**[Supplementary material]**

**Sources of early Islamic silver: lead isotope analysis of dirhams**

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**OSM 1 Materials and methods**

The total dataset includes lead isotope data relating to 143 coins and elemental data relating to 142 (Tables S1–S4).

The dirhams analysed in this study were selected to encompass the four major geographical regions of the Caliphate (North Africa, Iraq, Iran and Central Asia) during the period AD 700–900, with particular emphasis on the most prolific mints during the periods of high output. We rely on global and relative numbers based on databases of documented dirham hoards as a proxy for mint output: though there may be inherent biases in this approach, this is the only available method that can be applied to dirhams from this period. Priority was given to the chief mints: Wasit and Damascus in the Umayyad period, and Baghdad and Tehran in the Abbasid period. Using the data from Gert Rispling’s dirham database, Wasit was the primary Umayyad dirham mint, making up two-thirds of Umayyad dirhams of identifiable mint, and 88 per cent of dirhams struck after AD 722 (104 AH). Dirhams struck at mints in Baghdad and Tehran comprise 56 per cent of known Abbasid dirhams (Noonan 1986). The peak of early Abbasid dirham production occurred in the last quarter of the eighth century to the first decade of the ninth century AD, and we mirror this concentration in our dataset.

The majority of the sampled dirhams were whole and all could be identified by mint, dynasty and date of issue (in some instances, to a defined window of time, rather than a specific year). These important identifying traits had already been identified by curators and were independently reviewed by Jani Oravisjärvi. In most cases, the second identification confirmed earlier ones, occasionally adding further detail. In the case of coins sampled in a previous study (Bychkov 2011), some previous identifications were overturned.

The analyses of 111 dirhams sampled for this study stem from three separate collections (Tables S1–S4). In most cases, the archaeological context of the original find circumstances is unfortunately unknown. Where documentation is more complete, the dirhams can be shown to derive from silver hoards deposited in Scandinavia in the ninth century: this is likely to be the case with most of the dirhams bereft of archaeological context, since they all stem from European museum collections. The datas*et al*so includes a small number of dirhams metal-detected from the Viking-Age town of Hedeby (Schleswig, modern-day Germany) and from the winter camp of Torksey, Lincolnshire, England, occupied by the Viking Great Army in AD 872/3. The latter are fragmentary, but sufficient information survives for their dynasty, mint and date to be established.

Permission to sample was granted by Adi Popescu (Fitzwilliam Museum, University of Cambridge), Luke Treadwell (Faculty of Oriental Studies, University of Oxford) and Frida Ehrnsten (Coin Chamber, National Museum of Finland, Helsinki).

***Fitzwilliam Museum, University of Cambridge***

24 dirhams were analysed by nanosecond laser ablation multicollector inductively coupled plasma mass spectrometry (nsLA-MC-ICPMS).

***Faculty of Oriental Studies, University of Oxford***

58 dirhams were sampled (i.e. <30mg of material was taken from the coin edges).

***Coin Chamber, National Museum of Finland, Helsinki***

29 Abbasid dirhams were sampled (i.e. <30mg of material was taken from the coin edges).

**Methods**

**University of Oxford**

*Elemental analysis (School of Geography)*

Samples of 87 dirhams were taken for solution-based quadrupole ICP(Q)MS. All samples were cleaned of corrosion by abrasion and were analysed by portable X-ray fluorescence (Thermo Scientific Niton™ XL3T Analyzer) prior to sample dissolution. The elemental concentrations of a 26-dirham subset and the analytical methods have been published (Merkel 2021).

*Lead isotope analysis (Department of Earth Sciences)*

Solutions were prepared in the clean suite laboratory, and the analytical methods have been published (Standish *et al*. 2021). All Pb isotopic data have been normalised using the bracketing standard measurements to 208Pb/206Pb = 2.16701, 207Pb/206Pb = 0.91459, and 206Pb/204Pb = 16.9356 for NIST981. The average non-normalised values of NIST981 and normalised values of NIST SRM982 on the measurement days are listed in Table S12. The long-term variability of NIST981 over 1.5 years, expressed as 2SD, are 0.004 for 206Pb/204Pb, 0.005 for 207Pb/204Pb, 0.018 for 208Pb/204Pb, 0.0001 for 207Pb/206Pb and 0.0003 for 208Pb/206Pb.

