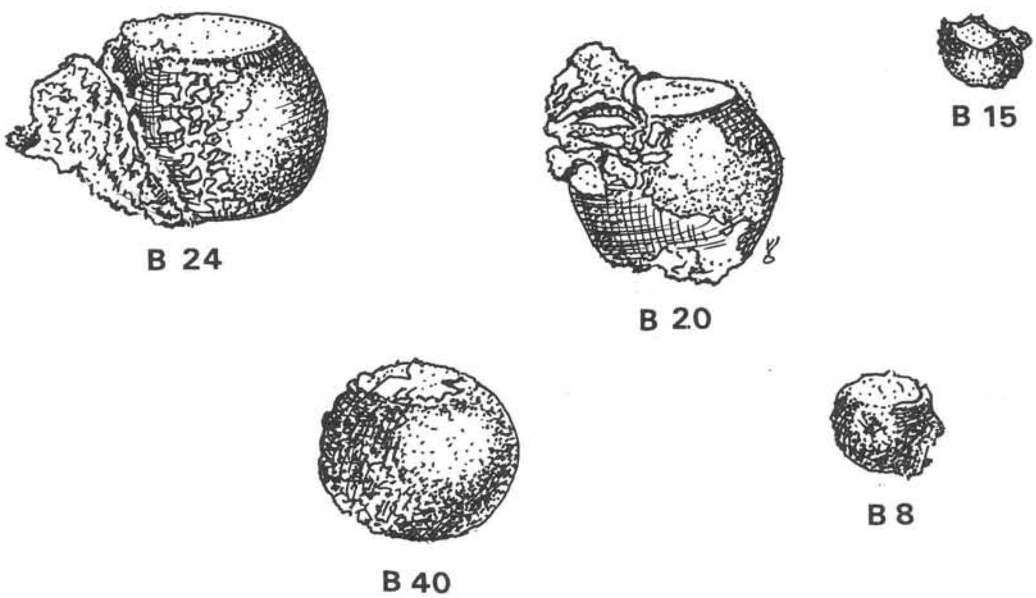
Weight or Volume?

A study of bronze covered iron weights

by Erik Sperber



Weights from Häffinds, Burs, Gotland.

Summary

Until lately the bronze clad iron core weights evidently in every day use at market places in Sweden, like Birka and elsewhere, have been judged almost only by their weight.

As the weights have corroded, sometimes badly, during the many hundred years in the earth, this is not a very good way of estimating their true weight and to ascertain the weight system used.

Kyhlberg in I980 pointed to the fact that the ball shaped weights retained their form for a much longer period than their weight.

His ideas have been developed when studying a new weight find from Häffinds, Burs Parish, Gotland. Out of some 40 ball shaped weights, I5 could be measured and calculated using simple geometric mensuration formulas.

The main weight system was found to be based on a "Unit weight" of 4.I9 ± 0,02 grams (Standard error).

Similarly a few weights from Björkö were found to belong to a system based on a 3.97 ± 0,03 grams "Unit weight".

The systematic errors are still difficult to estimate, but the figures are believed to be accurate within ± I % or so. - Further studies are being planned.

WEIGHT OR VOLUME ? A STUDY OF BRONZE COVERED IRON WEIGHTS.

By Erik Sperber, The Archeological Research Laboratory, University of Stockholm.

Over the years a variety of ball shaped weight pieces have been found in the Swedish soil. They belong to the centuries around A.D. 1000.

The usual type of the ball shaped weights is a sphere, where the two pole areas have been cut away by two parallel cuts at approximately equal distance from the equator. The core of the weight consists of iron and it is covered with a thin shell of bronze. The weights cover the region from some 4 g up to 200 g or so. The small weights are sometimes made of solid bronze. Other materials also occur. The most common size of the weights is 10-40 g.

Very often they bear witness to the skill of the man who made them. Indeed some are real pieces of art.

Most probably the objects originally occurred in sets, but single weights are very common and may lead us to suspect some secondary use of the pieces.

They were evidently costly and may therefore have been kept as valuable property or status symbols, or perhaps even used as substitute for money.

The weight pieces constitute an important sourse of knowledge of early medieval weight systems.

Finds of weights concentrate in Björkö, that is the old Birka township. Lately a large hoard of weights has been found in Häffinds, Burs parish on the island of Gotland.
This find is the immediate impulse of the investigation reported here. It consists of some 200 pieces, many of which are corroded. Several, however, are in a relatively good shape.

The Corrosion of the Ball Shaped Weights.

The construction of the ball shaped weights implies that they will corrode typically in a manner distinct from that of solid bronze weights or solid iron weights.

If two metals are in contact with each others in water or even with moisture, there will be galvanic currents like in a short circuited battery. The less noble metal will be dissolved as ions in the solution, where it probably will be transformed into other products of corrosion, thereby allowing more of the weaker metal to be dissolved and the gradual process of destruction to proceed.

The ball shaped weights constitute such a system, the bronze being the nobler metal and the iron the less noble one and consequently the looser.

If the bronze shell were free of leaks the moisture would have no opportunity of reaching the iron core and the weight would behave as one of solid bronze. This seems never to be the case, however. There are always small leaks, mostly at the edges of the polar surfaces.

Tapper, investigating the construction of two weights, suggested that the iron core of the weight had been covered with bronze by dipping it in melted bronze. This being the case, there seems to be no reason why leaks should occur mainly at the lids. The matter evidently needs further investigation.

After galvanic corrosion has taken place for some time, rust will be found as lumps attached to the weight and covering most of the weight surface. A corresponding amount will also have been formed inside the shell (Figure I).

