Devaluing the *mitqal*

Inherent Trading Fees in the Metrics of Birka

Introducing a Method for Archaeometrological Analysis by means of 3D scanning & Computer-Aided Design
Abstract: Previous research on the Viking Age trade centre of Birka has suggested the parallel use of two harmonising standard weight units, differing in mass by five percent. As an explanation to this phenomenon, this paper puts forward a hypothesis of a trading fee, embedded in the weights. This is corroborated through a hypothetical deductive study; including a reassertion of earlier results by means of a new method for archaeometrological analysis, using a 3D scanner and Computer-Aided Design. Further, the role of silver, as a preferred unit of payment in Birka, is supported through a spatial analysis of the distribution of Islamic coins and Oriental beads in the provinces of Middle Sweden. Plausible manufacturing sites for the cylindrical lead weights, adhering to the Birka mitqal, are discussed as a possible way of falsifying the hypothesis. The results suggest that a trading fee was extracted, using the Birka mitqal for imports and the Islamic mitqal for exports. The metrological analysis was also expanded to weights from Sigtuna, which proved the Birka mitqal, as well the dual metrics system, continued to be in use there until, at least, the first half of the 11th century. Finally, a short study on the origins of the Scandinavian/Islamic weight system suggests that the direct influence for the system primarily can be attributed the Volga-Bulgarians.
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1. Introduction

This thesis investigates a puzzling discrepancy in the weight system of Birka, observed by Erik Sperber (1996) in a study of Viking Age weights from the emporium. Sperber mentions that “there remains to explain why the mitqal of Birka seems to have been 4.00 g instead of the expected 4.23 g” (Sperber 1996:106). This discrepancy is interesting all the more, since weights of the 4.23 g Islamic mitqal also have been found there. Furthermore, the discrepancy is not random; since the difference in mass amounts to 1/20th, with 4.0 being 19/20th of 4.23. What possible rationale might account for the use of two harmonising weight systems in the same location and time? Employing a new method for archaeometrological analysis, new insights regarding this phenomenon will be presented.

1.1. Definitions

When the following terms are used, these definitions are meant to apply:

CAD – An application for Computer-Aided Design.

Unit – a unit of mass, such as the gram or the litra.

Standard unit – a unit which serves as a base for lesser units, such as the kilo or the mitqal.

Unit of payment – a piece of material, for instance silver, generally accepted as payment.

System – in metrological discussions, this refers to a system of weights.

Weight – Referring to the actual objects, not their mass.

The Hinterland of Birka – Referring to the area supplying Birka with subsistence and goods for export: in this thesis defined as the combined region of the Swedish provinces of Uppland, Södermanland, Västmanland, Gästrikland and Dalarna.

1.2. Research background

In the 19th century, scholars like Gustaf Gabriel Hällström, Christoph Andreas Holmboe and Hans Hildebrand pioneered the study of Viking Age metrics in the Baltic region. None of them was able to correctly identify the standard unit though. Hällström suggested that the Russian zolotnik (4.27g) was the standard unit in the material he studied, which was a set of weights found in Salla, Kuolajärvi in Finland (Hällström 1842). This was quite possibly correct, and his methods were metrologically significant, but the material was dated to the 12th century and therefore not really applicable to the Viking Age. Holmboe meant that the
standard unit in fact was the örtug, with a mass of 8.906g, ultimately derived from the Roman system (Holmboe 1862). Hildebrand correctly placed the origin in the Middle East, but with a standard unit of 4.72g (Hildebrand 1894).

T. J. Arne published his famous work *La Suède et l'Orient* in 1914, in which the standard weight unit was set to ~ 4.25 g, which he proposed derived from the Sassanian *drachma* (Arne 1914:176-196). The result was approximated; due in part to the poor state of the material he worked with, but also the lack of accurate measuring and statistical methods. Despite this, Arne's result was quite close to that of Walther Hinz (4.233g) which endures to this day (Hinz 1970:2). The identified standard unit was not Sassanian though, but that of the *mitqal*, standard unit for gold in the Islamic weight system, introduced by the Umayyad Caliph Abd al-Malik (reign 685 – 705 CE).

The system was constructed upon the gold vs. silver value ratio. At the time and place of introduction, this ratio was 14:1. The *mitqal* represented the base gold value and the *dirham* represented silver. One *dirham* was initially 0.7 *mitqal* in mass (2.96 g), and with a 14:1 conversion rate, 20 *dirham* of silver were worth 1 *mitqal* of gold. As new silver deposits were discovered within the Caliphate however, the relative value of silver dropped. The *dirham* was decreased in mass to 2.82 g or 2/3 of a *mitqal*. This was known as a *market dirham*.

![Figure 2: The Islamic weight system (A), the modified system used around the Baltic, as proposed by Sperber (B) and the initial legal weight set of Abd al-Malik (C) From Sperber 1996.](image)
Hinz work was complemented by Heiko Steuer, who outlined the emergence and diffusion of the Islamic system in Northern Europe. He also studied the distribution of various types of scales and weights, in order to identify the Viking Age regions of trade in Northern Europe (cf. Steuer 1987).

The Swedish scholar Ola Kyhlberg classified the weights from Birka in his dissertation Vikt och Värde (Weight and value, 1980), which later served as a foundation for Erik Sperber’s research on the use of the Islamic system around the Baltic, where he discovered the existence of a local version, modified to better suit the conditions of the region (figure 2). He named this modified system “the Swedish/Islamic system”. This definition is problematic, since Sweden didn’t exist at the time in question, nor was the system exclusive for the Hinterland of Birka. I will therefore call it “the Scandinavian/Islamic system”, since such a description gives a more encompassing and apolitical description of its geographical extent. The use of the term “Islamic” for things originating in the Caliphate is also problematic, due to its religious connotations. But since it is an accepted term for numismatic material, it would be confusing to use another term for Metrology.

Also, the standard unit of 4.0g in Birka, deviating from the mitqal by 1/20th, had been touched upon in earlier work, but identified by Sperber as a separate system (Sperber 1996:83), albeit in harmony with the Scandinavian/Islamic system.

The work of Ingrid Gustin should also be mentioned here. In her dissertation from 2004, Mellan gåva och marknad (Between gift and market), she examines to what extent free market mechanisms were applied in Birka. She found that the royally administered market system, usually associated with Viking Age emporia and the gift economy, was supplemented by individual trading actors, seeking profit for themselves. These merchants were greatly assisted by the protection and privileges accommodated by the local king (Gustin 2004:268).

In my own research I have attempted to reconstruct the trade relations of Birka, reaffirming that the emporium was an inter-regional hub for trade, linking west and east, as long as the trade routes to the Caliphate were open. Once these were made impassable in the latter half of the 10th century - probably due to a shift in political control along the route - the flow of silver into Birka dwindled and the centre of trade in the Baltic shifted to Gotland, as proposed by Hatz (Hatz 1974:164), leaving the newly founded town of Sigtuna in the periphery, forcing its merchants to more actively seek trade abroad (Schultzén 2005:27ff).

1.3. Hypothesis & implications

The hypothesis is that there was a built-in discrepancy in the metrics of Birka, generating a margin between import and export. And since the Birka-mitqal of 4.0 g is lighter than the Islamic mitqal, it must have been applied when goods were sold to the town, or it would instead generate a loss. A number of implications can be inferred from this hypothesis.

1: Introducing a fee into the very fabric of your weights is a bold thing to do if the local producers have a choice in the location where to sell their goods. Birka must therefore have enjoyed a monopolistic position in the region (its Hinterland, as defined above), either by royal decree, its range of goods on offer, or both.

This has been the focus of many studies, ever since the remnants of the town were rediscovered in the 17th century. The notion of Birka being the dominant trade centre in the Baltic region may be in dispute, but its importance as a trade centre in the Lake Mälaren
region cannot be underestimated. The archaeological findings clearly show connections with Western Europe and the Byzantine Empire, but most of all with the Caliphate and hence indirectly with India and China. The geo-political location of Birka on the sea and river route from west to east, in a time when the Moorish conquest of Spain effectively placed a lock on Gibraltar, supports its status as a central transit point for goods moving either way. In this thesis, I will not expand specifically on Birka’s outstanding role in the region, as it will be indirectly verified through a corroboration of the other implications.

2: The Birka mitqal differs from the Islamic mitqal, but harmonises with it (i.e. 19/20th of the Islamic mitqal, as has been proposed). Otherwise it would have constituted a completely different system, and would thus falsify my working hypothesis. I will perform an analysis on weights from Birka, to test the results of Sperber. This will be done using a new method, including 3D scanning of the weights and then extrapolating the areas lost to corrosion in a CAD system.

3. Weights and scales are mainly used for transactions of accepted units of payment, whether they are valuable metals or a certain type of goods. The preferred unit of payment in Birka was undoubtedly silver, based on the use of the Islamic weight system, and the sheer amount of silver coins discovered. Since the proposed trading fee would apply when goods are sold to Birka, the preferred method of payment should also have been in silver, or else, if for instance the Birka merchant would pay the local farmer in kind, no reduction in cost through weighing would occur. This means that the Islamic silver should have accumulated in the Hinterland, rather than with the Birka merchants themselves. The latter probably had little interest in letting their capital lay idle in some treasure deposit.

The verification of this interpretation requires an analysis of the geographical dispersion of such Islamic silver coins that might have passed through Birka, particularly those dating from the onset of the emergence of the Islamic weight system around the Baltic (ca 890 AD (Sperber 1996:111)) to the demise of Birka, generally estimated at around 970 AD. The results will then be cross-referenced with an analysis of goods known to have been produced or sold in Birka.

4. The fourth implication of my hypothesis is that the cylindrical lead weights, corresponding to the Birka mitqal, were manufactured locally. Apart from looking at the archaeological evidence, an analysis of isotope ratios could disclose the provenance of the lead. Although this could never falsify the implication (the provenance of the lead does not prove the site of manufacturing), an origin from a deposit outside the Hinterland of Birka - but within the area where the Scandinavian/Islamic system was in use – would open up for debate on the exclusivity of the Birka mitqal.

In conclusion; the purpose of this thesis is to test the above hypothesis and the applicability of the CAD method on Archaeological material. The main analysis is supplemented by a comparative analysis of Viking Age metrology and iconology in Eastern Europe, theorising on the origins of the Scandinavian/Islamic weight system.

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1 Based upon my 2009 study for the advanced course Bagdad-Bysans-Birka, at the Department of Archaeology, Stockholm University.
2. Material

The method described below will be applied, as far as possible, to the same set of weights from which Sperber identified the Birka mitqal (Table 1). The purpose is to test Sperber’s conclusions, and also to compare the results of the Statistical method with those of the CAD-method. According to Sperber, these weights derive from excavations of graves, and are in a poor state of conservation, as most bronze-covered iron weights from Birka are (Sperber 1996:82f).

Furthermore, I will apply the CAD-method to a sample of previously not analysed weights, excavated at the Garrison of Birka in 2003 by AFL (Archaeological Research Laboratory at Stockholm University), in order to test Sperber’s results on a larger population.

Finally, I will include a number of weights of various types from Sigtuna, in order to try and establish a post-Birka standard unit. The inclusion of different types of weights will also serve as a test of the CAD-method, and as an extension of its range of application.

Table 1: Bi-polar spherical weights from Birka analysed by Sperber, to be reanalyzed with the CAD-method. From Sperber 1996.

