litra*' bronze weight standard of Hieron II as equivalent to an Egyptian trihemiobol (one quarter drachm) cannot be rejected. Kincaid cited an exact exchange relationship of four Syracusan *litrae* to one Ptolemaic drachm.[21] Ptolemaic bronzes of the post-reform period are known in Sicilian finds and museum collections[22] and the relationship between the two empires long outlived the brief period of Ptolemaic bronze coinage on Sicily itself.

Empirical data of convincingly large samples now provide reliable mean coin weights that are consistent over long time periods and wide geographic extent so

18 Van Driessche 1988: 71 with table.
19 Wolf and Lorber 2011.
20 Wolf and Lorber 2011
21 Kincaid 1985: 128.
22 Kincaid 1985: 128.

that a description of Ptolemaic bronzes in terms of incorrect hypothetical or 'ideal' weights is no longer necessary nor justified. Continuing to describe the post-reform Ptolemaic bronze drachm as '72 grams', for the sake of convenient arithmetic propagates Ptolemaic bronze coinage ideas now best abandoned.

A unit weight ratio of 3:2 for post-reform and pre-reform bronzes implies that bronze was devalued by one third through a 50% increase in the unit-value weight (e.g. the post-reform diobol weighs 50% more than a pre-reform diobol). We might note that some replacement exchanges are simple in light of the 3:2 ratio and likewise express the devaluation of bronze. For example, one 'new' tetrobol weighs about the same as three 'old' diobols (a new tetrobol might exchange for an 'old' drachm worth of bronze). Likewise the 'new' drachm is easily exchanged for nine of the 'old' obols (one new drachm for 1.5 'old' drachm worth of bronze). Easily replacing one circulating coinage with another is an appealing motivation and the 3:2 ratio simplifies many exchange calculations using six obols per drachm and eight *chalkoi* per obol.

The observed metrological consistency among a broad range of coin types and over a lengthy time period exposed an additional previously unrecognized coin denomination, namely the 20-*chalkous* coin type of Series 4, exemplified by Sv 1167. Analyses also suggest that one pre-reform type had a value of five *chalkoi* rather than previously assumed value of four *chalkoi*. We cannot neglect that denominations used here are partly based on earlier approximations of coin weights and their ratios, creating some risk of tautology. This survey should not just circularly confirm denominations based on earlier weight approximations and ratios; it should improve confidence in the previously presumed value relationships, refute others that fall to empirical scrutiny, and point to some new ones.

A weight standard implies ratios of weights approximately equal to ratios of values. The concept is associated with many types of coinage from ancient precious metal coinage to modern times. For the Ptolemaic bronze coins, if diobol coins weigh about twice as much as obol coins then we can infer that the value of the coins was related to their weight as consistent with these findings. There is an unavoidable implication that the bronze coins, despite their weight ranges, had value expressed in the aggregate by the amount of metal used to produce the coins. The weights of some types vary by 30–40% so individual coin weight was not as well-controlled as with precious metals. Nevertheless the large-scale value and weight relationships are inescapable and lead to the conclusion that value was proportional to metal content. The weight standards of gold and silver (with very precise weight ratios) are typically expressed by individual coins. A weight standard manifest in precise ratios, expressed over large quantities, may be called an aggregate weight standard. It is necessarily achieved using equal quantities of bronze to produce large equal amounts of different denominations, in proportion to their values.

Aggregate weight standards also imply partial or relatively intrinsic value of bronze coins in the Ptolemaic empire. The usual interpretation of Ptolemaic bronze is in the role of a purely fiduciary coinage intended to replace silver[23] at a much lower cost to the ruler than precious metal. The results here imply an intrinsic valuation of bronze coinage. Absent intrinsic quality there would be no need for drachms to weigh (and cost the regime) twice as much as hemidrachms, even in the aggregate. The alternative of different denominations produced from similar amounts of metal and explicitly marked for their values is excluded by the results of this metrological survey. No sensible explanation for the nearly precise equivalence of denomination and weight ratios is at hand other than that Ptolemaic bronze coins had intrinsic value. Even if bronze coins circulated in place of silver in a fiduciary role (i.e., without free exchange to silver) we must accept intrinsic valuation within the bronze coinage itself. We can describe this relationship with the term "relatively intrinsic".

A modern example of relatively intrinsic coinage is exemplified in U.S. silver coins of the nineteenth century. The Coinage Act of 1853 (Federal Register: 32nd Congress, Session II, Ch. 79 p. 160) legislated that the weight of fractional silver coin denominations (5, 10, 25, and 50 cents) be reduced relative to the silver dollar coin. The fractions retained weight ratios with respect to one another equal to their denomination ratios (i.e., the 50-cent coin had twice the silver of a 25-cent coin). Those fractions were termed 'fiduciary silver' at the time but we can see they had both fiduciary (low silver quantities relative to their fraction of the dollar coin) and intrinsic ('correct' weight ratios relative to one another) qualities.

An explicitly intrinsic metal-valued Ptolemaic bronze coinage may be the best interpretation, nevertheless. Scheidel (2010) has recently discussed how, even for base metal coinage of ancient China and Rome, the quality (metal content) and quantities of coins in circulation influenced their value. The weight ratio observations reported here suggest a structure of perceived quality as well as limitation of circulating quantities. Parallels in Ptolemaic Egypt to Scheidel's 'metallist' observations for ancient base metal coins of China and Rome suggest avenues for additional research.

For a given coin denomination, e.g. the Ptolemaic bronze drachm, the observed conservation of average denominational weight clearly tells us the coins were produced *al marco*, conforming to a specific average weight irrespective of the question of a weight standard (a parallel between weight ratios and denomination ratios).

That a fixed amount of bronze was used to mint equal (large) quantities of coins over long periods of time and in different locations raises the question of the engineering method by which this precision could be achieved. One means of assuring consistency of average weight is piece by piece (atomic) adjustment, and

23 Van Driessche 1988.

another is the engineering of flan casting to achieve sufficient uniformity without individual adjustment. The central depression resulting from surface smoothing of the cast flans prior to striking is a visually obvious property of post-reform Ptolemaic bronze coins that also share uniform average denominational weight. The individual smoothing of flans might have been an atomic weight adjustment method used to achieve the *al marco* criterion. Some of the large Ptolemaic bronzes are neatly beveled or have nicely finished edges and sometimes file marks that are possible indications of alternative atomic adjustments. We may be able to deduce whether atomic weight adjustment, as described by Stannard (2009) for some other types of coins, was the means by which consistent average weight was achieved. Stannard suggested statistical indicators of a weight distribution that would reflect individual weight adjustments *al marco*, namely high values of the kurtosis (excessively narrow and tall weight distribution peak) and a negative skew (a bias of the distribution toward weights less than the mean).

Table 10 shows kurtosis and skewness values for a few distributions of Series 5 drachm types that were all surface-smoothed, are well-represented here, and which have nearly Gaussian weight distributions. We do not see Stannard's statistical indications (kurtosis > 3 and large negative skewness) of atomic weight adjustment. Flan preparation through smoothing, beveling or other operations, though labor intensive and almost universally applied to post-reform Ptolemaic bronze flans, does not appear to have been employed to adjust individual coin weights to assure consistent mean weights.

Table 10. Distribution shape statistics for three Series 5 drachm types.