**University of Southampton**

*Lead isotope and Au, Pb and Bi concentration analyses*

A total of 24 dirhams were analysed to capture, simultaneously, lead isotope ratios and Au, Pb and Bi concentrations by *in situ* nanosecond laser ablation (nsLA)-MC-ICPMS. Eight of these were published in a pilot study using this method (Standish *et al*. 2021).

**Additional dirham lead isotope datasets**

We merged this new data with 32 previous lead isotope analyses of dirhams.

The first lead isotope analysis of an early Islamic silver dirham used thermal ionisation mass spectrometry (TIMS) (Brill & Shields 1972). The analytical errors are described as 206Pb/204Pb = 0.6%, 208Pb/207Pb = 0.4% and 206Pb/207Pb = 0.3% (Brill & Wampler 1967).

Ten analyses of Abbasid-period dirhams were published in 2008 (Sarah 2008). Elemental concentrations were measured by LA-ICPQMS. The analytical uncertainties for elemental characterisation are described as < 5% in most cases and < 10% in all cases for the seven main and minor elements found in silver (Ag, Cu, Zn, Sn, Au, Pb and Bi) (Sarah *et al*. 2007*)*. Lead isotope ratios were measured with TIMS at the BRGM using physical samples (protocols, see Pomiès *et al*. 1998). The reported errors based on repeat analyses of samples and standards are 0.12% for 206Pb/204Pb, 0.16% for 207Pb/204Pb and 0.22% for 208Pb/204Pb.

Twelve analyses of Abbasid-era dirhams were published in 2016 by one of the present authors (SM) (Merkel 2016). Lead isotope ratios were measured by *in situ* femtosecond (fs)LA-MC-ICPMS. Variation during measurement is usually < 0.1% (2RSD) for 204Pb normalised ratios and < 0.05% for non-204Pb ratios. Elemental concentrations were measured by *in situ* nsLA-ICPQMS and uncertainties, given as 95% confidence intervals, were between 5–10% relative to the measured value for most elements.

The final set of nine analyses were provided by Natasha Eniosova as part of a study carried out at Lomonosov State University, Moscow (Bychkov 2011). Micro-samples were taken and analysed by ICPMS (Thermo Scientific™ Element). The results were normalised to 100 wt. %. For lead isotope analysis, 5mg samples were digested and the matrix was separated using anion exchange chromatography (Bio-Rad AG-1X8 resin) with dilute HBr and HCl. Analysis was undertaken by MC-ICPMS (Thermo Scientific™ Neptune) at the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry Russian Academy of Sciences (for methods, see below). Thallium was used to correct for mass fractionation (205Tl/203Tl = 2.3889±1) and long-term variability of NIST SRM981 over a three-year period are <0.02% (2SD) for 206Pb/204Pb, 207Pb/204Pb and 208Pb/204Pb. The reported NIST981 values are 208Pb/206Pb = 2.1677, 207Pb/206Pb = 0.91489, and 206Pb/204Pb = 16.9412.

**Theoretical basis for provenance studies of silver**

The use of geochemical signatures to characterise and provenance silver have been ongoing since the 1970s. Such efforts have relied largely on lead isotope analysis, a technique that measures the relationships between the radiogenic isotopes and the non-radiogenic isotope of lead, revealing detailed information about geologic age and ore genesis (Stos-Gale 1993; Stos-Gale & Gale 2009). Lead occurs naturally in silver ore and contains geochemical source-related information in its isotope ratios. The lead isotope ratios of end-products (e.g. silver coins) can be directly compared to those of ores, allowing potential sources to be identified.

For silver, it is possible that the lead isotope ratios directly relate to the source of metal. However, two anthropogenic processes can alter the lead isotope characteristics of silver, compromising the use of lead isotope analysis in provenance studies: mixing and cupellation.