<table>
<thead>
<tr>
<th>Grave no.</th>
<th>Diam. (mm)</th>
<th>Height (mm)</th>
<th>Thickness bronze cover (mm)</th>
<th>Volume (ml)</th>
<th>Weight (g) Average</th>
<th>Size</th>
<th>Unit weight (g) Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>710A</td>
<td>10.9</td>
<td>8.5</td>
<td>0.5</td>
<td>0.564</td>
<td>4.57</td>
<td>1</td>
<td>4.57</td>
</tr>
<tr>
<td>396</td>
<td>13.0</td>
<td>10.0</td>
<td>0.2</td>
<td>0.995</td>
<td>7.86</td>
<td>2</td>
<td>3.93</td>
</tr>
<tr>
<td>476</td>
<td>14.7</td>
<td>11.8</td>
<td>0.6</td>
<td>1.471</td>
<td>11.85</td>
<td>3</td>
<td>3.95</td>
</tr>
<tr>
<td>740</td>
<td>15.4</td>
<td>11.5</td>
<td>0.7</td>
<td>1.564</td>
<td>12.68</td>
<td>3</td>
<td>4.23</td>
</tr>
<tr>
<td>SHM 14837</td>
<td>15.0</td>
<td>10.9</td>
<td>0.55</td>
<td>1.500</td>
<td>12.08</td>
<td>3</td>
<td>4.03</td>
</tr>
<tr>
<td>710B</td>
<td>20.4</td>
<td>16.3</td>
<td>0.4</td>
<td>3.89</td>
<td>30.83</td>
<td>8</td>
<td>3.85</td>
</tr>
<tr>
<td>710C</td>
<td>21.1</td>
<td>14.9</td>
<td>0.3</td>
<td>4.08</td>
<td>32.19</td>
<td>8</td>
<td>4.02</td>
</tr>
<tr>
<td>SHM 14563</td>
<td>20.9</td>
<td>15.5</td>
<td>0.8</td>
<td>4.19</td>
<td>33.68</td>
<td>8</td>
<td>4.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.01</td>
<td>32.28</td>
<td>4.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.04</td>
<td>32.51</td>
<td>4.06</td>
<td></td>
</tr>
<tr>
<td>SHM 13838</td>
<td>22.05</td>
<td>14.8</td>
<td>—</td>
<td>4.53</td>
<td>39.57</td>
<td>10</td>
<td>3.96</td>
</tr>
<tr>
<td>SHM 5208/217</td>
<td>34.5</td>
<td>26.1</td>
<td>0.5</td>
<td>17.90</td>
<td>141.3</td>
<td>34?</td>
<td>4.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>36</td>
<td>3.96</td>
</tr>
</tbody>
</table>

Average unit weight (710A not included) 4.03 ± 0.04
3. Introducing the CAD-method for archaeometrological analysis

In short, the method applied is one of digitally recreating the original form of the weight, thus establishing the volume, from which the initial mass can be appreciated. Prior to CAD systems and 3D scanners; mass was appreciated by calculating the variables of density and volume from the artefacts displacement in water, measuring with a calliper or microscope and by estimating the composition ratio of the metals involved. In the sections below; the benefits and problems of both the Statistical and the Computer-aided method of Archaeometrology are discussed. First, the CAD-method will be described in detail.

3.1. Preparing the weight

In order to perform a proper scan of the weight, its protective coating, such as paraffin or lacquer, may have to be removed. The surface of the weight might otherwise be to reflecting for a good scan and the volume will be miscalculated if the protective coating is too thick. Removal is preferably achieved with a solvent, such as Acetone (oil free), under well ventilated conditions. If found; newly arisen corrosion should be removed at this stage. This is done with a scalpel and dental brush, using 2% EDTA solution and ultrasound to loosen the corrosion products. In some cases the object may need to be emerged in 2% EDTA solution, pH 6.5-7, for 10-15 minutes, in order to sufficiently loosen the corrosion products. If the surface of the weight is made out of bronze, the temperature of the solution shouldn’t exceed 40ºC.

The weight must then be stabilised in a buffer solution consisting of Na$_2$HPO$_4$. To ensure that there is no residual water, the object is then dried in a heat cabinet at 60ºC and thereafter in vacuum with silica gel. It is very important to store the objects under proper conditions, while stripped of their protective coating.

3.2. Analysis

After lacquer and possible corrosion has been removed, the objects are weighed with an analytical scale. They are then scanned with a 3D scanner, according to the standard procedure for the system used. In this analysis I have used a non-touch high resolution optical 3D-scanner: ATOS II SO, manufactured by GOM, with the measuring volume 35x28x15mm, and a resolution of 0.027mm. Although it hasn’t been tested, the method would probably work with a lower resolution as well.

From the 3D object, created through scanning, the present volume can be calculated. Usually, this is done with a built-in analysis tool. Dividing the mass with the volume gives the density. The 3D object can then be modified, using best-fit or manually applied suitable geometric shapes, in order to recreate the original shape (see figures 7 and 9 for examples). For this thesis I have used Geomagic Studio 9 as the CAD system for the re-creation phase.

Finally, the initial mass can be estimated by multiplying the volume of the recreated 3D object with the density, calculated above.

3.3. Post analysis conservation

Although the scanning process is non-destructive and non-touch; contamination may still occur. Weights, having had their protective coating removed, should therefore be cleaned, using a solvent such as Acetone (oil free), after which they are once again stabilized in a phosphate buffer solution. After having been completely dried out in vacuum with silica gel, a
protective coating can be reapplied. Paraffin may be considered depending on the amount of iron that has surfaced. 

If the protective coating was left intact, a simple overhaul of the weight will suffice, preferably under a microscope. Residues of clay, used to fix the weight in place during scanning (needed since the object is rotated on a slanted plate), might have gotten stuck in cracks or indentations on the surface. Carefully remove these with proper conservationist’s tools, making sure the protective coating isn’t breached in the process.

3.4. Calculating volume – benefits and problems

With the Statistical method the volume of a bi-polar spherical weight had to be calculated manually, by measuring the diameter of the equator along with a number of meridians. Of course, a certain measure of correction for the impact of corrosion on the weight had to be made. Estimations, such as the one in figure 3, were applied in search of the lost original surface. Some measure of correction could be done for stereo-metrical irregularities.

With a CAD system the volume of the scanned object will be calculated exactly, independent of any geometrical flaws in its shape. However, the measured volume will include corrosion layers, which presents both an advantage and a disadvantage. The advantage is that the corrosion layers are part of the objects initial mass, which is used to calculate the density. On the down side, corrosion has a lower density than the metal core, which will affect the mean density negatively. Of course, the same correction for corrosion layers as with manual calculation can, if deemed necessary, be applied to the CAD calculations.

A reservation by Kyhlberg states that, since markings on the surface reduce the volume in a way that cannot be reconstructed, the Statistical method gives a result which is a bit too high (Kyhlberg 1980:235). This is a reservation that also applies to the CAD-method. However, I don’t agree with Kyhlberg’s reservation, since the markings are punched into the metal, rather than etched, i.e. effectively creating a decrease in volume, but at the same time; a corresponding increase in density. Therefore, since punching is no more than compressing the metal, calculating the volume without rectifying for the markings gives a correct indication of the initial mass, as long as density is calculated with rectification for the markings. And as

![Figure 3: Effects of long-time corrosion on a bronze surface. An example of the estimations used to recreate mass with the Statistical method. I. Original surface. II. State of surface when excavated. III. After stabilisation and the removal of loose corrosion. IV. Surface after practically all corrosion has been removed. Drawing by Fernando Alonso. From Sperber 1996.](image)
that is how the CAD-method is designed, the markings don’t present a problem in calculating either density or volume.

In the next stage, when the shape of the object is extrapolated in the CAD system, it will, as with manual calculations, be presumed perfectly symmetrical. Not necessarily a perfect sphere though; corrections for spheroid shapes can be made, either by changing the variables of radius and axis length if possible or, as in this analysis, by using a sandpaper function to bring the 3D shell closer to the original. The latter method also adds a degree of manual control to the process, minimizing the risk for a “Black-box approach” (non-critical application of results from an automated process). Corrosion layers will, as they should in the calculation of volume, be disregarded. All factors considered; the two methods should have a somewhat equal chance of producing a result close to the initial volume.

### 3.5. Calculating density – benefits and problems

Sperber calculated the density of the iron core, using the normal density of pure iron, which is 7.8 g/ml (Sperber 1996:31). The density of bronze is more difficult to calculate without knowing the composition of the alloy or the method of manufacturing. Sperber’s estimate was 8.8 g/ml (Sperber 1996:32). The iron/bronze ratio was calculated by measuring magnetic flow, applied through the poles of the artefact. The thicker the bronze shell, the less magnetic flow was able to pass through. The method returned the thickness of the bronze shell, at the poles, with an error margin of about ±0.1 mm (Sperber 1996:31).

With the CAD-method, no such estimations are made, since the density is calculated by simply dividing the mass with the volume. The problems implicated with such a straightforward method are as follows:

- It takes no regard of the fact that the iron/bronze ratio has altered through corrosion or other loss of material.
- It includes the corrosion products, which have a lower density than the core metal.

However, the Statistical method also relies on appreciating the iron/bronze ratio and assumptions concerning such things as wear and the actual density of the metals. The same assumptions can of course be applied to the CAD-method, if a higher level of accuracy is needed. A composite of both approaches is the use of MNCA values, suggested below.

The problem with corrosion is minimized by removing as much of it as possible before weighing and scanning, which is desirable also from a conservationist’s standpoint.

### 3.6. MNCA values

Since many weights have been seriously affected by corrosion, and having had their density altered as a result of that, a different approach is needed for them. The solution is fairly straightforward. By using the mean density value for a population of non-corroded weights, instead of the altered actual value, a result close to the initial density should be achieved. This mean value of non-corroded artefacts (MNCA) must be calculated individually for each weight type, whether the difference is in shape or in the composition of materials. As more weights are being scanned, creating a greater population base, the MNCA value will gain in accuracy. This provides a density based on the actual qualities of the artefacts.
3.7. Testing the CAD-method.

The accuracy of the CAD-method was tested, using a mock object with known volume and density, which then was subjected to artificial wear prior to analysis. Unable to create a mock object replicating the shape and metal constitution of the bi-polar spherical weights, it was instead cast in a slightly conical shape, out of tin with an aluminium core (figure 4). Tin has a density of 7.352 g/ml and aluminium 2.643 g/ml, to be compared with bronze: 8.8 g/ml and that of pure iron: 7.8 g/ml. The impact of these discrepancies on the test result is discussed below.

First the test object was scanned in “mint condition”, in order to get an initial true volume (figure 4). The test object was also weighed on an analytical scale, which produced the density by dividing the mass with the volume. The extrapolation routine was then applied to this “mint condition” 3D object as a way of checking the calibration of the analytical scale, the scanner and the CAD program in unison. It proved 99.9% accurate in both volume and mass.

Figure 4: The test object prior to artificial wear; the actual object (left) and as a scanned 3D object (right). Height 10mm, base diameter 20.5 mm, top diameter 19.5 mm.

Figure 5: The test object after having been subjected to artificial wear. The surface has been sandpapered and both shell metal (Sn) as well as core metal (Al) has been removed.
In the next step artificial wear was accomplished by chipping away metal from the tin surface and boring into the core, to remove a sufficient amount of aluminium (figure 5). This was done to mimic the effect of long term corrosion on an iron object with a bronze shell, breaking from the pressure of the expanding core. The core, constituted by a less noble metal, looses a greater volume, and consequently also mass, than does the shell; which looses metal mostly to breakage rather than to corrosion. The surface was then grinded with fine grade sand paper, in order to simulate the loss of the original surface layer to corrosion. Finally, a thin layer of corrosion, as well as rust boils, were simulated applying a dull paint (figure 6). Since the CAD-method takes no regard to the way alterations in shape may have occurred; an exact replication of the corrosion process was not necessary. However, it was important that the shape wasn’t just altered symmetrically, for instance by making a simple straight cut through the object, since that would prove only the basic principles of geometry, and not the applicability of the CAD-method on corroded objects.