From this time on, the weight of the corroded piece is no longer an exact measure of its original weight, and measuring the shape remains the only way to characterize the weight as suggested by Kyhlberg.

Eventually the lumps of rust inside and outside the weight may tighten the leaks in the bronze shell so that the iron corrosion is proceeding only slowly. The protective action of iron on the bronze will then gradually diminish so that the bronze corrodes practically as if no iron core existed or even slower where the weight is now covered with a compact rust layer.

The corrosion of the bronze surface in the earth mostly proceeds evenly, pit corrosion being uncommon.

Provided important losses do not occur, the corrosion products all have in common that their volume exceeds that of the metal they were formed from. Although no corrosions are chemically or physically identical, very approximate values of the increase in volume can be given.

The rust inside the bronze shell therefore gradually expands, usually lifting the lid, in the best case only partially so that its original place can still be reconstructed. This being the case, it will probably, after the customary conservation procedures, be possible to find a number of "meridians" sufficiently free from corrosion products to make a good estimation of the volume of the weight possible.

The rate of the corrosion is of course difficult to estimate. An intelligent guess can be made by observing the edges and over all appearance of ornamental pits of artefacts from the bronze age. Such a guess was made by Åke Bresle. He found 0,2 mm. bronze loss per 1000 years a probable figure.

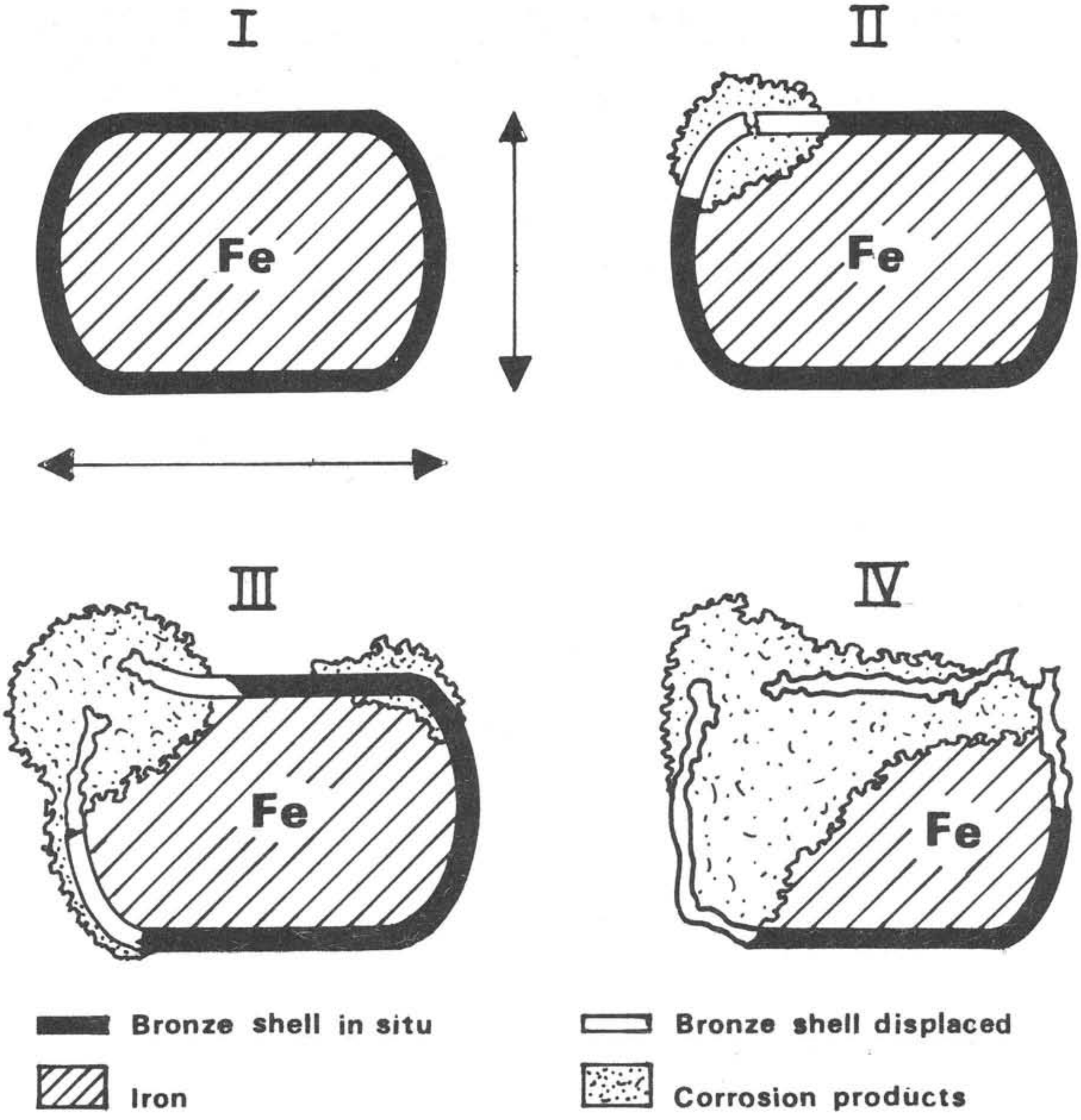


Figure 1. Deterioration of a weight in the soil.

I. Bronze weight when buried. Both weight and volume can be accurately estimated

II. The first pore has appeared in the shell. The original weight can no longer be estimated. The volume can still be measured with good accuracy.