* **Mixing**: mixing, through the recycling and melting down of metal from two or more sources, results in the homogenization of lead isotope ratios. In lead isotope diagrams, the isotopes of items produced from two mixed sources will plot along ‘mixing lines’ between the two sources (end-members) (Pernicka 2014). The mixing of three or more sources will produce a polygon region; items produced from this silver must lie in the volume of isotope space between the end-members, their precise position reflecting the relative contribution of each source.

Mixing also effects the calculated model ages (*T*) and U/Pb (*µ*) and Th/Pb (*κ*) ratios (Albarède *et al*. 2012). It has been noted that ore formation processes tend to produce isochron lines that relate *T*, *µ* and *κ*. An archaeological silver stock that matches the isochron defining a specific ore deposit could originate from that ore, but if the metal stock trends crosses several isochrons, it is more likely that mixing of ore sources occurred (Eshel *et al*. 2019). Therefore, the alignments of *T*, *µ* and *κ*, in comparison to know ore source alignments are important factors in identifying potential sources and mixing of metal stocks.

* **Cupellation**: cupellation is a process of refining impure silver. It involves the heating of silver with additional lead so that the lead reacts with oxygen to form a litharge. The litharge remains separate from the noble metal and can be drained or skimmed off to leave behind purified silver. Since the lead added to the silver to aid this process is far greater in quantity than that which occurs naturally within silver, the lead isotope ratios of the refined silver will reflect the source of the added lead, rather than that of the silver. This is especially detrimental to questions of provenance if the added lead and silver originate from different mining areas.

An additional limitation to the use of lead isotopes to provenance silver is ore overlap. Lead isotope ratios reflect geochemical and age-related factors of ore genesis, which are seldom unique to individual deposits. Commonly, several deposits share similar lead isotope characteristics, which means the deposits formed at similar ages and geological conditions. This often limits the resolution and interpretation of lead isotope data, especially in regions with widespread reoccurring geochemical characteristics, such as the Aegean (Killick *et al*. 2020).

However, in the case of early Islamic dirhams, these limitations are mitigated by several factors. The large size and wide geographical scope of the sampled material diminishes the risk of ore overlap, since the study area crosscuts a diverse range of geological units that formed under various conditions at different times (radiogenic future model ages to the Precambrian) and thus produces diverse lead isotope ratios with limited overlap between regions. Moreover, we find evidence suggesting a lack of both routine recycling of silver coinage and systematic cupellation at the mints over much of the study period, as described in the main text. In addition, concentration data relating to minor elements in the silver that stem from the original ore and are minimally affected or unaffected by cupellation convey additional source-related information. Gold is unaffected by cupellation, while bismuth remains in the silver until the final stages of cupellation (McKerrell & Stevenson 1972; Pernicka & Bachmann 1983; L’Héritier *et al*. 2015). The relative concentrations of these elements vary between regionally and temporally confined silver stocks, helping to further discriminate between potential sources.

Our dirham data can show correspondence between these source-indicator elements (gold and bismuth) and lead isotope characteristics, which are also dependent on geographical and chronological factors. These features point to a dynamic silver supply composed of discrete sources and reveal that mints were typically supplied with silver from a limited number of sources.

**OSM 2 Interpretation of results**

**Interpretation of lead isotope results**

Datasets were evaluated using both 204Pb and 206Pb normalised ratios. The geological history and setting of the ore are further useful parameters for distinguishing geological provinces. Alongside initial lead isotope (LI) values, we therefore also considered U and Th concentrations (expressed as 238U/204Pb (μ), 232Th/238U (κ)) and the model age (*T*) of lead in the silver (Albarède *et al*. 2012). The data were compared against ratios derived from regional ores and archaeological artefacts. Large collections of analyses have been combined into databases (e.g. Killick *et al*. 2020; OXALID database: Sasanian) we specifically considered data from Spain, North Africa, the Mediterranean, the Arabian Peninsula, the Near and Middle East, the Caucasus and Central Asia. Emphasis was given to sources with archaeological or historical evidence of use in the medieval or earlier periods, and ore and slag from lead-bearing polymetallic deposits known to contain significant quantities of silver were prioritised. We make the assumption that mints would have had a preference to use the nearest sources of metal and that these should first be excluded before considering more distant sources and sources in territories controlled by other political entities. The data are interpreted within their historical context and interpretations are made using abductive reasoning, starting with a set of observations and then seeking to find the simplest or most likely explanation, often through a process of elimination. Only lead isotope data obtained by MC-ICPMS and TIMS were used for comparison and, due to differences in methodology and analytical sensitivity, a range of tolerability of +/- 0.1% for 204Pb normalised ratios was given.