Paint doesn’t have the same density as, in this case, tin oxide (the applied enamel’s density being only 1.0 - 1.2 g/ml, hypothetical solid tin oxide about 7.0 g/ml); which in effect presented a further challenge in the calculation of initial density for the test object, compared to a live analysis of a real artefact.

After the artificial wear stage, the test object was scanned again and processed in a CAD system in the manner described above (figure 7). The initial mass needed to be reproduced within a deviation of <2%; the same error margin allowed for the Statistical method by Sperber (Sperber 2004:64).
3.7.1. Results of the test

Table 2: Results from the test of the CAD-method on a mock object with known initial volume and mass.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Initial value</th>
<th>Calculated pre-artificial wear value (calibration)</th>
<th>Post-artificial wear value</th>
<th>Reproduced initial value</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>3.40737 ml</td>
<td>3.4122 ml</td>
<td>3.2135 ml</td>
<td>3.3975 ml</td>
<td>-0.2%</td>
</tr>
<tr>
<td>Density</td>
<td>8.396 g/ml</td>
<td>8.387 g/ml</td>
<td></td>
<td></td>
<td>-0.1%</td>
</tr>
<tr>
<td>Mass</td>
<td>28.60941 g</td>
<td>28.649 g</td>
<td>26.95225 g</td>
<td>28.4948 g</td>
<td>-0.4%</td>
</tr>
</tbody>
</table>

- The column “initial value” in table 2 presents the actual values that the method aims to reproduce; i.e. the values for the test object in mint condition.
- The second column shows the result of a calibration test, running the CAD-method process on the test object in mint condition.
- The third column displays the actual values for the object, after having been submitted to artificial wear. This shows a decrease in volume and mass of 5.7% and 5.8% respectively, i.e. the amount of material removed in the process.
- Finally, the fourth column presents the end result of the CAD-method applied on the object in its altered state; i.e. the reproduced initial values.

The reproduced mass was 28.4948 g, deviating from the initial mass (28.60941 g) by -0.4%, thus well within the 2% margin allowed for the Statistical method.

The precision of the CAD-method was tested by repeating it on the same object twice more. The results were 28.5761 g (3.4072 ml) and 28.6097 g (3.4112 ml) respectively. This gives a standard deviation of 0.0482 g, or 0.17% of the mean (initial value not included). No testing of reproducibility with other systems has currently been done.

3.8. Discussion on applying the CAD-method on actual artefacts

Would the CAD-method be equally accurate with real artefact objects? In order to answer this question, we need to look at the differences in preconditions between the test object and the actual artefacts. The bi-polar spherical weights, for instance, consist of a bronze shell encompassing an iron core. In this test, a small aluminium core was enveloped in tin. Do these differences matter in calculating density? The answer is yes; the greater the difference in density between the components of an object, the greater the impact will be on overall density, if one of those components would lose more mass than the other. Since iron and bronze have similar densities (7.8 g/ml and 8.8 g/ml respectively), the density is affected less for the artefacts than for the test object, which was composed of tin (7.352 g) with a core of aluminium (2.643 g).
The same principle can be applied to issues concerning the corrosion layer. Here, we need to look at the differences in density of pure iron (7.8 g/ml) and iron oxide (~ 5.24 g/ml). The density of iron oxide is for a theoretical solid state, but any remaining corrosion after conservation should be very close to that. The theoretical density of copper oxide in solid form is ~ 6.4 g/ml compared to Sperber’s estimate of 8.8 g/ml for the bronze used in the shell. In comparison; the enamel applied to the test object, simulating a layer of corrosion, has a density of only ~ 1.1 g/ml. So again, the effect on density should have been greater for the test object than for the artefact objects, yet deviated with only 0.1%. This means that, with a post-conservation pure metal vs. oxides ratio, the effect on density calculations are negligible.

The difference in shape is also a factor to be considered. The test object had a slightly conical form with a sloping top plane, but was otherwise geometrically uncomplicated. The artefacts are spherical, with some stereo-metrical deviations, and have flat poles, which also may have a certain degree of slope. But as long as stereo-metrical irregularities and sloping planes can be discerned from the artefact object, they can be replicated. Instead of using a cone and two planes to recreate the object, a sphere and two planes are applied.

These factors considered, there is no reason why the CAD-method should fail to reproduce the initial mass, within the allowed deviation of <2%, when applied to artefact objects of reasonable structural integrity.

3.9. Recreating other shapes

Viking Age weights came in many shapes. There were the bi-polar spherical weights, described above. There were also cylindrical shapes, similar to the test object, also described above. Further; there were cubooctaedrical, cubical, bi-conical, half-spherical and more. These shapes can, of course, not be recreated in the same manner as the spherical or cylindrical ones. For that reason, this section describes briefly how these other shapes may be recreated.

3.9.1. Cubooctaedrical weights

In many cases, the bronze cubooctaedrons are in such good condition that no recreation needs be done. However, there are those that have been broken or badly worn through use and corrosion. Usually, the cubooctaedrons have sharp edges and pronounced features on the surfaces. If the edges and sides are softened and blurred, one might expect that a certain loss of material has occurred. The recreation of a cubooctaedron is very straightforward. It entails the creation of a sphere, or any other shape that might encompass the weight in its entirety, after which planes are fitted to each of the fourteen surfaces. These planes are then used to cut the excess material from the sphere, leaving a 3D object representing the cubooctaedron with sharper edges and unworn surfaces. At this stage, it is up to the operator’s discretion whether any “sandpapering” needs to be applied.

3.9.2. Cubical weights

Cubical weights are usually made out of lead, and as such they more easily get worn around edges and corners. These weights require an element of caution though, since we can’t be sure that softening of the edges and corners wasn’t just a way of calibrating mass. Looking at the cubical weights in figure 16, they appear to have had rather sharp edges, but this may not have been universal. I submit this method, therefore, with a caution to bear this possibility in mind.

Cubical weights are recreated in much the same manner as the cubooctaedrons. A sphere encompassing the weight, cut off by planes applied to each of the six sides. “Sandpapering” is recommended to slightly soften the edges, mimicking the soft properties of lead.

3.9.3. Bi-conical weights

These are usually cast out of bronze and have therefore often withstood corrosion to such an extent, that metrological analysis may be performed without recreation. If such is deemed necessary anyway, the best method would be to apply two best-fit cones, cutting away each others excess material at the intersection. Thereafter planes can be fitted to the two poles, cutting the extruding parts of the cones. The bi-conical weights are usually slightly curved, so “sandpapering” will probably need to be applied as well. If the curvature is great enough to permit it; two intersecting spheres could be applied instead of cones.

3.9.4. Half-spherical weights

For half-spheres, simply apply a best-fit sphere and cut using a plane fitted to the base surface. “Sandpapering” may be applied if the weight’s shape is found to be spheroid.
4. Analysis

4.1. Applying the CAD-method to metrological analysis

Figure 9: Four of Sperber’s weights from table 1, passing through the steps of the CAD-method.

Column 1: the scanned 3D representation of the weight.

Column 2: the applying of planes and spheres to encompass the shape.

Column 3: the sphere has been polygonised and has had its poles cut by the two planes.

Column 4: the recreated shape of the weight.

From top SHM 14837:3, SHM 34000:Bj740, SHM 14563:15 and SHM 13838.
### 4.1.1. Revisiting Sperber’s bi-polar spherical weights from Birka

In the following section, a number of the weights from Birka analysed by Sperber (table 1), will be re-analysed using the CAD-method. The purpose of this is to further evaluate the CAD-method on available reference material, as well as reaffirming the existence of the 4.0 g standard unit.

Not all weights in table 1 were available for analysis. I was only able to retrieve four out of ten for this comparison. However, since the objective is to compare methods and test Sperber’s results rather than question them, this sample should be sufficient.

Figure 9 shows the weights as they pass through the steps of the CAD-method. The first column shows the scanned 3D representation of the weights. The second column shows the use of planes and spheres to encompass the shape. In the third column the sphere has been polygonised, and the poles have been cut by the two planes. In addition, a certain amount of “sandpapering” has been applied, to properly mimic the original spheroid shape of the weights. Finally, in the fourth column, only the recreated shape of the weight is presented.

The result of the metrological analysis can be seen in table 3. As a stand alone analysis; it would point to the existence of three weights adhering to the Birka mitqal in this sample, as well as one to the Islamic mitqal. This was also Sperber’s conclusion. Comparing the results to those of Sperber, they come in lower as well as higher, preventing any conclusions on which method is the more accurate. Both may indeed have an error margin of +/- a few percent compared to the proposed target mass (i.e. the initially intended mass), which in turn we know was difficult to achieve with Viking Age manufacturing techniques to begin with.

Although I hesitate, at this point, to propose that the CAD-method is as accurate as the Statistical method, this comparison, at the least, shows that it may be applied when sorting weights into already identified systems.

### Table 3: Results of the re-analysis of four bi-polar spherical weights from Birka. Comparison with the results of Sperber on the same population.

<table>
<thead>
<tr>
<th>ID</th>
<th>Current volume (ml)</th>
<th>Current mass (g)</th>
<th>Current density (g/ml)</th>
<th>Reproduced volume (ml)</th>
<th>Reproduced mass (g)</th>
<th>MNCA applied</th>
<th>Proposed standard unit (g)</th>
<th>Proposed multiple</th>
<th>Proposed target mass (g)</th>
<th>Deviation (unacceptable in bold)</th>
<th>Sperber’s result (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHM 14837:3</td>
<td>1.47</td>
<td>11.274</td>
<td>7.6693878</td>
<td>1.542</td>
<td><strong>11.826196</strong></td>
<td></td>
<td>4.00</td>
<td>3</td>
<td>12.00</td>
<td>1.45%</td>
<td><strong>12.09</strong></td>
</tr>
<tr>
<td>SHM 14563:15</td>
<td>4.125</td>
<td>31.656</td>
<td>7.6741818</td>
<td>4.115</td>
<td><strong>31.579258</strong></td>
<td></td>
<td>4.00</td>
<td>8</td>
<td>32.00</td>
<td>1.31%</td>
<td><strong>32.82</strong></td>
</tr>
<tr>
<td>SHM 13838</td>
<td>4.577</td>
<td>39.568</td>
<td>8.644964</td>
<td>4.632</td>
<td><strong>40.043473</strong></td>
<td></td>
<td>4.00</td>
<td>10</td>
<td>40.00</td>
<td>0.11%</td>
<td><strong>39.57</strong></td>
</tr>
</tbody>
</table>
4.1.2. Additional Weights from Birka

It is not possible to draw any statistical conclusions from a population of only four weights. I have therefore analysed an additional seven (table 4), found during excavations of the Birka Garrison area in 2003, within the project “Borgar och befästningsverk i Mellansverige 400-1100 e.Kr” (Forts and fortifications in middle Sweden 400-1100 AD), conducted by Lena Holmquist Olausson (project leader).

Two of these weights fell outside of the 2% deviation margin for a standard unit of 4.0 g or 0.8 g (0.8 g is a unit within the proposed Birka system). Weight 14311 had no original surface left, making recreation very difficult. For weight 14405A, one of the poles was completely lost, so I recreated half the weight and multiplied the result by two. This means that any stereo-metrical irregularities between the two halves are equated, which could have had an impact on the result.