Svoronos no.	Sample size	Distribution shape statistics		
964	164.	Gaussian: 0.90	Kurtosis: 2.67	Skewness: -0.04
1125	139.	Gaussian: 0.61	Kurtosis: 2.84	Skewness: -0.23
1126	49.	Gaussian: 0.74	Kurtosis: 2.52	Skewness: 0.14

Stannard suggests it is unlikely that thin flans of silver in his study could be cast accurately enough to achieve uniform weight aggregates, necessitating individual flan weight adjustment. Large, thick Ptolemaic bronze coins differ from the thin silver types for which Stannard found statistical signs of individual coin weight adjustment. I propose a simple technique that could allow precise aggregate weight standards for the large Ptolemaic bronzes, namely the use of water to measure the total volume of a large number of coin disc molds. A thought experiment can illustrate production of some arbitrary large number, say 1,000 for convenience of argument, of bronze drachm coins. To obtain 1,000 coins with a predictable, repeatable, average weight requires casting 1,000 bronze discs in molds that may vary in size (thickness, diameter) from one to the next, but with a specific total physical volume equal to the volume of (a little more than) 68.9 kg of bronze. Rather than precisely control the exact volume of each individual bronze coin mold or adjust the weight of each flan after casting, assuring a specific total volume of 1,000 molds automatically assures the total quantity (e.g. 1,000) of coins has the same total (and thus average) weight in each lot. Even if molds are damaged, destroyed or made in different lots, water can easily be used to measure their aggregate volume. If a specific weight (volume) of bronze is used to cast 1,000 flans then their average weight is 1/1,000 of that total weight (less flan preparation loss). The observed Aggregate Weight Standard is easy to assure irrespective of substantial individual variation. No atomic weight adjustment is required to achieve a uniform average weight if each large flan production run uses a repeatable volume of material. Water volumetry can easily assure the volume of 1,000 molds equals (slightly more than) the volume of 68.9 kg of bronze. In this example of 1,000 drachm coins the volume is about 7.5 l, large enough to be accurately repeated. Average losses from casting sprues and flan smoothing are also easy to determine through large quantity weight comparisons (e.g. before smoothing vs. after striking) and to compensate volumetrically.

Volume measurement of flan molds might be less reliably precise, however, in achieving highly accurate ratios over a range of denominations. Some smaller denominations are slightly lighter than predicted by their value ratios and flan preparation might have effected relatively greater metal loss prior to striking smaller volume flans.

Individual flan preparation after casting was clearly performed but apparently not for the purpose of weight adjustment of individual coins. Techniques to achieve both *al marco* production for individual denominations as well as a fairly accurate aggregate weight standard were therefore both simple and adapted to the high-output minting operations. A measured volume hypothesis for large numbers of bronze flans is consistent with the substantial individual variation yet highly conserved mean weights and weight distribution properties observed in this study.

Appendix 1: Metrological tables 1–4

Table 1. Metrology of Series 1–2

Svoronos	Series	*Chalkoi*	No.	Mean (g)	SD	Gauss	CF no.	OL no.	+CF-OL	Mean +cf-ol	Gauss +cf-ol	Mean/*Chalkous* +cf-ol
17	1	1	16	0.929	0.163	0.78	3					
28	1	1	3	0.960	0.156							
31	1	1	7	0.994	0.157		3					
53	1	1	10	0.974	0.206	0.77	3					
58	1	1	5	0.788	0.184		1					
		1	**41**	**0.936**	**0.186**	**0.58**	**10**	**1**	**50**	**0.957**	**0.61**	**0.957**
46	1	4	6	4.115	0.639		1					
47	1	4	1	3.530								
51	1	4	1	4.050								
57	1	4	2	3.785	0.215							
		4	**10**	**3.984**	**0.542**	**0.90**	**1**	**0**	**11**	**4.073**	**0.94**	**1.018**
163	2 A	4	12	4.072	0.520	0.59	4					
167	2 A	4	4	3.518	0.083		1					
171	2 A	4	17	3.709	0.493	0.88	5					
173	2 A	4	1	4.700								
		4	**34**	**3.844**	**0.528**	**0.60**	**10**	**0**	**44**	**3.902**	**0.38**	**0.976**

155	2 B	5	9	5.508	0.622	0.96					
156	2 B	5	19	5.073	0.656	0.94					
157	2 B	5	5	4.610	0.675		1				
172	2 B	5	45	5.142	0.736	0.20	3				
		5	**79**	**5.138**	**0.725**	**0.69**	**4**	**0**	**83**	**5.137**	**0.79**	**1.027**
50	2 C	1	4	1.035	0.025		1				
52	2 C	1	3	1.093	0.187						
54	2 C	1	1	1.100							
56	2 C	1	6	0.883	0.077						
		1	**14**	**0.987**	**0.136**	**0.99**	**1**	**0**	**15**	**0.987**	**0.98**	**0.987**
114	2 C	4	1	6.400							
115	2 C	4	8	4.089	0.620						
119	2 C	4	4	4.549	0.444						
130	2 C	4	1	4.800							
135	2 C	4	4	5.168	0.574						
136	2 C	4	3	3.063	0.526		1				
138	2 C	4	1	4.500							
		4	**22**	**4.385**	**0.923**	**0.84**	**1**	**0**	**23**	**4.368**	**0.85**	**1.092**

UNC	2 Di	1?	4	2.264	0.361							2.264?
239	2 Di	2	26	2.625	0.515	0.11	6	3	29	2.610	0.61	1.305
189	2 Di	4	1	4.500								
UNC	2 Di	4	1	3.088								
238	2 Di	4	6	3.550	0.951		1					
332	2 Di	4	1	2.640			2					
		4	**9**	**3.503**	**0.904**		**3**	**1**	**11**	**3.211**	**0.11**	**0.803**
186	2 Di	8	9	9.172	1.409							
188	2 Di	8	10	8.750	1.422							
196	2 Di	8	2	8.750	0.550		1					
202	2 Di	8	1	7.500								
215	2 Di	8	2	8.095	1.255							
220	2 Di	8	49	8.608	1.359		1					
225	2 Di	8	1	8.150								
226	2 Di	8	7	8.899	0.536							
235	2 Di	8	44	7.997	0.769		2					
237	2 Di	8	14	7.901	1.354		1					
		8	**139**	**8.388**	**1.225**	**0.46**	**5**	**3**	**141**	**8.368**	**0.84**	**1.046**
184	2 Di	16	3	15.73	0.596							
193	2 Di	16	3	16.20	1.062							
206	2 Di	16	37	15.35	1.532		2					

213	2 Di	16	1	18.40								
230	2 Di	16	1	14.28			1					
		16	**45**	**15.48**	**1.517**	**0.09**	**3**	**0**	**48**	**15.39**	**0.23**	**0.962**
192	2 Di	24	3	21.63	0.467							
212	2 Di	24	1	20.95								
		24	**4**	**21.46**	**0.501**		**0**	**0**	**4**	**21.46**		**0.895**
269	2 Dii	16	2	14.89	0.910							
271	2 Dii	16	18	15.60	1.855		4					
272	2 Dii	16	3	15.31	1.307							
274	2 Dii	16	1	15.40								
275	2 Dii	16	12	15.56	2.070							
276	2 Dii	16	1	16.20								
277	2 Dii	16	1	15.75								
278	2 Dii	16	9	16.02	1.827		5					
279	2 Dii	16	4	15.81	1.681		1					
280	2 Dii	16	2	16.11	0.255							
281	2 Dii	16	1	18.00								
282	2 Dii	16	1	16.50								
283	2 Dii	16	2	14.16	3.290							
284	2 Dii	16	1	17.45								
285	2 Dii	16	7	15.08	1.207							