The following data sources, grouped by region, provided critical reference data:

Central Asian ore

Ore (tetrahedrite and secondary minerals) from the Laskherek mine (Merkel 2016)

Ore data from Middle Tien Shan west of Talas-Farghona fault (MTS-W) (Chiaradia *et al*., 2006)

Galena (with common lead) Chatkal-Kurama district (Chernyshev *et al*. 2017)

Arabian ore and slag

Ore and slag from Pb-Zn-Ag mine of Jabali (Merkel *et al*. 2016)

Ore (galena) Arabian Shield (Stacy *et al*. 1980)

Ore from Pb-Zn-Ag mine of Jabali (al-Ganad 1991)

Iranian ore, litharge, slag and Sasanian metalwork

Sasanian silver plate, only ‘good’ quality and better (OXALID)

Ore data Urumieh-Dokhtar and Sanadaj-Sirjan Zones in Iran (Mirnejad *et al*. 2011)

Ore data Alborz and Central Iran (Mirnejad *et al*. 2015)

Ore data Iran, various (Molasalehi & Mirnejad 2010)

Lead ore and slag Nakhlak (Pernicka *et al*. 2011)

Ore and slag Iran, various (Stos-Gale 2004)

North African ore and slag

Ore, Pb-Zn, Nappes zone Tunisia (Jemmali & Souissi 2018)

Ore, Ag-Hg deposit Zgounder, Anti-Atlas Morocco (Marcoux & Wadjinny 2005).

Ore, galena and secondary minerals, Morocco (Duthou *et al*. 1976)

Ore, Cu-Pb-Zn veins, Bouskour, Anti-Atlas, Morocco (Bouadbellah *et al*. 2016)

Ore, galena, Ag-Hg deposit Imiter, Anti-Atlas Morocco (Pasava 1994)

Ore and slag, Ag-Hg deposit Imiter, Anti-Atlas Morocco (Milot *et al*. 2018)

Ore and slag, Morocco, various (Baron *et al*. 2020)

Ore, polymetallic, Tighza Central Morocco (Tarrieu 2014)

Taurus ore, litharge and metalwork

Ore and slag, Taurus Mountains (Seeliger *et al*. 1985)

Metal artefacts, Turkey, Syria, Iraq (Sayre *et al*. 1992)

Ore and metal artefacts, Turkey (Yener *et al*. 1991)

Ore and litharge, Northern Syria (Pernicka *et al*. 1998)

**Use of elemental legacy data**

The first multi-element characterisation of Early Islamic dirhams was undertaken in the late nineteenth century (Fiala 1895). Since then, hundreds of dirhams have been subject to elemental analysis, using numerous analytical techniques with varying levels of quality and resolution. The primary motives for analysis have been to explore the use of dirhams as a raw material for western European coinage (McKerrell & Stevenson 1972; Ilisch *et al*. 2003; Sarah 2008; Merkel 2016) to determine silver fineness with an aim to reconstructing economic policy (Caley 1957; Gordus 1972; al-Saa’d 1999; Ilisch *et al*. 2003) and to identify patterns that relate to technological processes, metal stocks and/or ore sources (Brill & Shields 1972; Gordus 1972; Stos-Fertner 1975; Gondonneau & Guerra 2002; Ilisch *et al*. 2003; Bychkov 2011; Murillo-Barroso *et al*. 2012; Merkel 2021; Standish *et al*. 2021). These datasets have been important in developing the research trajectory of the Late Antique and Early Islamic economy and form a rich resource for the present study.