Weight no 14151 has a current density of only 7.69 g/ml, which seems to light for Bronze, but with that density it fits a multiple 3 of the 0.8 unit with a deviation of just 0.35%. However, with MNCA applied it fits a unit of 2.67 g even better. Such a unit has not been proposed earlier, but would in effect be to the dirham (2.82 g), what 4.0 g is to the mitqal, i.e. 19/20th, and also exactly 2/3rd of 4.0 g, the same relation as with the Islamic dirham and mitqal. Under the submitted hypothesis of this study, such a unit should exist, given the fact that there are several Islamic dirham weights in the Birka material (Sperber 1996:80 table 7.13). In deed, there is also a weight in the Sigtuna material (table 5) which fit a 2.67 g unit very well.

In all, five of the weights were within the margin for deviation for the Birka mitqal, and can therefore be attributed this system. In short, the result corroborates the existence of the Birka mitqal as well as implication 2 of the hypothesis; The Birka mitqal differs from the Islamic mitqal, but harmonises with it.

Table 4: Results of the analysis of an additional seven weights, excavated at the Birka Garrison. 14311, 14151 and 14223 are cubooctaedrical. 14577, 14405b, 14405a and 14099 are bi-polar spherical.

<table>
<thead>
<tr>
<th>ID</th>
<th>Current volume (ml)</th>
<th>Current mass (g)</th>
<th>Current density (g/ml)</th>
<th>Reproduced volume (ml)</th>
<th>Reproduced mass (g)</th>
<th>MNCA applied</th>
<th>Proposed standard unit (g)</th>
<th>Proposed multiple</th>
<th>Proposed target mass (g)</th>
<th>Deviation ( unacceptable in bold)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14311</td>
<td>0.258</td>
<td>2.0784</td>
<td>8.0558915</td>
<td>0.27</td>
<td>2.3216115</td>
<td>Y</td>
<td>0.80</td>
<td>3</td>
<td>2.40</td>
<td>3.27%</td>
</tr>
<tr>
<td>14151</td>
<td>0.296</td>
<td>2.2762</td>
<td>7.6900000</td>
<td>0.311</td>
<td>2.6741525</td>
<td>Y</td>
<td>2.67</td>
<td>1</td>
<td>2.67</td>
<td>0.16%</td>
</tr>
<tr>
<td>14223</td>
<td>0.274</td>
<td>2.3460</td>
<td>8.5618978</td>
<td>0.284</td>
<td>2.431579</td>
<td></td>
<td>0.80</td>
<td>3</td>
<td>2.40</td>
<td>1.32%</td>
</tr>
<tr>
<td>14577</td>
<td>0.602</td>
<td>4.36009</td>
<td>7.2426744</td>
<td>0.618</td>
<td>4.741163</td>
<td>Y</td>
<td>0.80</td>
<td>6</td>
<td>4.80</td>
<td>1.23%</td>
</tr>
<tr>
<td>14405b</td>
<td>2.088</td>
<td>14.34106</td>
<td>6.8683238</td>
<td>2.081</td>
<td>15.964984</td>
<td>Y</td>
<td>4.00</td>
<td>4</td>
<td>16.00</td>
<td>0.22%</td>
</tr>
<tr>
<td>14405a</td>
<td>3.102</td>
<td>22.55391</td>
<td>7.270764</td>
<td>3.208</td>
<td>24.611086</td>
<td>Y</td>
<td>4.00</td>
<td>6</td>
<td>24.00</td>
<td>2.55%</td>
</tr>
<tr>
<td>14099</td>
<td>5.345</td>
<td>38.888</td>
<td>7.2755472</td>
<td>5.279</td>
<td>40.499352</td>
<td>Y</td>
<td>4.00</td>
<td>10</td>
<td>40.00</td>
<td>1.25%</td>
</tr>
</tbody>
</table>
4.1.3. **Weights from Sigtuna**

One purpose for expanding the metrological analysis to Sigtuna was to apply the CAD-method to a wider range of weight shapes (see “Recreating different shapes” above). The sample consists of spherical weights, as well as cubo-octahedrons, cubical, cylindrical and bi-conical weights. Also, the results can be used to supplement the data from Sperber’s analysis of spherical weights from Sigtuna (Sperber 1996:88f); covering only six weights in all, not enough to properly identify a standard unit. Further, it would be interesting to establish whether the Scandinavian/Islamic system survived the abandonment of Birka, and if so; for how long?

The results in table 5 show that six, out of eight weights, fit multiples of the *Birka mitqal* within the acceptable deviation. Sig, Pro 1:15017 was found in a late 10th century context, which is the earliest for the population. The latest is Sig, Pro 1:2392, found in a 13th to 14th century context, although that just sets a TAQ for its manufacturing. The remaining weights all came out of contexts dated to the first half of the 11th century (Wikström April 2009, personal msg.). Consequently, the dual system was in use up until this period at least. The two weights from the excavation at Humlegården 3 were found in contexts dated to 1010-1030 (Hum 3:101550/1550 (Wikström 2008:296f)) and 1050-65 (Hum 3:103227/3226 (Wikström 2008:352f)) respectively. The recreated mass of the latter fits perfectly with the *Birka mitqal*, and is a well preserved example of the bi-conical shape, which is common for this period.

*Table 5: Results of the analysis of eight weights from Sigtuna.*

<table>
<thead>
<tr>
<th>ID</th>
<th>Current volume (ml)</th>
<th>Current mass (g)</th>
<th>Current density (g/ml)</th>
<th>Reproduced volume (ml)</th>
<th>Reproduced mass (g)</th>
<th>MNCA applied</th>
<th>Proposed standard unit (g)</th>
<th>Proposed multiple</th>
<th>Proposed target mass (g)</th>
<th>Deviation (unacceptable in bold)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hum 3: 101550/1550</td>
<td>0.556</td>
<td>4.755</td>
<td>8.5521583</td>
<td>0.554</td>
<td><strong>4.7378957</strong></td>
<td>0.80</td>
<td>6</td>
<td>4.80</td>
<td>1.29%</td>
<td></td>
</tr>
<tr>
<td>Hum 3: 103227/3226</td>
<td>3.751</td>
<td>31.427</td>
<td>8.3782991</td>
<td>3.811</td>
<td><strong>31.929698</strong></td>
<td>4.00</td>
<td>8</td>
<td>32.0</td>
<td>0.22%</td>
<td></td>
</tr>
<tr>
<td>Prof 1: 15017</td>
<td>1.046</td>
<td>8.121</td>
<td>7.7638623</td>
<td>1.047</td>
<td><strong>8.1287639</strong></td>
<td>4.00</td>
<td>2</td>
<td>8.00</td>
<td>1.61%</td>
<td></td>
</tr>
<tr>
<td>Prof 1: 11001</td>
<td>3.233</td>
<td>20.799</td>
<td>6.4333436</td>
<td>3.222</td>
<td><strong>24.718491</strong></td>
<td><strong>Y</strong></td>
<td>4.00</td>
<td>6</td>
<td>24.0</td>
<td>2.99%</td>
</tr>
<tr>
<td>Prof 1: 14509</td>
<td>0.778</td>
<td>8.535</td>
<td>10.970437</td>
<td>0.771</td>
<td><strong>8.4582069</strong></td>
<td>4.23</td>
<td>2</td>
<td>8.46</td>
<td>0.02%</td>
<td></td>
</tr>
<tr>
<td>Prof 1: 13404</td>
<td>0.309</td>
<td>2.667</td>
<td>8.631068</td>
<td>0.311</td>
<td><strong>2.6842621</strong></td>
<td>2.67</td>
<td>1</td>
<td>2.67</td>
<td>0.53%</td>
<td></td>
</tr>
<tr>
<td>Prof 1: 13049</td>
<td>0.178</td>
<td>1.577</td>
<td>8.8595506</td>
<td>0.179</td>
<td><strong>1.5858596</strong></td>
<td>0.80</td>
<td>2</td>
<td>1.60</td>
<td>0.88%</td>
<td></td>
</tr>
<tr>
<td>Prof 1: 2392</td>
<td>2.781</td>
<td>27.787</td>
<td>9.9917296</td>
<td>2.866</td>
<td><strong>31.441272</strong></td>
<td><strong>Y</strong></td>
<td>4.00</td>
<td>8</td>
<td>32.0</td>
<td>1.75%</td>
</tr>
</tbody>
</table>
Since the result in table 5 supports a continuation of Birka’s dual metrics in Sigtuna, it seemed necessary to perform a re-analysis of Sperber’s results of the six weights from the excavations of the city block “Guldet”. I haven’t been able to retrieve these weights for analysis with the CAD-method; so instead I used the results from Sperber’s statistical analysis (Sperber 1996:89). The results are shown in figure 6.

Although Sperber achieved less overall deviation with his proposed 3.19g standard unit, the weights seem to fit pretty well with 4.0 g and 4.23 g respectively. Also, in order to fit the 41.08 g weight and the 35.15 g weight into a system with a standard unit of 3.19 g, Sperber had to suggest multiples of 13 and 11 respectively, which is very unlikely, as he also points out (Sperber 1996:92). Since we have support for the existence of the mitqal and its Birka version in Sigtuna, I would suggest that the weights that fall within the acceptable deviation belong to the Scandinavian/Islamic system. The two outliers may have belonged to another system. Other possible explanations for such deviations include miscalculations in the archaeometrological analysis, faults during manufacturing or even forgery.

Table 6: Results of a re-identification of the standard unit for six weights from Sigtuna, compared with the results of Sperber’s proposed 3.19 g unit.

<table>
<thead>
<tr>
<th>ID</th>
<th>Reconstructed Mass</th>
<th>Proposed standard unit (g)</th>
<th>Proposed multiple</th>
<th>Expected mass</th>
<th>Deviation (unacceptable in bold)</th>
<th>Deviation with 3.19 g unit (unacceptable in bold)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25.2</td>
<td>4.23</td>
<td>6</td>
<td>25.38</td>
<td>0.71 %</td>
<td>1.27 %</td>
</tr>
<tr>
<td>2</td>
<td>41.08</td>
<td>4.00</td>
<td>10</td>
<td>40.00</td>
<td>2.70 %</td>
<td>0.95 %</td>
</tr>
<tr>
<td>3</td>
<td>25.77</td>
<td>4.23</td>
<td>6</td>
<td>25.38</td>
<td>1.54 %</td>
<td>0.97 %</td>
</tr>
<tr>
<td>4</td>
<td>32.06</td>
<td>4.00</td>
<td>8</td>
<td>32.00</td>
<td>0.19 %</td>
<td>0.50 %</td>
</tr>
<tr>
<td>5</td>
<td>31.56</td>
<td>4.00</td>
<td>8</td>
<td>32.00</td>
<td>1.38 %</td>
<td>1.08 %</td>
</tr>
<tr>
<td>6</td>
<td>35.15</td>
<td>4.23</td>
<td>8</td>
<td>33.84</td>
<td>3.87 %</td>
<td>0.17 %</td>
</tr>
</tbody>
</table>

4.1.4. The problem of the 0.80 g unit.

The 12.7 g unit is supposed to have been the hinge, from which both the Scandinavian/Islamic system and the Birka system could be converted. It represented a mass of three mitqal, and Sperber suggests that the 0.8 g unit, which in turn is 1/5th of the Birka mitqal, derives from it (Sperber 1996:55). The conversion formula would be: 4.233 x 3 = 12.7 / 16 = 0.8 x 5 = 4.0. The problem is that 1/16th of 12.7 g is 0.794 g, which means the Birka mitqal should have been 3.968 g, i.e. 15/16th of a mitqal, rather than 19/20th, as proposed. It’s possible that this discrepancy appeared through inaccuracy in weights or scales, at the time the Birka system was constructed, but it could also be that the Metrological reconstruction is incorrect. A test of all the weights adhering to the Birka system, from the analysis above, against units of 0.794 g and 3.968 g gave inconclusive results. Some suffered a higher deviation; others seemed to fit these units better (table 7).
Table 7: Seventeen weights adhering to the Birka mitqal, tested against a standard unit of 3.968