286	2 Dii	16	11	15.58	0.741	0.97						
287	2 Dii	16	7	15.25	1.376							
288	2 Dii	16	8	15.55	0.937		3					
		16	**91**	**15.58**	**1.630**	**0.24**	**13**	**1**	**103**	**15.53**	**0.76**	**0.971**
289	2 Diii	16	3	14.94	0.249		3					
290	2 Diii	16	1	13.80								
292	2 Diii	16	24	16.62	1.391							
293	2 Diii	16	11	15.45	1.336							
294	2 Diii	16	1	14.40								
295	2 Diii	16	2	15.34	0.260							
296	2 Diii	16	0				1					
297	2 Diii	16	1	17.00								
298	2 Diii	16	14	16.40	1.308		1					
299	2 Diii	16	9	15.52	1.621							
300	2 Diii	16	9	15.99	1.391							
301	2 Diii	16	6	16.14	1.643							
302	2 Diii	16	7	16.10	1.602							
303	2 Diii	16	5	15.06	1.382		1					
		16	**93**	**15.99**	**1.500**	**0.74**	**6**	**0**	**99**	**16.00**	**0.78**	**1.000**
550	**2 E**	**16**	**17**	**14.44**	**1.612**	**0.87**	**0**	**0**	**17**	**14.44**	**0.87**	**0.902**
549	**2 E**	**20?**	**2**	**17.85**	**2.400**							**0.893**

565	2 F	8	1	7.390								
601	2 F	8	5	8.120	1.015							
		8	**6**	**7.998**	**0.966**		**0**	**0**	**6**	**7.998**		**1.000**
553	2 F	16	48	16.00	1.351		8					
556	2 F	16	2	13.03	1.125							
560	2 F	16	11	15.41	1.230							
563	2 F	16	5	16.72	0.838							
568	2 F	16	10	15.29	1.635							
571	2 F	16	5	15.22	2.078		1					
576	2 F	16	28	15.51	1.572		1					
580	2 F	16	15	15.93	1.576							
586	2 F	16	20	16.30	1.308							
593	2 F	16	9	15.55	0.711		7					
598	2 F	16	10	15.55	1.096							
600	2 F	16	3	15.92	1.075							
		16	**166**	**15.77**	**1.464**	**0.03**	**17**	**4**	**179**	**15.77**	**0.40**	**0.979**
554	2 G	16	5	14.61	1.122		2					
564	2 G	16	4	15.20	1.467							
		16	**9**	**14.91**	**1.320**		**2**	**0**	**11**	**14.98**	**0.57**	**0.936**

562	2 H	8	4	7.687	0.763		3					
582	2 H	8	6	7.464	1.017							
602	2 H	8	5	7.464	1.017							
625	2 H	8	1	8.050								
		8	**16**	**7.651**	**0.783**	**0.89**	**3**	**0**	**19**	**7.526**	**0.53**	**0.941**
557	2 H	16	10	14.74	0.753							
561	2 H	16	10	13.35	1.693		1					
562	2 H	16	0				1					
572	2 H	16	11	15.46	2.416							
577	2 H	16	3	15.02	0.690		1					
581	2 H	16	31	14.64	1.572		4					
587	2 H	16	5	14.01	1.654		1					
589	2 H	16	11	13.60	1.221		8					
594	2 H	16	3	12.66	0.879		4					
		16	**84**	**14.38**	**1.732**	**0.10**	**20**	**3**	**101**	**14.31**	**0.31**	**0.894**
82	Cyprus	1	5	1.126	0.105		4	0	9	1.130		1.130
79	Cyprus	4	4	3.842	0.164		1					
80	Cyprus	4	14	4.234	0.608	0.53	1					
81	Cyprus	4	2	4.560	0.960		2					
		4	**20**	**4.188**	**0.629**	**0.15**	**4**	**0**	**24**	**4.190**	**0.09**	**1.048**

74	Cyprus	8	14	7.956	0.782	0.86	1					
75	Cyprus	8	8	7.971	0.785							
76	Cyprus	8	1	9.600			3					
77	Cyprus	8	1	9.010								
78	Cyprus	8	13	8.452	1.080	0.96						
		8	**37**	**8.206**	**0.933**	**0.27**	**4**	**0**	**41**	**8.258**	**0.25**	**1.032**
72	Cyrene	1	2	0.590	0.060		2	0.733		0.187		0.733
69	Cyrene	2	1	2.200								1.100
65	Cyrene	4	1	3.120			2					
67	Cyrene	4	1	3.300								
70	Cyrene	4	8	3.801	0.289							
71	Cyrene	4	4	3.745	0.222							
		4	**14**	**3.701**	**0.322**	**0.85**	**2**	**0**	**16**	**3.571**	**0.40**	**0.893**
326	Magas	4	2	4.835	0.295							
333	Magas	4	7	3.884	0.495							
334	Magas	4	1	4.250			2					
335	Magas	4	2	4.300	0.500							
337	Magas	4	5	4.872	1.364							
		4	**17**	**4.357**	**0.941**	**0.06**	**2**	**0**	**19**	**4.317**	**0.20**	**1.079**

321	Magas	8	5	6.192	0.316							
324	Magas	8	23	7.770	0.899	0.22						
325	Magas	8	2	6.130	0.020							
327	Magas	8	9	7.757	0.869							
328	Magas	8	3	5.747	1.857							
329	Magas	8	1	7.500								
331	Magas	8	3	7.370	0.380							
		8	46	7.361	1.139	0.21	0	1	45	7.433	0.49	0.929
K2	**Ceraunus**	**2**	**1**	**1.530**								**0.765**
K4	**Ceraunus**	**4**	**20**	**4.026**	**0.698**	**0.26**	**0**	**0**	**20**	**4.026**	**0.26**	**1.007**
K8	**Ceraunus**	**8**	**32**	**7.785**	**0.778**	**0.97**	**0**	**0**	**32**	**7.785**	**0.97**	**0.973**
382	**2 Mint 22**	**8**	**11**	**7.315**	**0.491**	**0.95**	**0**	**0**	**11**	**7.315**	**0.95**	**0.914**
341	2 Mint 22	16	5	14.42	3.452							
381	2 Mint 22	16	12	13.37	1.862							
		16	**17**	**13.68**	**2.487**	**0.72**	**0**	**1**	**16**	**13.32**	**0.54**	**0.833**
346	2 Mint 26	4	4	3.398	0.762							
351	2 Mint 26	4	4	4.538	1.085							
352	2 Mint 26	4	3	4.043	0.308							
383	2 Mint 26	4	4	3.341	0.652		2					