The large datasets obtained through dirham studies carried out over the last half century (particularly Caley 1957; Gordus 1972; Stos-Fertner 1975; Roux & Guerra 1998; Savage & Gordus 1998; al-Saa’d 1999; Gondonneau & Guerra 2002; Ilisch *et al*. 2003; Murillo-Barroso *et al*. 2012) were frequently consulted and were instrumental in the sample selection process, identifying temporal and regional patterns and influencing the interpretation of the analytical results.

Nonetheless, the diverse range of instrumentation, methodology and levels of awareness of analytical shortfalls can limit the direct comparability of many of these legacy data with the data presented in this study. For this reason, we have divided legacy datasets into three categories, according to the usability of the data: 1: quantitative, 2: qualitative, and 3: incompatible/unreliable.

*1: Quantitative/thorough studies*

Weight was given to studies using well-tested methods with published numerical values that are expected to be reliable and comparable. These data include minimally destructive LA-ICPMS (Sarah 2008) and studies where silver objects were destructively sampled for measurement by atomic absorption spectrometry (Caley 1957; McKerrell & Stevenson 1972; Murillo-Barroso 2012). They also include studies in which the analysts made efforts to counteract methodological shortfalls by abrasively polishing the area of analysis (al-Saa’d 1999) or micro-drilling (Harper & Meyers 1981). Photon activation analysis has the advantage of penetrating 300µm deep into the metal and can circumvent problems affecting other surface methods, and this method was applied to the study of pre-Islamic and Islamic silver coinage (Roux & Guerra 1998; Gondonneau & Guerra 2002).

*2: Qualitative/descriptive studies*

One of the most important issues is the incongruity of superficial surface compositions and the bulk metal. Numerous studies have shown that concentration of elements at the surface of silver objects can be impacted by enrichment and depletion processes to an uncertain degree (Condamin & Picon 1964; Meyers 1993; Beck *et al*. 2004; Merkel 2019). Two of the most sensitive elements in this regard are copper and gold, but mercury is also problematic for Islamic coinage. Copper is often depleted from the surface and gold often enriched. The concentrations of other elements can also have a degree of unpredictability, some uncertainty arising from enrichment/depletion process, superficial contamination and/or analytical interference. The problems are particularly relevant for widely used non-destructive surface-based analytical techniques, such as energy and wavelength dispersive X-ray fluorescence (XRF). Even the measurement of reference materials cannot ensure the reliability of non-destructive surface analyses because the reference materials were not subject to the same burial and treatment conditions as archaeological metals. Furthermore, archaeological metals are not all impacted to the same degree. For these reasons, non-destructive analyses of unprepared silver surfaces were used as a qualitative comparison (Stos-Fertner 1975; al-Kofahi *et al*. 1997; Ilisch *et al*. 2003). These problems can also apply to neutron activation analysis (NAA) performed on coin streaks if the surface is not first prepared by abrasive cleaning (Gordus 1972; Harper & Meyers 1981; Savage & Gordus 1998). In the case of NAA, these differences between the surface and the bulk are visible, though often minor.

*3: Incompatible and/or unreliable studies*

A recently published study of Umayyad dirhams using particle-induced X-ray emission (PIXE) (Jozi *et al*. 2019) is problematic because the reliability of the method was not demonstrated, and the results are highly inconsistent with the research of others using established methods. The results are thus judged to be unusable in a wider context.

Inter-laboratory compatibility

The data gathered in this study originate from different laboratories using differing analytical methodologies. While several studies were undertaken entirely independently, others can be directly compared through the analysis of common reference materials, which allow the evaluation of inter-laboratory comparability. Next to the universal lead isotope standards NIST981 and NIST982, a series of in-house and commercial reference materials were created and/or obtained (Tables S12–S17). Samples from two early medieval artefacts were used as secondary reference materials (RMAg3834 and RMAg12467) and have been characterised in four of the six laboratories used in this study. Additionally, these two secondary reference materials were independently characterised isotopically and elementally in a previous study (DBM-Bochum and Goethe-University Frankfurt-am-Main Department of Geoscience) (cat. nos. 180 and 187 in Merkel 2016).