<table>
<thead>
<tr>
<th>ID</th>
<th>Reproduced mass (g)</th>
<th>Proposed standard unit (g)</th>
<th>Proposed multiple</th>
<th>Proposed target mass (g)</th>
<th>Deviation (unacceptable in bold)</th>
<th>Deviation with units of 0.8 or 4.0.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sig, Pro 1: 13049</td>
<td>1.5858596</td>
<td>0.794</td>
<td>2</td>
<td>1.59</td>
<td>0.13 %</td>
<td>0.88 %</td>
</tr>
<tr>
<td>Bir, Gar 03: 14311</td>
<td>2.3216115</td>
<td>0.794</td>
<td>3</td>
<td>2.38</td>
<td>2.54 %</td>
<td>3.27 %</td>
</tr>
<tr>
<td>Bir, Gar 03: 14223</td>
<td>2.431579</td>
<td>0.794</td>
<td>3</td>
<td>2.38</td>
<td>2.08 %</td>
<td>1.32 %</td>
</tr>
<tr>
<td>Hum 3: 101550/1550</td>
<td>4.7378957</td>
<td>0.794</td>
<td>6</td>
<td>4.76</td>
<td>0.55 %</td>
<td>1.29 %</td>
</tr>
<tr>
<td>Bir, Gar 03: 14577</td>
<td>4.741163</td>
<td>0.794</td>
<td>6</td>
<td>4.76</td>
<td>0.48 %</td>
<td>1.23 %</td>
</tr>
<tr>
<td>Bir, SHM 476a</td>
<td>7.771518</td>
<td>3.968</td>
<td>2</td>
<td>7.94</td>
<td>2.07 %</td>
<td>2.86 %</td>
</tr>
<tr>
<td>Sig, Pro 1: 15017</td>
<td>8.1287639</td>
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<td>2</td>
<td>7.94</td>
<td>2.43 %</td>
<td>1.61 %</td>
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<tr>
<td>Bir, SHM 476b</td>
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</tr>
<tr>
<td>Bir, SHM 14837:3</td>
<td>11.826196</td>
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<tr>
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<td>15.964984</td>
<td>3.968</td>
<td>4</td>
<td>15.87</td>
<td>0.59 %</td>
<td>0.22 %</td>
</tr>
<tr>
<td>Bir, Gar 03: 14405a</td>
<td>24.611086</td>
<td>3.968</td>
<td>6</td>
<td>23.81</td>
<td>3.37 %</td>
<td>2.55 %</td>
</tr>
<tr>
<td>Sig, Pro 1: 11001</td>
<td>24.718491</td>
<td>3.968</td>
<td>6</td>
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<td>3.82 %</td>
<td>2.99 %</td>
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<tr>
<td>Sig, Pro 1: 2392</td>
<td>31.441272</td>
<td>3.968</td>
<td>8</td>
<td>31.74</td>
<td>0.95 %</td>
<td>1.75 %</td>
</tr>
<tr>
<td>Bir, SHM 14563:15</td>
<td>31.579258</td>
<td>3.968</td>
<td>8</td>
<td>31.74</td>
<td>0.52 %</td>
<td>1.31 %</td>
</tr>
<tr>
<td>Sig, Hum 3: 103227/3226</td>
<td>31.929698</td>
<td>3.968</td>
<td>8</td>
<td>31.74</td>
<td>0.58 %</td>
<td>0.22 %</td>
</tr>
<tr>
<td>Bir, SHM 13838</td>
<td>40.043473</td>
<td>3.968</td>
<td>10</td>
<td>39.68</td>
<td>0.92 %</td>
<td>0.11 %</td>
</tr>
<tr>
<td>Bir, Gar 03: 14099</td>
<td>40.499352</td>
<td>3.968</td>
<td>10</td>
<td>39.68</td>
<td>2.06 %</td>
<td>1.25 %</td>
</tr>
</tbody>
</table>

Sperber does actually use a unit of 0.794 g in his analysis of cubo-octaedrical weights from Birka (Sperber 1996:81 table 7.14), and in figure 2 above, a unit representing 15/16th is suggested as part of the Scandinavian/Islamic system. In his analysis though, the actual mass of the weights persistently deviated by ~ +0.05 g, suggesting a unit of 0.8 g.

This need to be studied further, since a Birka mitqal of 3.968 g, could possibly open up for correlations with other systems, in addition to that of the Caliphate.
The question whether the *Birka mitqal* was 4.0 g or 3.968 g will have to be a stone left unturned for this thesis. It would not have any impact on the hypothesis of a dual metrics system, other than the correction of the margin extracted; from 1/20th to 1/16th.

### 4.2. Islamic silver vs. Birka produce – a spatial comparison.

![Spatial comparison of Oriental beads and Islamic silver in Mid-East Sweden](https://example.com/image.png)

Figure 10: Find distribution of Islamic coins and beads of carnelian or rock crystal in Dalarna, Gästrikland, Södermanland, Uppland and Västmanland.

Data for finds of Islamic coins: Database of the Numismatic Institute, Department of Archaeology and Classical studies, Stockholm University.

Data for finds of oriental beads: Jansson 1989. Finds after 1989 are not included.

The third implication derived from the hypothesis (see Hypothesis & Implications above) - *if silver was the preferred method of payment, it should have accumulated in the Hinterland rather than Birka* - will now be subject to analysis.

Large quantities of silver were, in deed, distributed into the Hinterland of Birka, but they might have ended up there as the result of something else than trading with the town. One way of linking the Islamic silver with Birka would be to study the hoard assemblage and context in which it was found. Are there other objects in the hoard that can be attributed to Birka: import products such as glass, non-local pottery, silk or products associated with Birka manufacturing?

However, in this thesis, I have had to limit this analysis to a comparison of the find distribution of Birka-associated goods and Islamic silver. To what degree do the patterns of distribution for these two artefact groups match? The choice of Birka-associated goods fell on
beads of carnelian and rock crystal, also known as Oriental beads. These types of bead have been connected with the easternmost part of the Caliphate, as well as with India (Jansson 1989:586). As they are not of local origin; they are likely to have been imported mainly through Birka. A spatial correlation between Oriental beads and Islamic coins would therefore suggest that the bulk of the latter also was acquired at Birka. Oriental beads in Scandinavian contexts also date to the period in question, i.e. the 10th century (Ambrosiani & Danielsson 1992:75f). Figure 10 shows the finds of Oriental beads in combination with Islamic coins for the Swedish provinces of Dalarna, Gästrikland, Södermanland, Uppland and Västmanland.

On a parish level, it almost seems as if plentiful finds of beads omit larger finds of Islamic silver. However, a study with such high resolution will tend to give arbitrary results, since the number of individual finds (hoards) per parish rarely exceeds one or two. Also, the contexts in which beads and coins are generally found differs; beads usually found in grave contexts; coins in hoards or as stray finds in relation to settlements. Resulting in coins, to a greater extent, being found in parishes with more agricultural activity, while beads tend to appear in relation to exploitation. The view should therefore be expanded to a more regional level. Doing so, the distribution patterns correspond very closely. The distribution is also clearly concentrated along the river and sea routes to Birka.

In addition, the find distribution pattern for the Lake Mälaren region corresponds to areas preconditioned for agriculture (the fertile clay soils (yellow) shown in figure 11). These are of course also the areas with the highest degree of Viking Age settlement (see figure 12), which could be argued as being the main the reason for the concentration of finds there. However,
there are large populated areas where hardly any finds of Islamic silver or Oriental beads have
been made; for instance the inland of Attundaland (one of the Viking Age folk lands, encompassing the area just north of Stockholm). This was a region with a relatively large
agricultural population. The river route of Långhundra, leading from Trälhavet, near present
day Österåker, all the way to Uppsala, believed to have been travelable during the late Iron
Age, ran through the heart of it. The etymology of parish names like Fröstuna, Husby-
Långhundra, Närtuna, Östuna and Skeppstuna, indicates important Iron Age settlements. Why
this region would be so void of Birka-associated goods might therefore seem enigmatic.

The answer though, may lie in the actual course of the Långhundra river route. It effectively
bypasses Lake Mälaren, providing a direct route, for smaller vessels, from the Sea to Uppsala,
i.e. leading far from Birka. Passage through Norrström (at present day Stockholm) was not
possible until perhaps around 1000 AD (Skoglöv 2000:224f), thus a journey by boat from the
inland of Attundaland, to Birka, would have required travelling, either north by Uppsala, or
south, around Södertörn and into Lake Mälaren through the Telge channel. For that reason,
trade with Birka was probably conducted via middle hands, and as it would seem: with other
means of payment than silver.

The finds of Islamic silver and Oriental beads in Dalarna, and the north of Västmanland are
surprisingly few, given the region’s importance in the production of iron. This might, in part,
be explained by the numerous finds in Gästrikland and southern Västmanland, regions which
could have acted as middle hands for the iron trade and where refinement also may have taken
place (cf. Hyenstrand 1972), therefore also accumulating the silver through their contacts with Birka.

It is interesting that the spreading of Islamic silver from Birka into the Hinterland, to a large extent, seems to have been limited to those presumably in direct contact with the town. It suggests that silver might not have been a preferred unit of payment in transactions outside the emporium. As a transaction in silver required scales and weights, which in turn are intimately connected with merchants and emporia, this supports the implications that Birka would have enjoyed a monopolistic position in the region, as well as silver being the preferred unit of payment in the town.

In conclusion: There is a relation between the Islamic coins and the Oriental beads in this region, suggesting that the silver was, to a large extent, acquired in Birka. This is further corroborated by the concentration of Islamic silver in areas connected to Birka by direct sea or river route, as well as by the lack of Islamic silver and oriental beads along the river route of Långhundra, which effectively bypasses the emporium, as well as in Dalarna and northern Västmanland, where trade with Birka probably was conducted via middle hands.

4.3. Provenance of lead in the cylindrical Birka weights

The fourth implication of the hypothesis: the cylindrical weights, corresponding to the Birka mitqal, were manufactured locally, is an implication very difficult to either corroborate or falsify. Short of finding the weight in the same context as the mould, there really is no certain evidence either way. One hint, though, could be the origin of the material the weights were made of, in this case lead. Provenance of lead is established by comparing the ratios of the lead isotopes Pb208/206 and Pb206/204 against Pb207/206 (method developed by Brill and Wampler 1967). These results can be compared to reference data, if available for the region. A problem with this method could be that the isotope ratios of two regions may overlap. This overlap may even be unaccounted for, due to lack of reference data. For instance, we have no data for lead deposits in Sweden, which should be kept in mind here. It is also possible that ore from more than one source were involved in the manufacturing or refining, given that metal routinely would have been recycled (cf. Budd et al. 1995).

A provenance study of the lead in the weights from Birka has been done by Sophie Stos-Gale at the Isotrace Laboratory in Oxford (figure 13), indicating that most of the lead probably was extracted in Derbyshire, England. She also makes a comparison between the Birka weights and lead from the Medieval Cathedrals of Lincoln and Salisbury, claiming the lead undoubtedly originate from the same ore deposit (Stos-Gale 2004:328ff).

If so, since the Anglo-Saxons did not use the Scandinavian/Islamic weight system, the weights probably weren’t manufactured there. This means the lead would have been exported to the site of manufacturing. Such a site could have been Helgö, another Lake Mälaren island, close to Birka, where moulds for casting of cylindrical lead weights have been found (Kyhlberg 1980:182f).