III. Large partsof the shell have been displaced from their original site. Estimation of the volume is now difficult and fairly inaccurate. Weighing is meaningless.

IV. Essentially only a lump of rust remains of the weight Neither weight nor volume will give useful information about the weight.

Although I find no reason to question this figure it seems obvious that corrosion of a bronze shell in close contact with iron should proceed at a slower rate. For the first few hundred years (?) the iron core is "sacrificed" at a slowly diminishing rate. In the meantime the weight is covered, in addition to the copper corrosion product, with a hard cover of rust which can be supposed to offer additional protection.

Considering the above circumstances and the inherent variability and also the lack of precision the mean corrosion rate over the years might be around -0,I mm. every I000 years.

Numerous measurements of the thickness of corrosion on several ball shaped weights appear not to contradict this assumption.

Fig. 2. shows in a highly simplified way the state of a weight after some I000 years when recovered from the earth.

The weight will then be subject to cleaning and preparation procedures, involving repeated treatment with EDTA, followed by brushing.

The final result will depend upon the personal opinion of the conservator. One may choose to free the surface from all corrosion, leaving the weight with a bright polished metal surface similar to that of brand new weights. This procedure takes away all copper and tin that has been transformed into oxides. The resulting surface will be correspondingly lower than the original one, according to the above discussion by some -0,I mm.

This mode of working destroys some of the information that can be obtained from the weight. Therefore many conservators prefer to leave the weight with some of its copper corrosion, giving it a brownish or a greenish appearance. As the original copper corrosion layer includes or at least may include the position of the original surface, chances are that the volume of the preserved weight will correspond more or less closely to its originally intended value. For the present investigation this mode of working is much to be preferred simply because it preserves more of the original material.

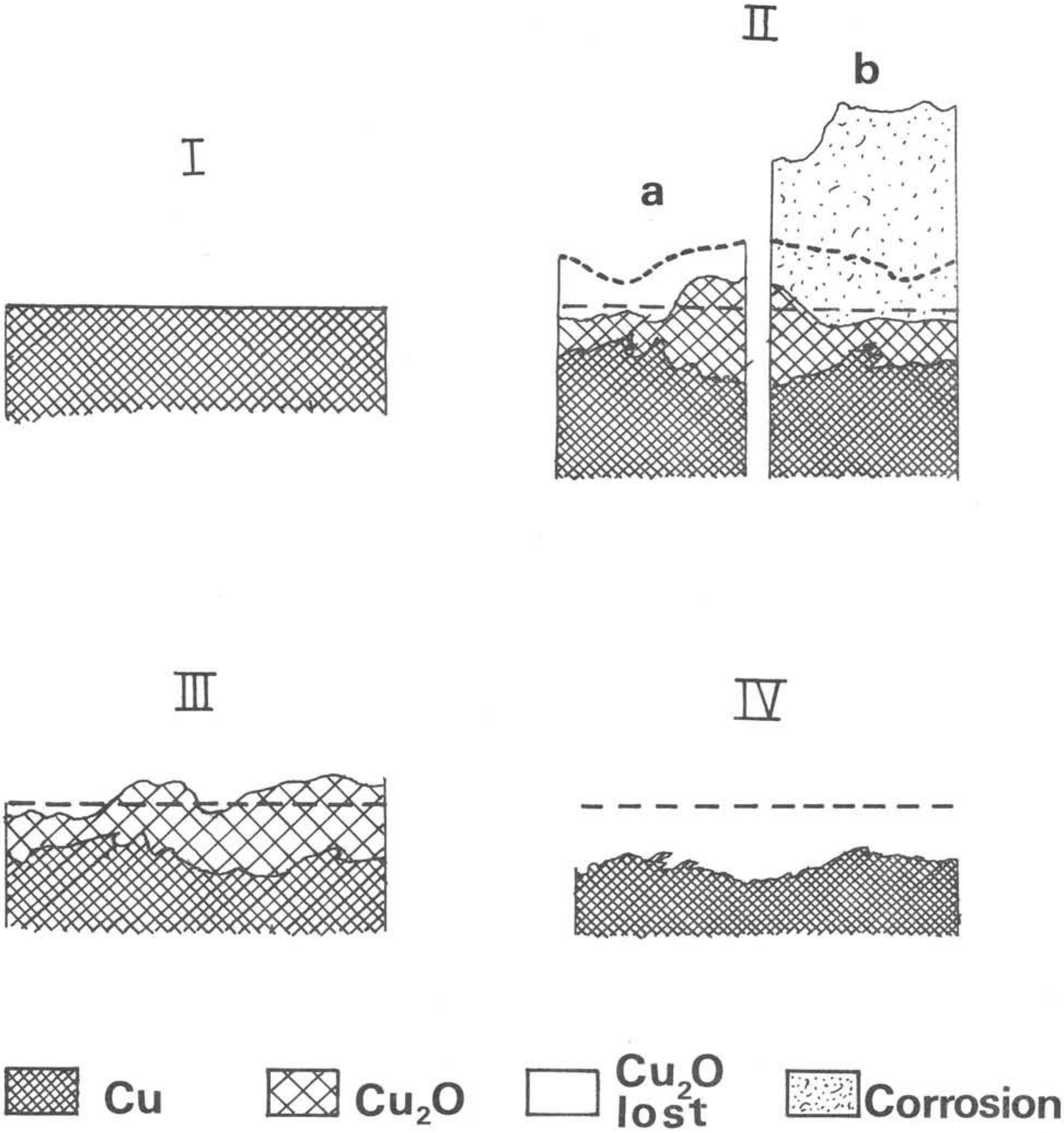
The above discussion makes clear, that measuring the volume of the weight piece may be a promising way of determining its weight with some precision, even if the item is moderately corroded. It also indicates some of the errors to be expected.