***Lead isotope analysis***

All multi-collector ICPMS datasets used in this study are linked directly or indirectly to the lead isotope standard NIST981. The primary lead isotope standard for solution-based MC-ICPMS (Oxford/Moscow/Frankfurt-am-Main) is NIST981 and for the fsLA-MC-ICPMS analyses (Hanover), micro-homogenised silver doped with NIST981 was used (Chernyshev *et al*. 2007; Merkel 2016). The datasets from Frankfurt-am-Main, Oxford and Hanover are linked to common NIST981 values (Todt *et al*. 1996). The University of Southampton data are indirectly linked to the same values through calibration using RMAg3834 measurements in Frankfurt-am-Main and Hanover (Standish *et al*. 2021). In comparison, the reported NIST981 204Pb-normalised ratios connected to the Moscow dataset (Bychkov 2011; Chernyshev *et al*. 2007) are heavier (c. 3%), so there is expected to be a slight offset towards higher 204Pb-normalised ratios, but the difference in the non-204Pb ratios is much smaller (-0.03%).

The best-characterised secondary reference materials are two archaeological silver fragments (RMAg3834 and RMAg12467) and allow isotopic results from three of the six laboratories to be directly compared (Figure S2). The analyses of these archaeological samples are identical (within analytical uncertainty) in each laboratory (Frankfurt-am-Main, sol. MC-ICPMS; Oxford, sol. MC-ICPMS; Hanover fsLA-MC-ICPMS; Southampton, nsLA-MC-ICPMS). Additionally, further reference materials were measured in both Southampton (nsLA-MC-ICPMS) and Oxford (sol. MC-ICPMS) and are all within their analytical uncertainty (2SD) (Figure S3). This confirms that the results from three laboratories used in this study are comparable.

The two datasets analysed by TIMS (Brill & Shields 1972; Sarah 2008) do not report the results of lead isotope standards, but the dirham results closely conform to the geochemical trends observed in the MC-ICPMS datasets. They are therefore deemed to be reliable within their reported analytical uncertainty.

***Elemental analysis***

The elemental datasets from four of the laboratories can be compared directly by using two archaeological silver samples used as secondary reference materials (RMAg12467 and RMAg3834). They were analysed with solution and surface-based laser ablation techniques. In addition to the analyses from four of the laboratories used in this dirham study, these reference materials were analysed independently at the DBM-Bochum by ICPMS (Merkel 2016). The results are highly consistent for most elements, despite major differences in the analytical methodology (Figure S4). Measurement uncertainty of the main source-related elements (Au and Bi) and the Bi/Pb ratio are better than 25% (2RSD). Variation of less than 20% (2RSD) can be assumed for the reproducibility of most elements in reference materials MBH 133x-AGA1 and AGA3 by comparing the results from Oxford (sol. ICPQMS) and Southampton (nsLA-MC-ICPMS) and the MBH given values (ICPOES) (Figure S5). Although the analyses from the Moscow laboratory cannot be directly compared with the other datasets through the analysis of joint reference materials, the dirham results are consistent with those analysed in other laboratories, within the variation describe above, and follow the same geographic and temporal trends.