Although it is possible that the lead was exported from England to, for instance Gotland, where the weights could have been cast and then exported on to Birka; no evidence for the existence of the Birka mitqal has so far been found there, or in any of the other sites around the Baltic where weight manufacturing may have taken place. Thus, this analysis neither corroborates the implication, nor suggests otherwise.
Figure 13: Diagram of lead isotope ratios showing the data of 25 lead weights from Birka, plotted against data for ores from Derbyshire (England), the Harz Mountains (Germany) as well as Hess and Baden-Württemberg (Germany). Analysis by Dr. Sophie Stos-Gale at the Isotrace Laboratory in Oxford. From Gustin 2004.
5. Discussion on the hypothesis of a dual-metrics system

From a modern day perspective it can be difficult to make sense of using metrics to extract fees. Why go the trouble of devising a system where special weights had to be manufactured for use in a specific type of transaction? Why not simply pay a certain amount, or percentage of the profits, to the recipient, with given intervals?

These are valid questions, but formulated from the context of a monetary economy. When we think of the value of a certain goods; we think in terms of currency. When a farmer in the Viking Age thought of buying livestock or selling his produce, he would have thought in quite different terms. Either he might have calculated in terms of bartering; where one goods was worth a certain number of another goods, or he would have calculated with a certain amount of silver (or other acceptable units of payment), specified by the appropriate unit of mass. These units, their denominations often lost to us, were probably as much part of the mind-set then, as the Dollar, or the Euro, are today. However, this was also a time when the common man or woman would have possessed very limited knowledge in arithmetic. Prices were probably set in simple fractions or multiples of the mass unit; such as 1/3rd or 2 ½. The frequent use of duodecimal amounts like a dozen and the gross makes such simple arithmetic even more important. The existence of 1/16th fractions in the Scandinavian/Islamic weight system, even suggests the use of a hexadecimal numeral system.

This means that if you wanted to extract a fee of 1/20th, you would first of all have to use weights, since there was no monetary system. But in order to avoid complications and raise suspicion with prices like 1.425 mitqal (if the normal price was one and a half) - a mass which would be difficult to assemble with weights, let alone understood by the average Viking Age person – the use of traditional units should somehow be left intact. There is really only one way of doing so, and that is to devalue the units, i.e. decreasing their mass. That way, the desired fee would have been extracted, without anyone having to think in fractions.

This analysis has aimed at corroborating or falsifying the following hypothesis: The metrics of Birka had a built-in discrepancy, generating a margin between import and export. A number of four implications were inferred from this hypothesis, of which the following required further study:

2. The Birka mitqal differs from the Islamic mitqal, but harmonises with it.

This implication was in fact already corroborated by the research of Sperber, from which the basis for the hypothesis was originally laid down. However, I chose to test his results by applying the CAD-method, described in section 3 above, to the same set of weights. Although I couldn’t retrieve all the weights for analysis, the results proved Sperber’s findings correct. I then expanded the study with a number of seven weights, previously not analysed, excavated at the Garrison of Birka in 2003. These could also be attributed to the Birka system, which in effect means that implication 2 above is corroborated.

3. The Islamic silver should have accumulated in the Hinterland, rather than with the merchants of Birka.

This required a study of the find distribution of Islamic silver vs. an artefact known to have been traded at Birka, in this case: beads of carnelian and rock crystal. A spatial correlation would support that the local producers of the region, who traded at Birka, probably acquired
their silver there as well. Of course, not all of these beads were acquired from Birka; nor was all the silver in its Hinterland the result of trade. But the distribution of finds along the water ways to Birka, and the lack of them along routes not leading there, provides sufficient grounds to say there is a relation between wares from Birka and Islamic silver. That supports the notion that silver was the preferred method of payment for the Birka merchants when buying produce from the Hinterland, since any trading fee, built-in to the weights, would be bypassed through bartering.

4. The cylindrical weights corresponding to the Birka mitqal were manufactured locally.

The last implication is a special case, in that it is very difficult to either support or falsify. Cylindrical lead weights are very simple to manufacture, and the lack of ornamentation makes it nearly impossible to link the few recovered moulds with the weights that were cast in them. Lead can be analysed for provenance, but that does not prove the site of manufacturing, as this case clearly shows. The analysis pointed to a source in England, where weights for the Scandinavian/Islamic system hardly could have been produced. Therefore this implication could neither be corroborated, nor falsified.

As three out of four implications were corroborated (the first, concerning Birka’s monopolistic position in the Lake Mälaren region and bordering provinces, not in need of further evidence), and none was falsified, the hypothesis stands. There in deed seems to have been a dual metrics system in use in Birka, for the purpose of generating a margin of 1/20th between import and export (or possibly 1/16th as discussed in section 4.1.4 above). The metrological analysis also shows that this system was inherited by Sigtuna, having implications on the way we should interpret the relation between the two emporia.

A number of questions arise from this: Who benefited from this system? Was it limited to Birka? What implications could this have on our view of Viking Age trade and the complexity of the region’s administration?

To answer the first question, we should consider the costs related to the upkeep of an emporium, such as Birka. Having been in charge of the latest number of excavations at Birka, Lena Holmquist Olausson has suggested that the warriors of the Garrison, belonging to the absolute top of the social and political strata, may have acted as supervisors of the manufacturing process, guaranteeing that proper mass was achieved and upheld (Holmquist Olausson, pers. msg. Sep 2008). It is a theory that needs further studying, but it is clear that some sort of supervision would have been needed. There are several reasons for this, among which the factor of trust may have been of the highest importance. Trust in the accuracy of the weights would have been crucial, when choosing to which emporium you should commit your trading activities. The accuracy of your counterpart’s weights could of course easily be tested, using your own set as reference. Weather this was routinely done, or perhaps subject to some sort of merchants code of trust, is not known. However, the possibility of testing the weights should have been enough to deter intentional cheating, at least when dealing with a fellow merchant. Therefore, control of the weight’s accuracy would certainly have been a matter of great importance to all that benefitted from the trade at Birka. Apart from weights, the warriors of the Garrison have also been suggested to have supervised the production of locks and keys, as well as controlling the water supply (Hedenstierna-Jonsson 2006:89).

Another factor of major importance would have been the guaranteeing of personal security for local merchants and foreign visitors, especially in a region, by many contemporaries,
considered uncivilised and pagan. The urgency of a military presence can be highlighted by the archaeo-
logical and historical evidence of attacks on Birka, such as that of the exiled King Anund, who appeared one day with a fleet of 32 long ships (Rimbert 1965: chapter 19). It has been estimated that such a fleet would have carried between 400 and 500 warriors (Edberg 2001:20). Even including an armed militia, the garrison would probably have been too few in numbers to counter such a threat, but would certainly have deterred raiding parties of a more reasonable size.

The hall-building of the Garrison at Birka has been dated to the second half of the 10th century (Holmquist Olausson & Kitzler Åhfeldt 2002:16); although the earliest activity phases for the Garrison area have been dated to the second half of the 8th century (Holmquist Olausson 2001). The strength of the permanent force in the 10th century has been estimated to forty men, possibly serving in shifts, keeping up the garrison all year round (Hedenstierna-Jonsson 2006:61). Another interpretation is that the permanent force was closer to twenty and reinforced to perhaps forty during certain periods (Olausson 2001:22f). These men would have been the elite of the warrior society, probably part of the King’s retinue (Hird), the closest thing to nobility for the Viking Age. It is not far-reaching to assume they also were educated in other fields than warfare. Some of them would have served in the Byzantine army, where they probably had to be literate and have an understanding of mathematics. Runic inscriptions on objects found in the Garrison, along with styli and fragments of a writing table, supports this (Hedenstierna-Jonsson 2006:62).

While in garrison, apart from feasting and training for war, their presence would have made sure that trade was conducted in an orderly and fair fashion. As mentioned, they might also have been responsible for certain controlling functions. The cost involved for the upkeep of this garrison would have been great. The osteological evidence, for instance, show that the warriors would have enjoyed beef and pork all year round (cf. Wigh 2001). Their equipment seems uniform, implying it was supplied to them (Stjerna 2001:43). Armour and weapons were among the most expensive items silver could buy. And this is where I believe the margin, generated through the dual metrics, comes into play. I suggest that the merchants, who used Birka as a base for their trading activities, subsequently being required to use the dual metrics system, paid the margin as a fee for the right to trade, and the guarantee of their personal safety.

No similar dual metrics system has yet been identified elsewhere, perhaps because the possibility of such a system hasn’t been accounted for. In fact, according to Sperber’s research, other mainland sites within the Hinterland of Birka seem to have used only the Birka mitqal (Sperber 1996:110). This suggests that these areas were expected to trade with Birka; a practise normally attributed to the Medieval period in Sweden (cf. Lindqvist & Sjöberg 2006:111ff)), and suggests a higher level of centralized government, than what is usually credited this region in the Viking Age. The implementation of a trading fee, extracted in this sophisticated manner, enforced throughout a larger region for the benefit of the upkeep of inter-regional trade through Birka, surely requires a great measure of centralized administrative power. So, even though we can’t go so far as to ascribe the region state-hood, I would not describe it as having been state-less.
6. A wider view

Where did this Scandinavian/Islamic system originate? As its denomination suggests, it built upon the system of the Caliphate, but was its implementation in the Baltic trade region really the result of direct exchange with the Islamic world?

Though merchants from Scandinavia, mainly Gotland and the Lake Mälaren region, very well may have travelled further, a large part of the eastern trade was conducted via middle hands within Eastern Europe, (roughly the area of present day Ukraine, Belarus and the European part of Russia). The question arises therefore if the weight system also may have been adopted from the cultures inhabiting these vast geographic expanses, separating Scandinavia and the Islamic world. A study of similarities and differences in weight typology and metrics of these regions may provide clues to an answer.

6.1. The origin of the Scandinavian/Islamic system

The main purpose of a standardized weight system is to facilitate trade between two parties. For this reason, cultures of different regions have, throughout history, adapted their systems of measurement to those, with whom trade was sought.

Weight units, their origins often lost in prehistory, have been adopted straight-off or with adaptations to local gold/silver ratios or preceding systems. Mass was not set arbitrarily, but in strict relation to whichever system was used by these, intended trading partners. Therefore, for instance, we can discern a straight line of adaptation from the Carolingian *media libra*, amounting to $\frac{1}{2}$ of the Islamic *ratl*, which was the same as 96 *zolotniki* of Southern Rus, and so on (cf. Pritsak 1998). Over time, deficiencies in scales and in the manufacturing of the weights caused systematic errors to occur, unintentionally altering the unit mass slightly with every step of the diffusion process. For this reason it may be difficult to establish the origins, without having historic sources stipulating, or at least hinting at the connections. Fortunately, for most areas, such sources are plentiful, due to the need for regulation of trade through charters and signing of contracts.

No other artefact group will provide such clear indications on cultural exchange, as those related to trade. Not only do the actual metrics pinpoint the preferred partners for interregional trade, but the iconology of the weights themselves can provide clues on how the system spread from its source: i.e. its diffusion pattern. Although form and metrics often walk hand in hand in this process of diffusion, it cannot be ruled out that weights with similar form adhere to different systems, or vice versa. The iconology may have been inherited from a previous system or actively chosen to reflect a cultural relation to a region, with which other factors than trade may have been of greater importance. However, if two regions have systems corresponding in both iconology and metrics, it is clear that one influenced the other. The direction of this influence can be established by studying the numismatic evidence, which often follows with a find of weights, as well as the typology established for the weight type in question.