Measuring technique.

If a weight has a radius of let´s say I0 mms. - which corresponds to a mass of some 30 grams - and if a measurement error of +0,I mm. (= + I%) occurs all around the weight, it will be found to weigh 0,9 grams (+3 %) too much.

Figure 2. The search for the long ago lost original bronze surface.
I. Bronze weight when newly buried.
II. Bronze weight when recovered from the soil.
III. Stabilized bronze weight after having been freed from rust and loose copper corrosion.
IV. Stabilized bronze weight freed from practically all corrosion.

Figure 2.



Evidently the measuring equipment should make measurements better than to 0,I0 mm. possible. Further, measurements in all three dimensions are next to necessary. Some means for the fixation of the item ensuring reproductibility will also be needed.

All these conditions were met by a Nikon Profile Microscope (Model 6CT2). By means of a coordinate table operated by micrometer screws and an uncalibrated screw for vertical motion, different surface points of the artefact to be measured, could be brought into the focus of the microscope. An objective giving 20 X magnification was used as a compromise between the sharp focus requirement and the need for reasonable working space.

Horisontally the reproductibility was 0,0I mm. or better, vertically it amounted to 0,02 - 0,03 mm. and was measured by a dial indicator.
Modern physical equipment using laser rays, computers, etc. would have made the work easier, but was not judged necessary considering the limited number of artefacts available (c. 20) and the uncertainty involved in the corrosion problems.

The thickness of the bronze shell is one of the parameters needed for the reconstruction of the weights. Several types of instruments were considered, mostly those intended for the measurements of the thickness of paint on metal, but found unsuitable or too expensive.

The problem was solved by H. Freij, working in the Archeological Research Laboratory. A permanent magnet was arranged so that the magnetic flow through the poles could be measured. When the poles were placed near an iron artefact the magnetic flow changed, depending of the distance between the poles and the iron, in our case depending on the bronze shell.

The instrument was standardized with a plastic wedge, attached to a piece of iron sheet. - The thickness of the shell could be read to about ± 0,I mm.

The Density of the Weights.

The mass of a weight is not only a function of its volume, it equally depends on the density of both the iron core and of the bronze shell.

The only certain way to obtain these figures would have meant destruction of the weights, a procedure that could be considered possible for one or two of the weights but not for several of them.

Instead, figures for the densities from customary sources were relied upon. Hütte, e.g. says:
"Spez. Gewicht des reinen Eisens, 7.876 kg/dm^3, sinkt mit steigendem C-Gehalt bei I% C auf 7.82 und wird weiter durch Abschrecken (Härten) um so stärker vermindert je höher C-Gehalt (0,5 % auf 7.80; I% auf rd 7.74). Auch Kaltverformung setzt spez. Gewicht etwas ab."

Our iron - if not cast iron, for which we have at present no proof - probably has a carbon content of around 0,5 % or even lower and it has probably been cold hammered. A density of 7.8 would therefore seem possible. Deviations from this figure by more than ± 0,5 % do not seem probable.

It seems that casting the iron core would be the production method of choice for semi-industrial manufacturing of bronze clad iron weights. Such iron has a density of only 7.2, making the weights some 8 % lighter, the volume given. - The matter requires further investigations also regarding the earliest time when cast iron technique was available in different parts of Europe and the Islamic countries.

L. Tapper, working at the Museum of National Antiquities in Stockholm has studied the interior of two ball shaped weights. He did not measure the density but he found that the core of low carbon steel had been hammered at a fairly low temperature, and had then been heated. The density of such material may be 7.75 - 7.80 in accordance with the figure 7.8 arrived at above.

As to the density of the bronze shell metal it is very difficult to calculate without knowing all facts including its composition and, equally important, the treatment the metal has undergone.

The density of the bronze was set to 8.8 which is a probable value for tin bronze, too low for lead bronze and too high for zinc bronze (brass).

Not all finds of weights are useful for the estimation of volume and calculated weight:

I. The "equator" of the weight should be circular within narrow limits. If not so, the weight must be in a very good shape, giving the opportunity to measure several meridians, in order to obtain an average. The diameter is the most important measure, its errors will double when calculating the volume of the weight.

2. It should be possible to measure the distance between the "poles". The pole areas should be parallel.

3. At least one, preferably several meridians should be clean enough to be measured.

4. The rusty areas or rust pecks at the meridians should be of types possible to compensate for, by means of the system described below.

If the above criteria were to be applied strictly, very few weights would be good enough. Therefore a number of weights of lower quality must also be tested. The results from these lower grades, however, must be regarded with a healthy suspicion.

Minor rustpecks and areas may be approximately corrected for. A simple system has been developed to that end :

(+) The bronze metal lies bare. From its appearance it can be concluded that it has been polished.

Correction + 0,I0 mm.

(·) "Normal" brownish or greenish corrosion is present, following closely the metal surface.

Correction 0 mm.

(-) The rust layer or peck is evidently thicker than can be accepted under ·

Supposed thickness 0,05 - 0,I5 mm. Correction - 0,I0 mm.

(=) The layer is no longer smooth and thin but still follows the metal surface the presence of which you can imagine a few tenths of a millimeter below.

Supposed thickness 0,I5 - 0,50 mm. Correction 0,25 mm.