386	2 Mint 26	4	4	3.775	0.369		1					
		4	**19**	**3.807**	**0.840**	**0.47**	**3**	**0**	**22**	**3.885**	**0.82**	**0.971**
360	2 Mint 26	8	1	7.420								
384	2 Mint 26	8	4	8.203	0.943							
385	2 Mint 26	8	3	6.929	0.557							
		8	**8**	**7.627**	**0.956**		**0**	**0**	**8**	**7.627**		**0.953**
347	**2 Mint 9**	**1**	**2**	**1.450**	**0.450**							**1.450**
356	2 Mint 9	8	30	7.884	0.883	0.87	1					
363	2 Mint 9	8	90	8.256	0.903	0.01						
377	2 Mint 9	8	21	7.990	0.861	0.16	3					
		8	141	8.137	0.907	0.00	4	5	140	8.214	0.40	1.027
UPI	**2 UPI**	**8**	**2**	**8.521**	**1.329**		**0**	**0**	**2**	**8.521**		**1.065**
345	**2 Mint 7**	**1**	**7**	**1.177**	**0.081**		**2**	**0**	**9**	**1.140**		**1.140**
379	**2 Mint 10**	**8**	**14**	**7.816**	**0.554**		**7**	**0**	**21**	**7.836**	**0.87**	**0.980**
387	**Byzantion**	**2**	**64**	**1.995**	**0.550**	**0.05**	**0**	**3**	**61**	**1.924**	**0.69**	**0.962**

627	Pt. 1 Tyre	4	3	4.253	0.437							
628	Pt. 1 Tyre	4	3	4.101	0.252							
630	Pt. 1 Tyre	4	8	3.724	0.276							
		4	14	3.918	0.388	0.63	0	1	13	3.846	0.89	0.962
216	**Pt. 2 Tyre**	**1**	**1**	**1.550**								**1.550**
217	**Pt. 2 Tyre**	**2**	**1**	**1.470**			**3**		**4**	**1.830**		**0.915**
635	Pt. 2 Tyre	4	1	2.960								
638	**Pt. 2 Tyre**	**4**	**11**	**3.804**	**0.576**							
641	Pt. 2 Tyre	4	15	3.749	0.450		2					
642	Pt. 2 Tyre	4	2	3.415	0.285							
		4	29	3.720	0.515	0.74	2	0	31	3.679	0.34	0.920
610a	Pt. 2 Sicily	**18**	**85**	**17.13**	**0.631**	**0.00**						
610b	Pt. 2 Sicily	**18**	**30**	**17.15**	**1.304**	**0.06**						
610x	Pt. 2 Sicily	**18**	**86**	**16.84**	**1.099**	**0.02**						
		18	**201**	**17.01**	**0.978**	**0.00**	**0**	**15**	**186**	**17.04**	**0.40**	**1.065**

Table 2. Metrology of Series 3.

Svoronos	Series	*Chalkoi*	No.	Mean (g)	SD	Gauss	CF no.	OL no.	+CF-OL	Mean +cf-ol	Gauss +cf-ol	Mean/*Chalkous* +cf-ol
Alexandrian Series												
418	3	2	28	3.310	0.611							
442	3	2	7	3.163	0.503							
453	3	2	17	3.167	0.444		1					
470	3	2	1	2.420								
485	3	2	4	2.863	0.383							
		2	**57**	**3.202**	**0.556**	**0.08**	**1**	**1**	**57**	**3.253**	**0.22**	**1.627**
417	3	4	20	3.779	0.889							
426	3	4	10	5.307	0.635							
441	3	4	17	5.349	0.710							
452	3	4	14	4.850	0.808		1					
469	3	4	10	5.088	0.592							
473	3	4	2	5.475	0.075							
484	3	4	12	5.023	0.831							
493	3	4	0				1					
501	3	4	5	4.710	0.754		2					
		4	**90**	**4.813**	**0.961**	**0.03**	**4**	**3**	**91**	**4.905**	**0.14**	**1.226**

416	3	6	33	7.395	1.056		1					
440	3	6	15	7.053	0.948							
451	3	6	22	6.455	1.154							
468	3	6	3	6.867	0.352		1					
483	3	6	6	6.260	1.941							
500	3	6	3	5.950	0.220							
		6	**82**	**6.925**	**1.213**	**0.26**	**2**	**5**	**79**	**6.927**	**0.33**	**1.161**
424	3	8	12	11.26	1.245							
439	3	8	38	10.96	1.235		1					
450	3	8	24	10.74	0.835		2					
467	3	8	18	10.79	1.800							
482	3	8	15	10.79	1.437		1					
493	3	8	2	10.10	0.900		1					
507	3	8	3	11.88	0.289		1					
		8	**113**	**10.90**	**1.301**	**0.47**	**6**	**3**	**116**	**10.87**	**0.94**	**1.359**
415	3	16	5	23.83	0.852		1					
423	3	16	5	22.02	1.977							
438	3	16	16	21.57	2.301							
449	3	16	28	21.38	2.604		1					
458	3	16	1	18.70								
465	3	16	14	21.65	1.581		1					

466	3	16	4	23.25	0.991							
481	3	16	6	20.25	1.740							
498	3	16	4	21.39	0.959							
506	3	16	14	22.20	2.019		1					
510	3	16	2	21.53	0.825							
516	3	16	2	22.71	0.355							
		16	**101**	**21.72**	**2.182**	**0.01**	**4**	7	**98**	**21.94**	**0.46**	**1.371**
414	3	32	3	47.40	2.344							
448	3	32	9	43.64	1.840							
480	3	32	1	45.65								
505	**3**	**32**	**11**	**45.85**	**2.958**							
509	3	32	6	46.27	2.210							
515	3	32	1	44.34								
		32	**31**	**45.38**	**2.667**	**0.62**	**0**	**0**	**31**	**45.38**	**0.62**	**1.418**
413	3	48	6	66.49	4.325		1					
422	3	48	11	69.90	4.090		1					
431	3	48	1	75.50								
437	3	48	17	67.74	4.393		1					
447	3	48	3	68.91	3.158							
457	3	48	2	69.40	1.600							
463	3	48	17	69.74	4.145							

497	3	48	18	69.00	4.771							
504	3	48	25	68.43	3.207		3					
514	3	48	8	69.35	3.569							
		48	135	68.65	4.080	0.08	6	3	138	68.65	0.25	1.428
					Non-Alexandrian Series							
790	3 Ake	16	13	22.60		0.75						1.413
789	3 Ake	32	4	46.78	3.285							1.462
788	3 Ake	48	6	64.54	8.831							1.345
761	3 Mint 27	8	20	9.640	2.089	0.05	2					1.215
760	3 Mint 27	16	11	21.60	1.119	0.75						1.350
759	3 Mint 27	32	15	44.43	2.695	0.49						1.467
758	3 Mint 27	48	14	68.24	3.977	0.90						1.422
838	3 Tyre	4	8	5.283	1.148							1.321
836	3 Tyre	8	5	10.37	0.827							1.296
UNC	3 Tyre	16	5	20.13	2.520							1.279
835	3 Tyre	32	5	42.65	3.362							1.291
834	3 Tyre	48	3	62.71	7.467							1.306
762	3 Amman	4	15	5.392	0.722	0.39						1.348
763	3 Amman	8	5	11.63	0.930		1					1.375

Combined Non-Alexandrian Series							
4	23	0	2	21	5.557	0.18	1.389
8	30	3	3	30	10.54	0.54	1.318
16	29	0	3	26	21.47	1.00	1.342
32	24	0	0	24	44.45	0.81	1.389
48	23	0	2	21	68.10	0.78	1.419

Table 3. Metrology of Series 4.