6.1.1. The origins of the cubooctaedrical form

Cubooctaedrical weights have been manufactured in Scandinavia. This is shown by a find from Gotland of a cast-chain containing four non-separated weights (Östergren 1989:171f). The find-distribution of cubooctaedrical weights shows a concentration around the Baltic Sea and, so some degree, the upper Dniepr and Volga rivers (figure 14).
In her dissertation, *Mellan gåva och marknad*, Ingrid Gustin studied the origins of the cubooctaedrical form element. It can be attributed to a number of different types of artefacts, mostly dress ornaments, spanning an area from Norway in the west to the Volga river bend in the east. Gustin argues for an origin of this form in the Permian silver rings (Gustin 2004:323), which in fact also seems to have been used as some sort of weights themselves (Thurborg 1989:91, 95). The Permian rings are concentrated to the north of the Volga river bend, but have also been found in Scandinavia (Gustin 2004:138ff).

Heiko Steuer cites a passage in the travel account of Ibn Fadlan to suggest a more Oriental origin for the cubooctaedrical form elements: Ibn Fadlan tells about the money-changers of the town of Chwarizm (modern day Chiva in western Uzbekistan), that they sold dice, *dirham* and what could be loosely translated as peg-tops or spinning tops (German translation: *kreizel*, Swedish translation: *snurror*) (Wikander 1978:35). These “peg-tops” are interpreted by Steuer as bi-polar spherical weights and the dice as their cubooctaedrical counterpart (Steuer 1997:46). According to Gustin this interpretation is problematic as the lesser weights of the Volga-Bulgarians are cubical in form (figure 16), not cubooctaedrical, as she means should have been the case if the form element originated in the Caliphate (Gustin 2004:320).

![Figure 14: The distribution of cubooctaedrical weights. From Steuer et al. 2002.](image-url)
I would not rule out the possibility that these “dice” could have been cubooctaedrical weights and that the cubical weights of the Volga-Bulgarians were simplified imitations. It is, however, problematic for such an interpretation that very few cubooctaedrical weights have been found within the historic borders of the Caliphate. The low frequency can be highlighted with an example from the ancient town of Caesarea Maritima (modern day Israel), which was abandoned in 1265, where just one, out of more than a thousand Islamic weights recovered, was cubooctaedrical in shape (Holland 1986). The common weight of the Caliphate seems to have been parallel-epipedical (brick shaped). Some of them had faceted corners, but most of them did not (Gustin 2004:321).

From a source-critical perspective Ibn Fadlans account becomes even more difficult to link to weights; simply because it would suggest that he, an educated and well-travelled citizen of the Caliphate, hadn’t been able to correctly identify weights used within its borders. This seems, to me at least, as being very improbable. It is, on the other hand, equally improbable that the merchants of Chwarizm had specialized on “dice and peg-tops”. For this latter reason, the objects should in deed have been weights, especially as they are mentioned in the same sentence as dirhams. The reason Ibn Fadlan failed to identify them correctly suggests that these merchants in fact where foreign, possibly Khazars or Volga-Bulgarians, using a type of weight unknown to him.

The combination of cubooctaedrical and bi-polar spherical weights was also standard in Northern Rus. These weights have been dated to the same time as the Scandinavian weights (Pushkina 1997:23f). However, since the emporia of Staraja Ladoga and Rjurikovo Gorodisce are so strongly linked to Scandinavia culturally, I have chosen not to treat this region as separate from the Baltic trade area.

I agree with Gustin’s interpretation that the cubooctaedrical form element originates from the Volga river bend, which also would imply that its application to weights is a purely Scandinavian idea, since the lesser weights of the Volga-Bulgarians were cubical in form. However, since the use of cubooctaedrical form elements in Scandinavia can be dated back to the migration period, its application to weights provide no clues to questions regarding the adoption of the Islamic weight system in the late 9th century.

6.1.2. The origins of the bi-polar spherical form

In figure 15 the distribution of the oldest type of bi-polar spherical weights is represented. The distribution is, as expected, practically identical to the distribution of cubooctaedrical weights in figure 14. Manufacturing of bi-polar spherical weights has been established, through the findings of so called Schmelzkugeln, in Birka, Sigtuna and Hedeby (Söderberg 1996:12, 2008:999ff).

There are similarities with roman weights (Gustin 204:319), but a continuity in form, spanning the half millennia separating the periods, cannot easily be established. The direct influence should therefore be sought elsewhere. Again the closest similarities can be found in the east. Bi-polar spherical weights have been found in graves of the Saltovo-Majaki culture, native to the Khazarian region between the Don and the Donets rivers (Micheev 1985:16). They were found in combination with scales, however not of the collapsible type, which according to Steuer has its origin in the Caliphate (Steuer 1997:46), so intimately associated with this type of weight in Scandinavia.
Some weights found in Scandinavia have pseudo-Islamic inscriptions on the surfaces of the poles (cf. Sperber 1996:96ff and figure 1). This phenomenon might be taken as an indication that the direct influence for the Scandinavian/Islamic weight system lies in the Caliphate. However, according to an analysis by Gert Rispling, the pseudo-Islamic inscriptions in question are so “barbaric” that they probably are imitations of the already “barbarised” coinage of the Volga-Bulgarians, despite the fact that such coins only constitutes about 1/10th of the total Islamic numismatic material from this period, found in Scandinavia. Especially, it seems the earliest minting of the Volga-Bulgarians may have stood model, according to Rispling, as its dating coincides with the introduction of the Scandinavian/Islamic weight system around the Baltic. These early coins are poorer imitations than the later minting, but still have a lesser degree of “barbarisation” than the inscriptions on the weights (Rispling pers. mess. Dec 2008).

Figure 16 depicts the most common types of weight found in the Volga-Bulgarian area. There are bi-polar spherical weights of Steuers type B1 früh, which dates them to late 9th/early 10th century (Steuer 1997:47). Note the absence of cubooctaedral weights as discussed above.
6.1.3. The weight system of the Volga-Bulgarians

The standard silver-unit of the Volga-Bulgarians, called nayat, was based upon a Samanidian dirham of 3.4125 g. This unit seems to have been adopted at the same time as the Volga-Bulgarians, or at least their ruling class, converted to Islam at about 900 CE. The unit for gold was the mitqal. In fact, two versions of the mitqal seems to have been in use, weighing 4.265625 g and 4.233 (the Scandinavian/Islamic standard) respectively. As a conversion unit, the ratl of the Caliphate was used, called a qadaq by the Volga-Bulgarians. This qadaq represented 96 mitqal. There were also a number of local units in use, such as the saum of 204.75 g (=1/2 qadaq) and the tin, both also used in Khazarian metrics (Pritsak 1998:35f). The gold/silver ratio seems to have been dependant upon the ratio in the eastern Caliphate, ranging between 1:12 and 1:15 during the 10th century (Pritsak 1998:18).

It should be mentioned here that such exact calculations that Pritsak puts forward must be seen as a purely mathematical construction. In reality, no measuring instruments capable of such precision existed before the analytical scales of our own time. With this in mind; we are still able to identify the weight system of the Caliphate with the Volga-Bulgarians.

6.1.4. The weight system of the Khazars

The standard unit for silver with the Khazars was called a tin, which according to Pritsak derived from the Turkish word for Marten/Squirrel (Pritsak 1998:24), referring, of course, to the value of the fur. According to Ibn Rustah (Rustah using the Arabic word for fur - dalaq) a tin equalled 2.5 dirham. The more common variant, altin, meant six tin and represented, according to Pritsak, 40.95 g. He bases this on a North African dirham of 2.73 g (Pritsak 1998:25), a claim that has been questioned due to the heterogeneity of the North African weight population. It is simply too diverse for a metrological analysis (Album 1999:37f). Also, Album continues, the Arabian merchants trading with the Khazars should have used the dirham of the eastern Caliphate.
An altin represented 1/10th qadaq, which could be linked to the mitqal, as mentioned above. According to Pritsak, the relation of gold to silver in Khazaria was 1:15, in contrast to 1:18 in Byzantium. Based on this; he suggests a solidus/mitqal (Pritsaks definition) of 4.55 g as a standard gold unit (Pritsak 1998:25). Further, he suggests a link to the Carolingian system, where 5 altin, which could also be called a sam of 204.75 g, equalled the media libra (Carolingian half-pound). He finds support for this theory in a find of a media libra weight from Hedeby of 204.615 g (Jankuhn 1963:219).

6.1.5. **The weight system of the Rus**

In Southern Rus, present day Ukraine, a unit called grivna (meaning necklace or ring) was in use. The grivna was convertible with the Byzantine litra as follows: 5 litra, of 327.6 g each, equalled 12 griven serebra (grivna of silver) of 136 g (Pritsak 1998:37f). Pritsaks calculations are based on an ideal mass of the litra, which according to Christopher Entwistle fluctuated over time. This was due to the declining mass of the underlying gold weight, the solidus. Entwistle suggests a litra during the 10th century of 319 g (Entwistle 2002:611), which in effect would lead to a grivna serebra of 132.92 g.

The relation gold to silver in Southern Rus was 1:15, as with the Khazarians, giving the relation 1:2 for the grivna serebra to the solidus (136.5 g/2)/15=4.55 g. Further a grivna kun was ¼ of the grivna serebra, in turn representing 15 kun of 2.73 g (Pritsak 1998:38).

The weight system of Southern Rus was, as we’ve established, compatible with Byzantine metrics. However, it was also compatible with the weight system of the Caliphate through the, so called, great grivenka of 409.5 g, i.e. a different name for the qadaq of the Volga-Bulgarians and the Khazars, which ultimately derived from the ratl. The ratio of conversion was 3 griven serebra of 136.5 g to 1 grivenka (ratl). A grivenka could also be divided into 96 zolotniki of 4.265625 g (Pritsak 1998:39). Pritsak claims that the zolotnik of the Rus was the same as the mitqal, which with these exact calculations seems undisputable. However, as mentioned above, any calculation with more than two decimals should be viewed as a purely mathematical construction, rather than the result of a statistical metrological analysis. The research of Hinz and Sperber identifies a mitqal of 4.233 g (Hinz 1970:2, Sperber 1996:110). Interestingly, Kyhlberg identified a standard unit for Birka of 4.26 g (Kyhlberg 1980:265), i.e. not quite in line with Hinz and Sperber, possibly suggesting the existence of two variants of the mitqal also in Scandinavia (not counting the Birka mitqal), as with the Volga-Bulgarians. Within the Caliphate, a number of mitqal versions were in use (Pritsak 1998:14ff), depending on the region, ruling dynasty and possibly also the fluctuations in the solidus.

Pritsak mentions one more thing regarding the weight system of Southern Rus: the existence of a weight, baptized the osminik by Pritsak, deriving from the Khazarian altin (Pritsak 1998:39f). This suggests that the Rus adapted their weight system to the Khazars, rather than the Caliphate. This also seems logical given the geographic preconditions, where the Rus were separated from the Caliphate by the Byzantines in the south and the Khazars in the east.

Through the monetary reforms of Vladimir, late 10th and early 11th century, the weight system of Southern Rus was altered to further accommodate trade with Byzantium. At the same time the weight system of Northern Rus adopted features reflecting the trade between the Volga-Bulgarians and Western Europe, mainly the German lands (Pritsak 1998:53).
7. Discussion on the origins of the Scandinavian/Islamic weight system

From this study of the metrics within the Eastern European area we may conclude the following:

- The Volga-Bulgarians and the Khazars adopted, in large, the weight system of the Caliphate.
- The Southern Rus adapted their metrics to Byzantium and, as I interpret it, to the Khazars and Volga-Bulgarians, rather than the Caliphate.

So, on to the issue: from where was the Scandinavian/Islamic weight system adopted? If we start by comparing the system of Southern Rus with the system of Scandinavia, it is clear that they were neither the cause nor the consequence of each other. The seemingly total lack of Byzantine influence in the Scandinavian weight system, as well as the strong connection to the mitqal of the Caliphate, indicates an origin further east. Likewise we can rule out a Khazarian transmitting role, as theirs was a system based upon both Byzantine units and units of the Caliphate, combined with a traditional system stemming from fur trade.