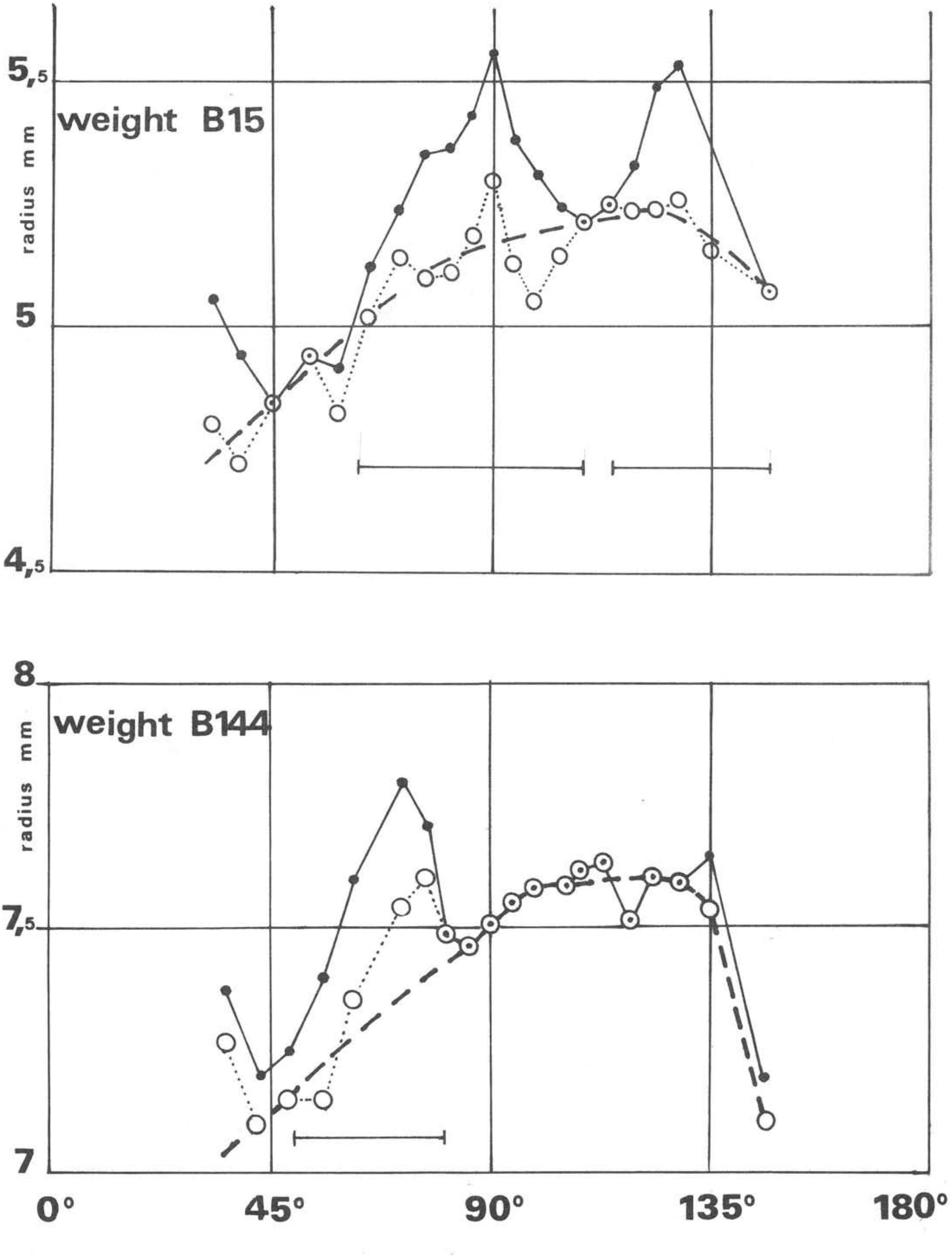
It is quite obvious that very many (=):s cannot be accepted before the precision of the weight reconstruction becomes unacceptably poor.

The corrections : -0,I0 and -0,25 were the calculated ones from a number of measurements on rust pecks on weights Burs I5 and I44, where the bronze surface could be satisfyingly approximated under the rust by interpolation between clean surface points. The thickness of the corrosion could then be estimated by measurements of its surface and also judged by its appearance. Under these circumstances the correlation between the two sets of rust estimation was satisfactory, in other cases it might not be so good. (Figure 3).

In several of the weights the effect of "normally occurring corrosion" on the measurements could be observed. It usually called upon a correction of the calculated volume by -I±0,8% (8 observations).

Figure 3. Correction for "rust pecks".
●——● radius measured.
○······○ radius, corrected for thickness of rust peck.
— — — radius curve, corrected for rust pecks and smoothed.
├——┤ extension of rust peck.
Polar coordinates. Linear magnification I00 x.
Approximate distance between consecutive points: B I5 0,6 mm, B I44 0,4 mm.

Figure 3.


5,5
weight B15
radius mm
5
4,5
8
weight B144
radius mm
7,5
7
0°
45°
90°
135°
180°

Calculations.

The volume of any body, whose limits are known, can be calculated. The formulas needed for this calculation can be found in proper textbooks. Such calculations are nowadays much easier and quicker than before thanks to calculators and computers.

The ball shaped weights can be approximated to rotation bodies. The main formulas here used for the calculations will be briefly introduced below. Nothing new will be said and those familiar with such calculations may well omit reading this chapter.

The following formulas apply to the calculation of rotation bodies:

I) The volume of a body generated by rotating a two dimensional figure, regular or irregular, is obtained by multiplying the area of the figure with the way described by its center of gravity.