Svoronos	Series	*Chalkoi*	No.	Mean (g)	SD	Gauss	CF no.	OL no.	+CF-OL	Mean +cf-ol	Gauss +cf-ol	Mean/*Chalkous* +cf-ol
Alexandrian Series												
1171	4A	4	3	4.940	0.769				3	4.940		1.235
1170	4A	8	31	10.05	1.195	0.80			31	10.05	0.80	1.256
1169	4A	12	22	14.30	1.258	0.32			22	14.30	0.32	1.192
1168	4A	16	12	21.83	2.530	0.46		1	11	21.25	0.86	1.328
1167	4A	20	48	28.26	2.854	0.53	1		49	28.21	0.69	1.411
1166	4A	32	63	44.54	3.281	0.17		3	60	44.38	0.35	1.387
478	4A	64	10	87.32	7.618	0.57			10	87.32	0.57	1.365
977	4B	6	2	8.265	0.995				2	8.265		1.378
976	4B	8	49	10.36	1.485	0.32		4	45	10.39	0.42	1.299
975	4B	12	61	14.19	1.532	0.02	2	7	56	14.38	0.09	1.198
974a	4B	20	2	27.17	0.930				2	27.17		1.359
974	4B	32	282	44.62	4.025	0.00	4	3	283	44.59	0.79	1.393
446	4B	64	95	89.63	7.482	.160		1	94	89.92	0.20	1.405
976	4C	8	9	11.06	1.276				9	11.06		1.382
975	4C	12	11	14.52	2.533	0.94			11	14.52	0.94	1.210
446	4C	64	1	85.52								1.336

976	**4D**	**8**	**1**	**8.298**								**1.037**
975	**4D**	**12**	**1**	**15.04**								**1.253**
1167	**4D**	**24**	**1**	**31.93**								**1.330**
974	**4D**	**32**	**5**	**41.99**	**1.342**							**1.312**
478	**4D**	**64**	**2**	**90.90**	**1.605**							**1.420**
1172	**4E**	**32**	**26**	**43.87**	**3.063**	**0.65**			**26**	**43.87**	**0.65**	**1.371**
412	**4E**	**64**	**52**	**91.75**	**5.695**	**0.03**		**8**	**44**	**93.27**	**0.95**	**1.457**
462	**4F**	**64**	**5**	**90.92**	**6.214**							**1.421**
502	**4F**	**64**	**1**	**76.46**								**1.195**
		64	**6**	**88.51**	**7.824**							**1.383**
					Combined Alexandrian Series 4A–4F							
	4A–4F	4	5						5	6.270		1.568
	4A–4F	8	90					1	89	10.35	0.96	1.294
	4A–4F	12	93				2	8	87	14.46	0.25	1.205
	4A–4F	16	12					1	11	21.25	0.86	1.328
	4A–4F	20	50				1	1	50	28.32	0.42	1.180
	4A–4F	32	447				4	5	446	44.47	0.82	1.390
	4A–4F	64	165					1	164	90.30	0.02	1.411
Unit Weight	4A–4F	~1	867					22	845	1.355	0.00	1.355
1173	**4X**	**4**	**3**	**6.263**	**0.437**			—				**1.566**

Non-Alexandrian Series												
UNC	4 Cyprus	1	2	1.947	0.353			—				1.947
843	4 Cyprus	3	16	3.878	0.533	0.79		—				1.293
842	4 Cyprus	4	12	6.426	1.974	0.34		—				1.607
841	4 Cyprus	12	9	14.37	1.412			—				1.198
UNC	4 Cyprus	32	3	47.52	1.577			—				1.517
UNC	4 Cyprus	64	2	94.29				—				1.473
868	4 Cyrene	1	2	1.060	0.060			—	2	1.06		1.060
857	4 Cyrene	2	7	2.182	0.299							
867	4 Cyrene	2	7	2.251	0.723		1					
872	4 Cyrene	2	8	3.201	0.499							
873	4 Cyrene	2	16	2.176	0.870		2					
874	4 Cyrene	2	1	1.550								
		2	39	2.385	0.809	0.50	3	—	42	2.317	0.60	1.159
856	4 Cyrene	4	3	3.375	0.367		4	—	7	3.373		1.205
855	4 Cyrene	8	8	7.710	0.710							
858	4 Cyrene	8	3	6.527	0.290							
859	4 Cyrene	8	1	9.400								
860	4 Cyrene	8	2	7.300	0.100							
862	4 Cyrene	8	3	7.677	0.796							

863	4 Cyrene	8	3	10.97	2.368							
864	4 Cyrene	8	1	5.800								
865	4 Cyrene	8	4	7.470	0.633							
866	4 Cyrene	8	5	7.442	0.955		1					
870	4 Cyrene	8	6	7.728	0.647							
871	4 Cyrene	8	38	7.472	0.929							
UNC	4 Cyrene	8	1	8.400								
		8	**75**	**7.637**	**1.212**	**0.00**	**1**	**—**	**76**	**7.647**	**0.00**	**0.968**
854	**4 Cyrene**	**16**	**5**	**13.53**	**2.504**		**3**					
1141	4 Cyrene	16	5	15.81	1.017							
1143	4 Cyrene	16	4	15.88	2.026							
1147	4 Cyrene	16	1	16.45								
1152	4 Cyrene	16	6	16.17	1.674							
		16	**21**	**15.41**	**2.111**	**0.27**	**3**	**—**	**24**	**15.07**	**0.20**	**0.942**
1050	4 RasIbnH	1	3	1.657	0.383							
1057	4 RasIbnH	1	4	1.828	0.410							
		1	**7**	**1.754**	**0.407**							**1.754**

1053	4 RasIbnH	3	5	4.534	0.212							
1054	4 RasIbnH	3	4	4.035	0.440							
1056	4 RasIbnH	3	18	4.233	0.338		1					
			27	**4.259**	**0.367**	**0.38**	**1**	—	**28**	**4.224**	**0.28**	**1.408**
1047	4 RasIbnH	6	4	8.350	1.506							
1048	4 RasIbnH	6	8	7.391	0.594							
1049	4 RasIbnH	6	4	5.920	2.140							
1055	4 RasIbnH	6	25	7.827	0.638							
			41	**7.412**	**1.190**	**0.03**		—	**41**	**7.412**	**0.03**	**1.235**
1051	4 RasIbnH	12	14	14.86	1.341							
1052	4 RasIbnH	12	1	13.30								
			15	**14.76**	**1.352**	**0.54**		—	**15**	**14.76**	**0.54**	**1.230**

Table 4. Metrology of Series 5.