What remains then is either a transmission via the Volga-Bulgarians or a direct influence from the Caliphate. The Volga-Bulgarians seems to have adopted this weight system, as part of the package, when the ruling class converted to Islam. Their unit nayat was based upon a Samanid dirham and the term itself is borrowed from the Arabic "naqd", meaning “pure silver” or simply “money” (Pritsak 1998:33). As a gold unit; the mitqal of 4.266 g was used, same as with the Rus (the zolotnik), and as a conversion unit they used the ratl of the Caliphate (renamed the gadaq). An older system was also in existence, but was probably not used for weighing silver. As a comparison, the Scandinavian/Islamic system is based on a standard unit of three mitqal of 4.233 g. Since the Volga-Bulgarians also used this variant, they stand out as the most probable source of influence.

Also when comparing the design of the weights, the similarities are striking. The Volga-Bulgarians used the same bi-polar spherical shape, and the pseudo-Islamic inscriptions on some of the Scandinavian weights have been interpreted as copies of Volga-Bulgarian coins. Even the cuboocetrical form seems to have been adopted from this area, in particular from the Permian rings. This iconology connected the regions as early as the migration period. The lack of similar types of weights in the Caliphate also supports a Volga-Bulgarian origin.

Since the Scandinavian/Islamic system predates most written sources in the area, and seems to have been replaced by medieval times, we don’t know the names of the units. The reason Pritsak can name the units Eastern Europe so well, is simply because they still were in use at the advent of bureaucracy. Also, trading with Byzantium and the Caliphate resulted in signing of trade agreements as early as the 9th century. If we knew what the people of Birka, Gotland or Hedeby called their units of weight, we might instantly be able recognize their area of origin. For instance: had the standard silver unit of the Scandinavian/Islamic system been called a dirham, or a similar Norse transcription, it would suggest that the system was adopted as a result of direct contact with the Caliphate. It seems more probable though; that the term was more similar to a nayat, since the metrics and iconology corresponds so well to the Volga-Bulgarian system. Then again, the terminology might very well have been the same as in medieval times, only differing in mass.
**Introducing the CAD-method**

The first part of this thesis consists of the presentation and testing of a new method for archaeometrological analysis. The traditional method of recreating the initial mass of a weight, in this thesis called the Statistical method, was one of manual measuring and calculating. It entailed estimating the ratio of the composition of materials, and using their appreciated densities to establish the mass. Other factors, such as the effect of corrosion on volume, also had to be taken into account. Furthermore, with the Statistical method, it was preferable to leave the corrosion products intact in conservation, which in effect prevents proper stabilisation of the artefact. All in all, the process was time consuming and largely based upon calculations instead of actual values.

With the CAD-method, the weight is scanned with a 3D scanner, producing a 3D object, from which the exact current volume can be discerned. Dividing the current mass, measured with an analytical scale, with the volume of the 3D object, gives the current actual density. If this value is found to have been affected by corrosion, i.e. deviating to far from the expected value, the MNCA (Mean value for Non-Corroded Artefacts) may be applied instead. This is, as the term suggests, the current mean value for artefacts, analysed with the CAD-method, unaffected by density altering corrosion. The more weights analysed, the more precise this value will get. Of course, there need to be a separate MNCA value for each type of material composition and weight shape. Prior to scanning, it may be necessary to remove the protective coating, such as lacquer or paraffin, in order to produce a good scan. However, I have not had to do this with any of the weights analysed in this thesis.

Once density has been established, the 3D object is imported into a CAD program for recreation of the initial volume. To obtain this, the original form of the weight is recreated with applicable geometric shapes, such as spheres, planes or cylinders. This needs to be done in a program where such shapes can be applied with a best-fit function, where the size of the sphere, for instance, is determined from the actual size of the weight. Once the form is recreated, the volume of this new object can be obtained, which should correspond closely to the volume of the weight in mint condition. Calculating initial mass is then just a matter of multiplying this volume with the density obtained earlier.

This should be a less time consuming, though not less accurate method, which also permits a good conservation of the artefacts. In fact, the removal of corrosion products is a definite advantage with the CAD-method, as they have a much lower density than the remaining core.

As more weights are analysed, a database of 3D representations will build up, providing the possibility of easy and safe sharing of the objects for future research, preserved from further deterioration in its digitised form.

The accuracy of the CAD-method was tested in two ways. First, a mock object was cast out of tin, with an aluminium core, simulating a weight composed of two materials with different density. The object was scanned and weighed in mint condition, providing the initial values to be recreated with the CAD-method. After this, the object was submitted to artificial wear,
simulated by sand-papering and the removal of material. In order to simulate the corrosive
effects on a composition of two materials, where one is more resilient, for instance bronze and
iron, a larger percentage of aluminium was removed. A layer of corrosion was also simulated
by applying dull paint to the surface. Finally, the steps of the CAD-method were applied,
producing a result deviating by -0.4 % from the initial mass. This is well within the 2 %
deviation allowed for the Statistical method.

Secondly, the CAD-method was applied on a set of four weights previously analysed with the
Statistical method. The results from this test (table 2) corroborated the conclusions from the
statistical analysis, proving the CAD-method is applicable also to real artefacts.

The hypothesis on dual metrics
Research by Erik Sperber has suggested a dual metrics system for 10th century Birka, where
one standard unit was the *Islamic mitqal* of 4.23 g and the other, called the *Birka mitqal*, had a
mass of 4.0 g. As this seems to make little sense, it presented an enigma, needing further
research. I came up with only one possible reason for having two weight systems in parallel;
using one for import and the other for export. This would effectively create a margin of 5%,
which I have interpreted as a trading fee, extracted without having to use fractional weights to
obtain the same result. In order to corroborate this hypothesis, I inferred four implications,
whereof three needed further testing.

The first implication, that Birka would have had to enjoy a monopolistic position for trade in
the region, for which this system was intended, has already been corroborated by several
studies, and was considered verified by default. It would also be supported indirectly, by
corroboration of the remaining three implications.

The second implication concerned the weight themselves. Sperber had identified the *Birka-
mitqal* of 4.0 g on a certain set of weights, which I retrieved in part for re-analysis with the
CAD-method described above. The purpose of this re-analysis was two-fold; evaluation of the
CAD-method on a population of weights already analysed with the Statistical method, and as
a test of Sperber’s results. These four bi-polar spherical weights were supplemented with
seven weights of both cubooctaedrical as well as bi-polar spherical form, excavated at the
Garrison of Birka in 2003. The metrological analysis clearly verified the existence of the
*Birka mitqal*, which corroborated the implication. Furthermore, an analysis of eight weights
from Sigtuna, as well as a re-analysis of six weights analysed by Sperber, clearly showed that
the *Birka-mitqal* and the dual metrics system were in existence as late as the first half of the
11th century.

A system constructed for the purpose of extracting trading fees through weighing, would have
required the use of a standardized unit of payment. In the Caliphate, the *mitqal* was a weight
used for gold. In Scandinavia the standard unit of payment - given the obvious predilection
for it - would have been silver. The third implication did therefore concern the distribution of
Islamic silver within the region supposed to have traded with Birka. If a dual metrics system
was in use, the silver should have accumulated in the Hinterland, rather than with the Birka
merchants themselves. To test this implication, I did a spatial comparison between finds of
Islamic silver and beads of carnelian and rock crystal. These Oriental beads constitute strong
indication of trade with Birka, when found in its Hinterland, and they also date to the 10th
century; i.e. the same period the proposed dual metrics system would have been in place. The
comparison did indicate a spatial relation between the beads and Islamic silver, but also a
clear concentration of finds along water ways leading to Birka. This was especially
emphasised by the lack of finds along the river route of Långhundra, which ran past important Iron Age settlement, but effectively bypassing Lake Mälaren and Birka.

The fourth implication stated that the cylindrical lead weights, adhering to the Birka mitqal, should have been manufactured locally. A study of the isotope ratios of the lead indicated that the metal originated in England. Since England didn’t use the Scandinavian/Islamic system, the weights probably weren’t manufactured there. However, there is a possibility that the weights were produced elsewhere within the region using this system. As this could be neither corroborated, nor falsified, the implication stands unverified.

However, three out of four implications were verified, and thus also the hypothesis. This study suggests that the dual metrics system, in deed was implemented to extract a margin between import and export. In the discussion, I suggest that this fee was intended for the upkeep of the garrison of Birka, which was presumed to have been a permanent force of perhaps forty warriors. There are indications that this garrison also performed certain controlling function, for instance overseeing the manufacturing of padlocks and possibly also the water supply. As a consequence, it is reasonable to assume they also had some sort of responsibility concerning the manufacturing and use of weights in Birka. Such a function would be especially critical with the use of a dual metrics system.

Analyses of weights from other sites in mainland mid-east Sweden, suggest a single metrics system, based upon the Birka-mitqal. This would mean that these areas were required to trade with Birka, and indicates a higher level of administrative complexity and power, than normally is attributed this region in the Viking Age. As the system survived the demise of Birka, and continued on in Sigtuna, it supports continuity between the two emporia, at least in respect to economic purposes and functions.

The origins of the Scandinavian/Islamic weight system

This short study of the types of weight and metrics in the Eastern European area was an attempt at discerning whether the Scandinavian/Islamic system was the result of direct influence from the Caliphate, or an adaptation to a system used by cultures closer to Scandinavia. A comparative analysis of the form elements of the Scandinavian manufactured weight types, i.e. the cubooctaedrical and the bi-polar spherical, showed that only the Volga-Bulgarian region could be associated with both.

The metrological study showed that the system of Southern Rus had been adapted to the metrics Byzantium, in a manner that separates it from the Scandinavian and the Volga-Bulgarian systems. It is also feasible that the Islamic elements in the metrics of Southern Rus were the result of adaptations to the systems of the Khazars and/or the Volga-Bulgarians, rather than to the Caliphate. Within the Eastern European area, it again seems the Volga-Bulgarian system stood model for the metrics of the Scandinavian/Islamic system. It is therefore probable that they acted as the transmitter of the system, even if a direct influence from the Caliphate can’t be ruled out completely.

Suggestions for future research

As the system also was implemented in Sigtuna, it indicates that the break in trade with Islamic silver didn’t affect the market mechanisms to any greater extent. It has been suggested earlier, including by my own research, that the abandonment of Birka and move to Sigtuna was part of a larger shift in the paradigm of the region. That might still be true in regard to politics and religion, but not in the field of commerce and collection of fees, it would seem.
One great novelty though, was the advent of minting in Sigtuna. How this related to the dual metrics system could be an interesting field of further study.

There’s also a possibility of mapping the geographical extent of influence for the rulers of Birka, by identifying the regions where the Birka mitqal was used in a single metrics system. Such a system wouldn’t have been adopted independently, since it would complicate trade with parties outside the system, hence implying the region was in some form subject to whoever also ruled over Birka.

I also touched briefly upon the problem of the slightly irrational 0.80 g unit of Sperbers Scandinavian/Islamic system. It is supposed to have represented $1/16^{th}$ of the superior 12.70 g unit (3 mitqal), but the mathematics doesn’t add up. As metric units are the result of an absolute relation to another unit, they should in theory be exact; deviations being the unwanted by-product of imperfections in the physical expression of metrology (scales and weights). The 0.80 g unit should therefore have been 0.794 g, which in consequence means that the Birka mitqal would have been 3.968 g in mass. A re-analysis of the weights already identified as belonging to the Birka mitqal, gave inconclusive results on this matter. Were it to be corroborated; it could imply correlations to other systems, apart from the Islamic. However, since the only effect on the hypothesis of this thesis would be a correction of the margin extracted, I left this issue to be studied by future research.
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**Personal messages**