2) The surface area of a body generated by a rotating line is obtained by multiplying the length of that line with way described by its center of gravity.

3) Simpson's rule for the area of an irregular figure. The figure is divided into an even number of panels, having the same width, by drawing parallel lines. The length of each line is measured. Looking upon one pair of panels, its limiting (I_I and I_3) and center (I_2) lines are joined by a parabola. After some calculation the combined area of the two panels will be found to be :

$$\frac{h\ (\ I_I + 4\ I_2 + I_3\ )}{3}$$

The procedure is continued with the next pair of panels.

4) The exact diameter of the weight is very important (I % error of the diameter will give 2 % error of the volume of the weight). A caliper or micrometer screw is useful only if opposite pairs of points can be found having a reasonably clean surface, that is, with the "right" degree of corrosion.

The profile microscope gives the possibility of measuring three points on the equator circumference line. The circumscribed circle can then be calculated.

$$D = \frac{abc}{2\sqrt{s(s-a)(s-b)(s-c)}}$$

a, b, and c are the sides of the triangle observed.

$$s = \frac{a + b + c}{2}$$

D = the diameter

The Häffinds, Burs Weights

Of the many weights from Häffinds, Burs, 40 ball shaped weights have now been prepared, stabilized and weighed.
The weights between I0 and 60 grams before preperation is illustrated in Fig. 3. 33 in number: They show some concentration around I2 grams. Other maxima can be traced but are hardly statistically significant.

After the preperation procedure, II of these weights were deemed to be good enough to be measured. Their volume and the corresponding weight was calculated and also shown in Fig. 3 and Table I. 4 more weights below I0 or over 60 grams complete the table. It is easy to attribute each of all the weights to each a multiple of a unit somewhat over 4 grams.

Three small weights form a separate group of one or three units, this unit being estimated to be 4,57 grams.
The unit is close to the weight of a Roman solidus coin.

All other weights, except B 2I, have a common unit of 4.23 grams with a standard deviation of ± 0,06 g and a standard error of the average of ± 0,0I9 only.
The probability that the weight B 2I, weighing ten units of 4.03 grams belongs to the same system is about I/I00 (t-test). It therefore seems to be good reason to treat B 2I separately. Indeed, it agrees very well with the Björkö weights, cf. below. (The weight B2I is in a poor shape. It was into the study after some hesitation, but so were also some of the other weights).

Eight weights, each having been measured 2 - 4 times were listed in Table 2 together with their values before and after preparation in order to show to the superiority of the new method to the direct weighing practised before or after the customary treatment, the new method being about 5 times more accurate.

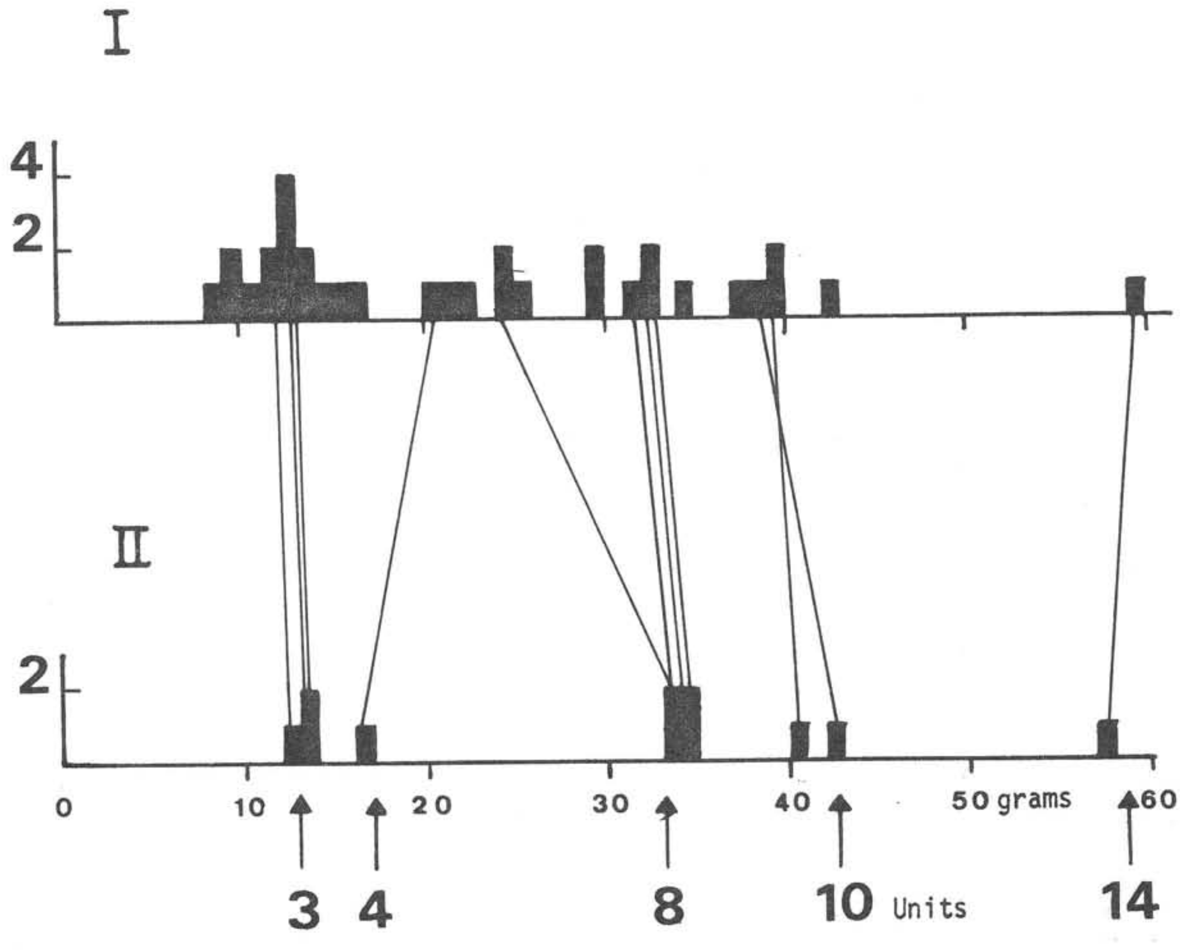


Figure 4.Comparison between some Burs weights.