Svoronos	Series	*Chalkoi*	No.	Mean (g)	SD	Gauss	CF no.	OL no.	+CF-OL	Mean +cf-ol	Gauss +cf-ol	Mean/*Chalkous* +cf-ol
						Alexandrian Series						
UNC	5A	4	1	5.840					1			1.460
1004	5A	16	1	23.30					1			1.456
1003	5A	24	14	35.32	1.933	0.89			14	35.32	0.89	1.472
1002	5A	48	7	70.53	2.981				7			1.469
971	5B	1	21	1.255	0.275	0.71			21	1.255	0.71	1.255
970	5B	2	34	2.596	0.470	0.28		2	32	2.522	0.94	1.261
969	5B	3	30	3.981	0.606	0.92			30	3.981	0.92	1.327
968	5B	4	34	5.241	0.582	0.98			34	5.241	0.98	1.310
967	5B	8	34	10.43	1.179	0.78	1		35	10.49	0.76	1.304
966	5B	16	43	22.10	1.909	0.05		2	41	22.39	0.12	1.399
965	5B	24	122	33.48	2.650	0.01		4	118	33.73	0.26	1.405
964	5B	48	164	68.84	3.998	0.06		3	161	69.05	0.90	1.439
Unit Weight	5B	~1	482				1	35	448	1.398	0.00	1.398
						Non-Alexandrian Series						
711	5B Tyre	2	21	2.582	0.287	0.70	1	1	21	2.582	0.70	1.261
710	5B Tyre	3										
709	5B Tyre	4	52	5.525	0.564	0.69			52	5.525	0.69	1.381

708	5B Tyre	8	49	11.23	1.068	0.46			49	11.23	0.46	1.404
707	5B Tyre	16	16	21.90	1.543	0.42		1	15	21.63	0.72	1.352
706	5B Tyre	24	19	34.16	1.870	0.46		2	17	34.24	0.55	1.427
705	5B Tyre	48	17	69.18	2.463	0.79			17	69.18	0.79	1.441
Unit Weight	5B Tyre	~1	174				1	4	171	1.393	0.11	1.393
1128	5C	24	43	34.81	2.189	0.30		1	42	34.96	0.33	1.457
1126	5C	48	54	68.70	4.154	0.06		5	49	69.65	0.74	1.451
Unit Weight	5C	~1	97					3	94	1.447	0.51	1.447
1127	5D	24	92	34.00	2.325	0.01		5	87	34.35	0.73	1.431
1125	5D	48	140	68.20	5.149	0.00	4	5	139	68.76	0.62	1.423
Unit Weight	5D	~1	232				4	11	225	1.433	0.79	1.433
Unit Weight	5C + 5D	~1	329				4	14	319	1.437	0.41	1.437
1130	5CD Tyre	24	35	33.69	2.999	0.01		3	32	34.02	0.89	1.418
1129	5CD Tyre	48	34	68.36	3.662	0.85	1	1	34	68.03	0.82	1.417
Unit Weight	5CD Tyre	~1	69				1	4	66	1.417	0.98	1.417
UNC	5E	2	4	2.684	0.381							1.342
UNC	5E	4	5	5.093	0.382							1.274

994/1151	5E	16	49	21.34	1.883	0.97						
1146?	5E	16	1	19.30								
		16	50	21.30	1.886	0.97						1.331
993	**5E**	**24**	**92**	**35.47**	**3.777**	**0.00**		**5**	**87**	**34.90**	**0.49**	**1.454**
1145	5E	32	9	46.23	2.285							
1148	5E	32	77	44.06	3.371							
1149	5E	32	51	44.30	3.838		4					
1150	5E	32	4	43.51	4.422							
		32	**141**	**44.27**	**3.565**		**4**	**1**	**144**	**44.40**	**0.48**	**1.388**
992	**5E**	**48**	**166**	**69.25**	**4.682**	**0.11**	**1**	**3**	**164**	**69.32**	**0.39**	**1.444**
Unit Weight	**5E**	**~1**	**458**				**5**	**11**	**452**	**1.410**	**0.01**	**1.410**
UNC	**5E Tyre**	**2**	**2**	**2.767**								**1.384**
1153	**5E Tyre**	**4**	**5**	**5.536**	**0.422**							**1.384**
UNC	5E Tyre	8	5	11.10	0.755							1.388
1140	5F	32	23	45.84	4.440		3					
1142	5F	32	16	44.10	3.512							
1144	5F	32	7	43.93	3.552							
		32	**46**	**44.95**	**4.108**	**0.76**	**3**	**44.76**	**4.167**		**0.92**	**1.399**

840	5 Caunus	1							15	1.671	0.48	1.671
839	5 Caunus	2							52	2.583	0.95	1.292
1063	5 Caunus	4							7	5.493		1.374
1000	5 Corinth	4	65	5.550	0.563	0.14	1	3	63	5.570	0.80	1.393
999	5 Corinth	6	15	8.118	1.463							
998	5 Corinth	6	2	8.700	1.400							
		6	17	8.186	1.468	0.98			17	8.186	0.98	1.364
997	5 Corinth	12	6	16.56	1.623							1.381
Unit Weight	5 Corinth	~1	88					3	85	1.391	0.68	1.391
1009	5 Cyprus	1	13	1.506	0.244	0.68	1	1	14	1.484	0.74	1.484
1008	5 Cyprus	2	33	2.918	0.384	0.88			33	2.918	0.88	1.459
1007	5 Cyprus	4	26	5.790	0.694	0.08		1	25	5.700	0.60	1.425
1006	5 Cyprus	8	39	11.92	1.240	0.17		1	38	11.82	0.39	1.478
1005	5 Cyprus	12	47	17.62	1.478	0.06		5	42	17.76	0.61	1.480
Unit Weight	5 Cyprus	~1	157				1	7	151	1.452	0.44	1.452
1411	5C Cyprus	32	5	46.90	2.524							
1413	5C Cyprus	32	2	45.43	2.925							
1414	5C Cyprus	32	3	44.30	1.469							
		32	10	45.82	2.616	0.40						1.432

820	5 Joppa	1	4	1.589	0.049		2		6	1.774		1.774
819	5 Joppa	2	18	2.765	0.455	0.99			18	2.765	0.99	1.382
818	5 Joppa	4	22	5.229	0.499	0.66	1		23	5.246	0.73	1.312
UNC	5 Joppa	8	1	12.07					1	12.07		1.509
793	5 Telmessos	2	58	3.401	0.595	0.26		4	54	3.555	0.26	1.778
792	5 Telmessos	4	10	6.508	1.683	0.56	1	1	11	6.408	0.48	1.602
791	5 Telmessos	8	58	11.12	1.250	0.00		1	57	11.02	0.49	1.378
Drachm	Alex Tyre	48							571	69.04	0.61	1.438
Tetrobol	5E 5F Cyp	32							204	44.60	0.67	1.394
Tetrobol	5E 5F	32							192	44.55	0.58	1.392
Hemidrachm	Alex Tyre	24							395	34.25	0.03	1.427
Diobol	All S5	16							107	21.87	0.22	1.367
Trihemiobol	Cor Cyp	12							48	17.63	0.35	1.469
Obol	All S5	8							179	11.15	0.09	1.394
6 Chalkoi	Corinth	6							17	8.186	0.98	1.364
4 Chalkoi	All S5	4							237	5.473	0.67	1.368
3 Chalkoi	969 only	3							30	3.981	0.92	1.327
2 Chalkoi	All S5	2							216	2.818	0.25	1.409
1 Chalkous	All S5	1							55	1.464	0.26	1.464

Appendix 2–Graphical and Statistical Methods

Graphs

Graphical presentations of coin weight distributions are indispensable for this type of study to allow comprehensive visual assessment of relationships within and between coin weight data groups. This study uses three types of graphs to display relations of coin weight sets. Regression plots with calculated least-squares fit lines were created using a commercial software package called Magic Plot Student version 2.0.1.[24] Esty (1989) reviewed a variety of graphical presentations that are useful in numismatic studies, including box plots and percentile plots both of which were used in this study. Box plots and percentile plots were created with online statistical calculators provided by College of Saint Benedict, Saint John's University.[25]

A. Box Plot

The box plot is a one dimensional presentation of a data set showing the middle half of the range of data values (from 25 to 75%, the second and third quartiles) within an outline box with a horizontal line at the median value (middle weight value, Y axis in these box plots). The remaining data range (from 0 to 25% and 75 to 100%, first and fourth quartiles) is represented by extended bars above and below the box. Box plots allow easy visual comparison of two or more data groups shown side by side. See Esty for more varieties of box plots and related coin data graphs.

B. Percentile Plots

A percentile plot shows the fraction (Y axis) of a data set spread over its full range of weights (X axis). The percentile ranges from 0 to 100% (Y axis) over the full range of a set of coin weights (X axis). It represents the area under a histogram or weight distribution. Histograms are sometimes useful but the data in this study are such that it is difficult to choose histogram 'bin' sizes that are consistent. The visual impression of histograms may depend on a choice of bin widths and that potential bias is avoided with percentile graphs. There are also helpful statistical tests (see below) that can compare percentile graphs for data that don't necessarily have bell-shaped distributions. When data have Gaussian (bell-shaped) distributions the corresponding percentile graph has a regular sigmoid shape.

C. Regression Plots

I introduce a simple, perhaps numismatically novel, statistical and graphic method for estimating weight standards. Linear regression calculates a line connecting

24 Magicplot Systems, LLC. See http://www.magicplot.com (last accessed September 22, 2013).

25 See http://www.physics.csbsju.edu/stats/ (last accessed September 22, 2013).

several data sets (weights, Y axis) for different coin types (denominations, X axis). Linear regression's 'least squares' method establishes the line that best fits all the data at once. The best fit is calculated that expresses the minimum total deviation between the line and all the data values. Regression plots show many weights and multiple coin denominations in one visual layout, associated with a statistic, the line's slope, that is independent of denomination and expresses a single weight per unit of value (weight standard). A regression plot allows visual inspection whether some types require corrections to their putative values. A regression plot's single slope number can also be compared with the overall mean unit weights separately to expose other relationships.

Statistical Tests

The Saint John's University web-based system cited above that generated many of the graphs here also includes numerous statistical tools used for comparisons and analyses in this study.

Three tests allow comparisons of pairs of coin weight distributions to one another:

A. Student's t-test

Student's t-test compares two (ideally Gaussian, bell-curve) distributions. The result is a value, P (ranging from 0 to 1) indicating whether the two distributions differ more than would be expected by chance. E.g. $P = 0.01$ suggests a likelihood of 1 in 100 that the data share common properties (mean, etc.). The online t-test calculator[26] used here also includes a graphing option to produce adjacent box plots.

B. Kolmogorov-Smirnov Test (KS-test)

The KS test compares the shapes of two data sets' percentile graphs and determines whether the maximum difference between them is large enough to assure they differ. KS tests can be used for data sets that are not necessarily Gaussian (bell-shaped distributions). The resulting P value indicates whether the similarity (or difference) between data sets exceeds the degree to which it might be expected by chance. The online KS test calculation system used here, cited above (provided by Saint Johns University), also produced the percentile plots shown in some of the supporting graphs.

The KS test can also provide a measure of the degree to which a single data set agrees with a bell curve or Gaussian ideal by comparing the empirical data to the 'ideal' percentile graph of a true Gaussian distribution of the same mean and variability. The online statistical calculators used here gave those Gaussian fit measures that are reported in the tables.

26 http://www.physics.csbsju.edu/stats/ (last accessed September 22, 2013).

The same test provides a report of 'outliers' that are identified according to the Tukey criterion, namely that outliers are those data values which lie more than 1.5 times the interquartile range below the first, or above the third, quartile limit. Outliers identified by the online calculators (according to the Tukey criterion) could then be excluded from data sets prior to the application of other statistical comparison tests. The numbers of outlier specimens in various data sets, as identified in this fashion, are reported in the tables.

C. Mann-Whitney U-Test

In addition to the KS test, the Mann-Whitney U-test (U) was also used by Veselỳ (2006) for numismatic metrology and it is helpful for our inquiries. The U-test measures whether the values of the two data sets are spread evenly among one another when the data are ordered and combined. If the combined data interleave evenly then the U-test will indicate the data are similar. The U-test, like the KS test, is helpful for data sets that differ in size and shape. The Mann-Whitney U-tests were performed using an online calculator provided by Virginia Commonwealth University.[27]

One additional test allows comparison of three or more weight data groups to one another to tell if they are all alike.

D. Analysis of Variance (ANOVA)

This test compares multiple data sets at once when the data are all of Gaussian form. The online statistical calculators used for ANOVA tests here also produced the box plots showing multiple data sets side by side. A P value ranging from 0 to 1 is obtained for the ANOVA. P value interpretations for ANOVA are similar to those of the other statistical comparison tests. High P values suggest that the data sets are similar to one another and we reject the hypothesis that they substantially differ.

E. Kurtosis and Skew

These statistics were calculated for a few distributions using an online calculator.[28]

Acknowledgements

I am grateful to to Amelia Dowler and Richard Ashton for helpful assistance viewing specimens of the British Museum Collection and for providing a digital data set of modern weights for BMC Ptolemaic bronzes. Maria C. Caltabiano provided data for Ptolemaic coins at the Messina Museum and Angelamaria Manenti assisted viewing Ptolemaic bronze coins in the Paolo Orsi Museum Collection of Syracuse. David MacDonald helped organize Ptolemy Ceraunos specimen data. G. Shiatis,

27 http://elegans.som.vcu.edu/~leon/stats/utest.cgi (last accessed September 22, 2013).
28 http://www.calculatorsoup.com/calculators/statistics/descriptivestatistics.php (last accessed September 22, 2013).

C. Michael, P. Pavlou, and W. Capers provided many additional specimen data and photographs. Andrew Meadows of the American Numismatic Society provided the ANS digital data set. Catharine Lorber provided pre-publication Ptolemaic bronze coin catalogues from her forthcoming book and other reference material as well as much encouragement and many helpful comments. Gille Gorre assisted with papyrological references. Many thanks are also due to the organizers and web site authors of online collections (Cambridge University's Fitzwilliam Museum, Yale University, and others) that were also helpful data sources, and also to the auction and sales companies that provided data on some coins in commerce.

References

Arslan, M., and A. Özen. 2000. "A hoard of unpublished bronze coins of Ptolemy Ceraunus." *AJN* 12: 59-66.

Ashton, R. 2002. "The Ptolemaic coins in Fethiye Museum." *Numismatic Circular* 110.1: 7–12.

Ashton, R., M. Arslan, and A. Dervişağaoğlu. 1996. "A Ptolemaic hoard in Fethiye Museum." *NC* 156: 269–272.

Bagnall, Roger S. 1999. Review of H. Cadell and G. Le Rider, *Prix du blé*. *SNR* 78: 198.