I. Weights weighed when found.

II.Weights measured and weight calculated after stabilisation.

Table 1. The Häffinds, Burs Weights.

Nr	Dimensions, mm Diam.	Height	Bronze cover	Volume ml	Weight g found	Average	Number of "Units"	"Unit Weight" g found	Average
B 15	11,20	8,60	0,7	0,544 0,571	4,50 4,70	4,60	1	4,50 4,70	4,60
B 8	15,47	11,32	0,67	1,700 1,743 1,723 1,612 (1,806	13,73 14,11 13,90 13,03 not	13,70 used)	3	4,57 4,70 4,63 4,34	4,56
B 144	15,1	12,0	0,85	1,636 1,671	13,35 13,87	13,61	3	4,45 4,62	4,54
B19-33	15,34	11,98	0,33	1,57	12,59	12,59	3	4,20	4,20
B 117	16,55	12,76	0,75	2,02 2,07 2,08	16,36 16,76 16,82	16,65	4	4,09 4,21 4,19	4,16
B 16	21,11	15,71	0,7	4,37 4,05 4,41 4,19	34,96 32,37 35,25 33,49	34,02	8	4,37 4,05 4,40 4,19	4,25
B 128	20,83	16,30	0,5	4,18 4,31	33,36 34,31	33,84	8	4,16 4,29	4,23
B 153	21,36	15,49	0,8	4,24 4,23	34,00 33,95	33,98	8	4,25 4,24	4,25
BNF 180	20,79	16,60	0,7	4,31	34,63	34,63	8	4,33	4,33
B 21	22,11	17,31	0,7	5,06 5,19 5,05 4,81	40,46 41,51 40,41 38,58	40,30	10 ?	4.05 4,15 4,04 3,86	4,03
B 166	22,70	16,71	0,7	5,31	42,98	42,98	10	4,30	4,30
B 25	25,6	18,9	0,8	7,28 7,13 7,16	58,28 57,15 57,35	57,59	14	4,16 4,08 4,10	4,11
B 40	27,6	21,1	0,35	9,65 9,63	76,73 76,62	76,68	18	4,26 4,26	4,26
B 24	35,1	24,4	0,8	17,85 18,31 18,4 17,95	142,0 145,7 146,3 142,8	144,2	34	4,18 4,28 4,30 4,20	4,24
B 108	34,6	26,2	0,6	19,02	150,6	150,6	36	4,18	4,18

Average "Unit weight", B 15, B 8, B 144 not included. 4,21±0,024 (S.E.)
B 21 also not included. 4,23±0,o19
B 15, B 8, B 144 only. 4,57

Table 2.Variance of the Burs Sample after Different "Treatment".
Allfigures expressed as estimates of the "Unit of Burs".

Weight Number	Size Units	Weight when found	Weight after preparation	Weight acc.to volume estimation. found	average
117	4	5,05	3,78	4,09 4,19 4,21	4,16
15	8	3,92	3,36	4,37 4,05 4,40 4,19	4,25
128	8	3,06	2,51	4,16 4,29	4,23
153	8	4,06	3,76	4,25 4,24	4,25
21	10	3,98	3,78	4,05 4,15 4,04 3,86	4,03
25	14	4,22	4,11	4,16 4,08 4,10	4,11
40	18	4,09	4,02	4,26 4,26	4,26
24	34	4,22	4,17	4,18 4,28 4,30 4,20	4,24
Average		4,08	3,69	(4,18)	4,19
Deg. of Freedom		7	7	15	7
Stand.Dev.		±0,5	±0,5	±0,10	±0,10

The Björkö weights likewise include one single weight, the smaller one, of 4,6 grams belonging to the same system for small weights found in the Burs material.

The rest, I0 weights, typically belong to a system with a unit of 4.03 ± 0,04.

One of the weights, the biggest one, should perhaps not have been included. One of its polar faces is missing, and the edge of its bronze mantel was used instead when measuring its height. If this edge had been corroded too (which almost certainly is the case) the volume of the weight might originally have been as much as 5 % more than now calculated and the average unit 4.0I instead of 4.03 - The difference is, however, not statistically significant. In addition we don´t know whether the weight is 34 or maybe 36 units.

The Björkö weights were chosen for comparison. They were - like the Burs weights - selected from a big material and it seems probable that they were selected in very much the same way.

Five of the Björkö weights were measured both by Kyhlberg and by the present author. It was found that some differences between the both series of measurements existed.
Indeed the old measurements of Kyhlberg gave the value of the unit 4.39 grams whereas the new figure was 4.II grams, a difference of 0.28 ± 0.II (SE) grams.

The whole of the difference could be explained by measuring differences in the diameter and height, indeed 2.62 % in each direction, making 7.9 % for the volume (= weight).