Boraik, M., and T. Faucher. 2010. "Le trésor des bains de Karnak." *Cahiers de Karnak* XIII: 79–100.

Brugsch, H. 1889. "Die Loesung der altaegyptischen Muenzfrage." *Zeitschrift fur Agyptischen Sprache* 27: 4–27.

Davesne, A., and Lemaire, A. 1996. "Trésors Hellénistiques du Proche-Orient." *RN* 6: 51–76.

Esty, W. 1989. "Percentile plots and other methods of graphing coin weights." *NC* 149: 135–148.

Faucher, T. 2010. "Le trésor de Tell Nowa." *Bulletin de l'Institut français d'archéologie Orientale* 109: 105–134.

Hazzard, R. A. 1995. *Ptolemaic coins: An introduction for collectors*. Toronto: Kirk & Bentley.

Hendin, D. 2009. "The metrology of Judaean small bronze coins." *AJN* 21: 105–121.

Hölbl, G. 2001. *A history of the Ptolemaic empire*. New York: Routledge.

Hultsch, F. 1903. *Die ptolemäischen Münz- und Rechnungswerte*. Leipzig: Teubner.

Huston, S. M., and C. C. Lorber. 2001. "A hoard of Ptolemaic bronze coins in commerce, October 1992." *NC* 161: 11–40.

Joel L. Malter Company. 1978. *The coinage of ancient Egypt, Auction II*. February 23 and 24. Los Angeles.

Kincaid, C. A. 1985. *Successors of Alexander the Great*. Reprint of edition 1910, London. Chicago: Ares Publishers.

Konuk, K. 2004. "The Ptolemaic coins in the Bodrum Underwater Archaeology Museum." In T*he Salmakis inscription and Hellenistic Halikarnassos,* *Helicarnassian Studies* vol. IV, edited by S. Isager and P. Pedersen, 165–175. Odense: University Press of Southern Denmark.

Lorber, C. C. 2000. "Large Ptolemaic bronzes in third-century Egyptian hoards." *AJN* 12: 67–92.

Lorber, C. C. 2005. "Development of Ptolemaic bronze coinage in Egypt." In *L'exception égyptienne? Production et échanges monétaires en Égypte hellénistique et romaine. Actes du colloque d'Alexandrie, 13–15 avril 2002*, edited by F. Duyrat and O. Picard, 141–157. Paris and Cairo : Institut français d'archéologie orientale.

———. 2007. "The Ptolemaic mint of Ras Ibn Hani." *INR* 2: 63–75.

———. 2007–8. "Ptolemaic bronze coinage of Tyre." *INJ* 16: 11–27.

———. 2012. "The coinage of the Ptolemies." In *The Oxford handbook of Greek and Roman coinage*, edited by W. E. Metcalf, 211–234. Oxford: Oxford University Press. 2012.

———. Forthcoming. *The coinage of the Ptolemaic empire*. New York: The American Numismatic Society.

Lorber, C. C., and A. Houghton. 2006. "Cappadocian tetradrachms in the name of Antiochus VII." *NC* 166: 49–97.

Maresch, K. 1996. *Bronze und Silber : papyrologische Beiträge zur Geschichte der Währung im ptolemäischen und römischen Ägypten bis zum 2. Jahrhundert n. Chr.* Opladen : Westdeutscher Verlag.

Muhs, B. 2011. *Receipts, Scribes, and Collectors in Early Ptolemaic Thebes (O. Taxes 2)*. Studia Demotica VIII. Louvain: Peeters.

Naville, L. 1951. *Les monnaies d'or de la Cyrénaïque*. Genève: Atar

Noeske, H.-C. 2000. *Die Münzen der Ptolemäe*r. Frankfurt: Historisches Museum Frankfurt am Main

Newell, E. T. 1927. *Two recent Egyptian hoards.* ANS NNM 33. New York: The American Numismatic Society.

———. 1935. *Five Greek bronze coin hoards.* ANS NNM 68. New York: The American Numismatic Society.

Olivier, J., 2006. *Les monnaies d'or lagides* (Master's thesis). Orlean: Université d'Orleans.

Picard, O. and T. Faucher. 2012. "Les monnaies lagides." In *Les monnaies des fouilles du Centre d'Etudes Alexandrines: Les monnayages de bronze a Alexandrie de la conquete d'Alexandre a l'Egypte moderne*. Etudes Alexandrines 25, edited by O. Picard, C. Bresc, T. Faucher, G. Gorre, M.-C. Marcellesi, C. Morrisson, 17–108. Alexandria: Centre d'Etudes Alexandrines.

Pitchfork, C. E. 2000. *The Jon Hosking Collection of Ptolemaic coins*. Sidney: Nicholson Museum, University of Sidney in association with Noble Numismatics Pty, Ltd.

Poole, R.S. 1882. *Catalogue of Greek coins [in the British Museum]: The Ptolemies, Kings of Egypt*. London: British Museum.

Puglisi, M. 2009. *La Sicilia da Dionisio I a Sesto Pompeo.* Messina: Departimento di Scienze dell'Antichita dell'Universita degli Studi di Messina.

Scheidel, W. 2010. Coin quality, coin quantity, and coin value in early China and the Roman world. *AJN* 22: 92–118.

Seif el Din, M., M. Shahin, and T. Faucher. 2008. Un tresor de monnaies ptolemaiques en bronze au Musee greco-romain d'Alexandrie: le tresor de Nag Hamadi 1937. In *Aegyptiaca serta in Soheir Bakhoum memoriam. Melanges de numismatique, d'iconographie et d'histoire*, edited by D. Gerin, A. Geissen, and M. Amandry, 79–94. Milano: Bibliotheque Nationale de France, Edizioni Ennerre.

Stannard, C. 2009. "Weight adjustment al marco in antiquity, and the Athenian decadrachm." In *Proceedings of the XIVth International Numismatic Congress*, edited by N. Holmes, 427–434. London: Spink & Son Ltd.

Svoronos, J. N. 1904–1908. *Ta Nomismata tou Kratous ton Ptolemaion/Münzen der Ptolemäer*. 4 vols. Athens: P. N. Sakellariou.

Vagi, D., 1997. "The Ptolemaic pentekaidekadrachm." *SAN* 20.1: 5–10.

Van Driessche, V. 1988. "A propos du monnayage des Ptolémées au IIIe s. av. J.-C." *Revue d'Archetecture et Histoire d'Art de Louvain* 21: 63–74.

Veselỳ, P. 2006. "Quantitative analyses." In Lorber, C. C. and A. Houghton, A., "Cappadocian tetradrachms in the name of Antiochus VII." *NC* 166: 49–97.

Visonà, P 1978–79. "A hoard of Ptolemaic bronze coins in the J. Paul Getty Museum." *The J. Paul Getty Museum Journal* 6–7: 153–162.

Weiser, W. 1995. *Katalog ptolemäischer Bronzemünzen der Sammlung des Instituts für Altertumskunde der Universität zu Köln*. Papyrologica Coloniensia XXIII. Opladen: Westdeutscher Verlag.

Wolf, D. and C. Lorber. 2011. "The 'Galatian shield without Σ' series of Ptolemaic bronze coins." *NC* 171: 7–55.