This correction, applied to Kyhlbergs data, brings the unit of Björkö down to 4.07 grams thereby eliminating all need for further explanations.

Table 3. The Björkö Weights.

Grave Nr	Dimensions mm.			Volume ml	Weight g		Number of "Units"	"Unit Weight" g	
	Diam.	Height	Bronze cover		found	Average		found	Average
710 A	10,9	8,5	0,5	0,564	4,57	4,57	1	4,57	4,57
396	13,0	10,0	0,2	0,995	7,86	7,86	2	3,93	3,93
476	14,7	11,8	0,6	1,471	11,85	11,85	3	3,95	3,95
740	15,4	11,5	0,7	1,564	12,68	12,68	3	4,23	4,23
SHM 14837	15,0	10,9	0,55	1,500 1,503	12,08 12,10	12,09	3	4,03 4,03	4,03
710 B	20,4	16,3	0,4	3,89	30,83	30,83	8	3,85	3,85
710 C	21,1	14,9	0,3	4,08	32,19	32,19	8	4,02	4,02
SHM 14563	20,9	15,5	0,8	4,19 4,01 4,04	33,68 32,28 32,51	32,82	8	4,21 4,03 4,06	4,10
SHM 13838	22,05	14,8	--	4,53	39,57	39,57	10	3,96	3,96
SHM 5208 /217	34,5	26,1	0,5	17,90	141,3	141,3	34 ? (36 ?	4,16 3,96	4,16 3,96)

Average, 710 a not included. 4,03±0,04 (S.E.)

SHM 5208/217 also not included 4,01±0,04

Weight SHM I3838.

This weight was found in "the Black Earth" of Björkö.
It was included into the collections of Statens Historiska Museum in I909 with incomplete description of the find circumstances, the find also contained some silver pieces, a fragment of a balance and bronze and iron artefacts.

The weight is a very beautiful piece of art. All corrosion has been removed and the bronze surface polished. It consists of solid bronze as distinct from all other weights studied.

On one of the polar faces there is an oval pit, 2,5 mm. deep, measuring c. 4,5 x 4 mm. It may have contained some precious stone, now lost. The bottom of the pit is bright greenish blue, possibly copper containing corrosion products.

The weight is especially suited for the study of geometrical problems.

- Is the weight really circular in shape ? If not, how big are the deviations from the true circle ? Two different diameters were measured with a caliper: 2I.95 and 22.II. Difference 0,I6 mm. = 0,7 % (± 0,36 % from the mean).

- The diameter was also calculated from the coordinates of several points around the equator of the weight : 22.03, 22.05, 22.II, 22.I2 : Average = 22.08 : largest deviation, 0,05 from the average = ± 0,2 %.

- When the weight was lying flat on a glass plate, the polar surfaces were found not to be parallel, the biggest deviation being 0,6 mm. measured over the diameter of a polar surface (I4 mm.) i.e. 2.5° . This constitutes a serious problem. For anyone of the other weights where measuring along two meridians 90° apart could not be made, it would lead to erroneous results or at least to the introduction of uncontrolled errors.

- The volume of the upper and lower halves were calculated:

Upper half:	2.300 ml	2.303 ml	Average 2.302
Lower half:	2.2I8 ml	2.239 ml	Average 2.229

  (measured from two meridians, 90° apart).
  The difference is 3,3 %.
  The pearlike form of the weight was evident from other sets of measurements too.

Although the weight evidently was produced with great skill, and though it is still in a very good state of preservation, the excellent facilities of the Archeological Research Laboratory for the measurements, made it possible to reveal imperfections in its form.

For this weight exact measurements could be made at almost any point. This was not possible for anyone of the other weights. We have no reason to believe them to be more perfect. Any diameter or height measure may therefore include possible errors amounting to several tenths of one per cent.

Discussion.

It has been shown that the above method for estimating the size of ball shaped weight is superior to weighing as soon as the interior of the weights may contain corrosion products.

The statistical considerations, however, show that some improvement can still be reached by measuring more points of the weights than until now, especially more exact estimation of the diameter and height of the weights should be considered.

The main problem is, however, still how exactly we have succeeded in approximating the site of the original weight surface, lost long ago.

The low standard errors suggest that we have succeeded fairly well in this task, but of course, do not prove it.

Some sort of a standard would be very welcome. It could be a weight of gold or silver or perhaps a quarts piece, where the corrosion is negligible.

A few compact bronze weights have been found. If treated in the same way as our weights and perhaps completed by chemical analysis of the surrounding earth for copper, lead and tin, they could also be used as standards. Copper is known to migrate, lead or tin may be more favourable. One important condition in such a case would be that the weight was not cleaned before preparation and that the adjacent earth was taken care of.

The present method of estimating the weights is not exact enough to attribute a single weight to one special system of the few very similar ones probably used in Sweden, the Standard error is too big (± 0,05 grams), you will need a set of weights, say at least 4 to 5 pieces to make an attribution reasonably safe.

Anyhow, further investigations are planned to elucidate e.g. geographical and chronological differences in the system of weighing used in Sweden and elsewhere.

It seems that the random errors of the estimations are low enough to be accepted. Systematical errors for different reasons are however obvious. They call for further studies mostly experimental. Probably they will always remain and make our conclusions uncertain.

The above figures for weights from Burs and from Björkö have not yet been corrected for the rust pecks. The correction was estimated to - I % ± 0,8 (SD). After it has been applied the units will be :
The Burs Unit 4.I9 ± 0,02 (SE) grams
and The Björkö Unit 3.97 ± 0,04 (SE) grams.

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