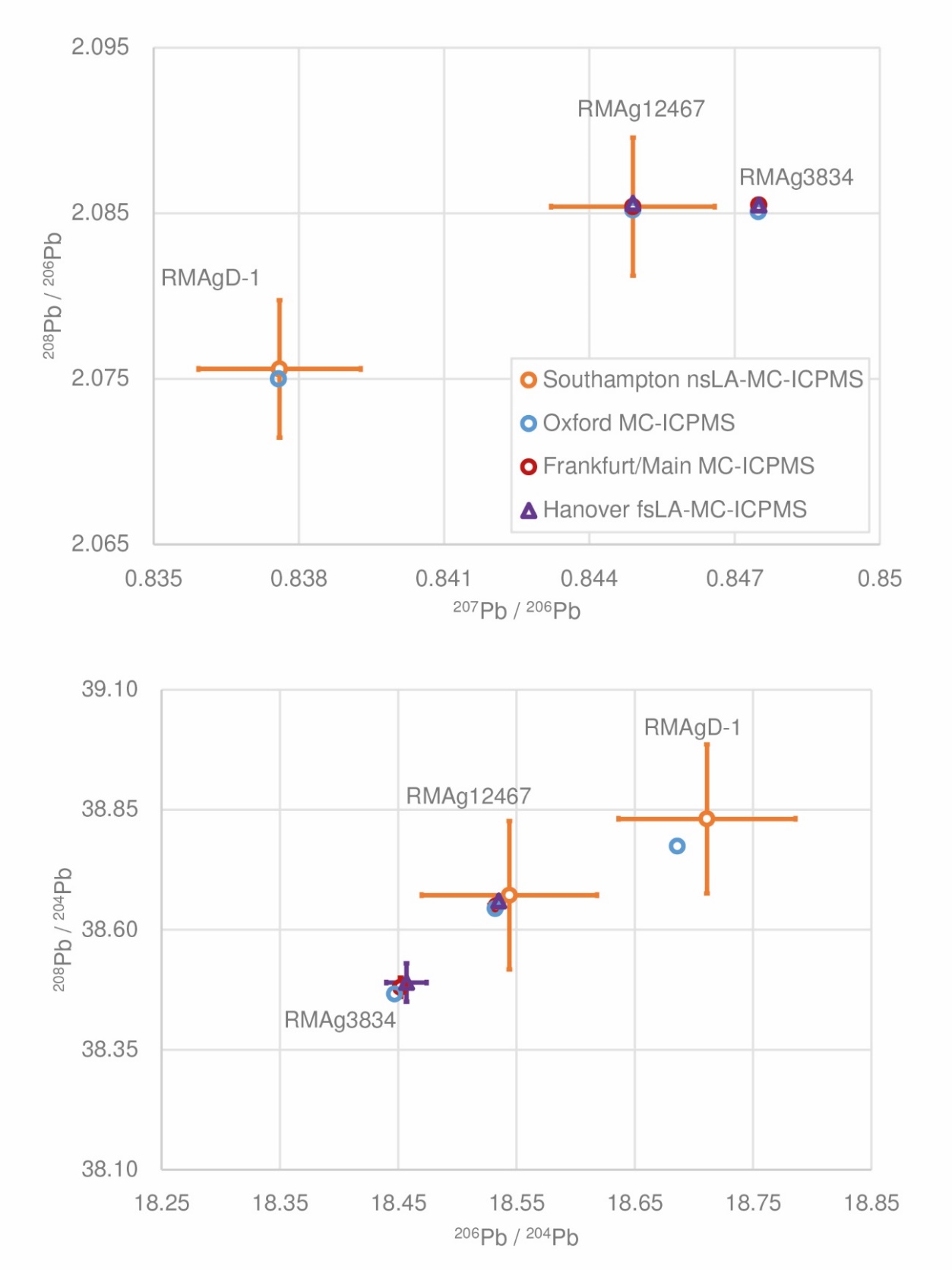
***Conclusions***

Acknowledging the analytical uncertainties inherent to the methods used, all elemental and lead isotope datasets used in this study are concordant, and the geochemical patterns seen in the data crosscut laboratory and methodology. In four of the five laboratories contributing dirhams elemental concentration datasets, the inter-laboratory propagated uncertainty for the main source-related elements (Au and Bi and Bi/Pb) can be estimated to be ≤30% (2RSD). Where the comparability of lead isotope ratios could be directly compared through the analysis of joint reference materials, the results are shown to be reproducible within their range of long-term range precision. The chief systematic and methodologically related difference is the lower analytical precision of 204Pb-normalised ratios measured by TIMS and nsLA-MC-ICPMS compared to MC-ICPMS and fsLA-MC-ICPMS.

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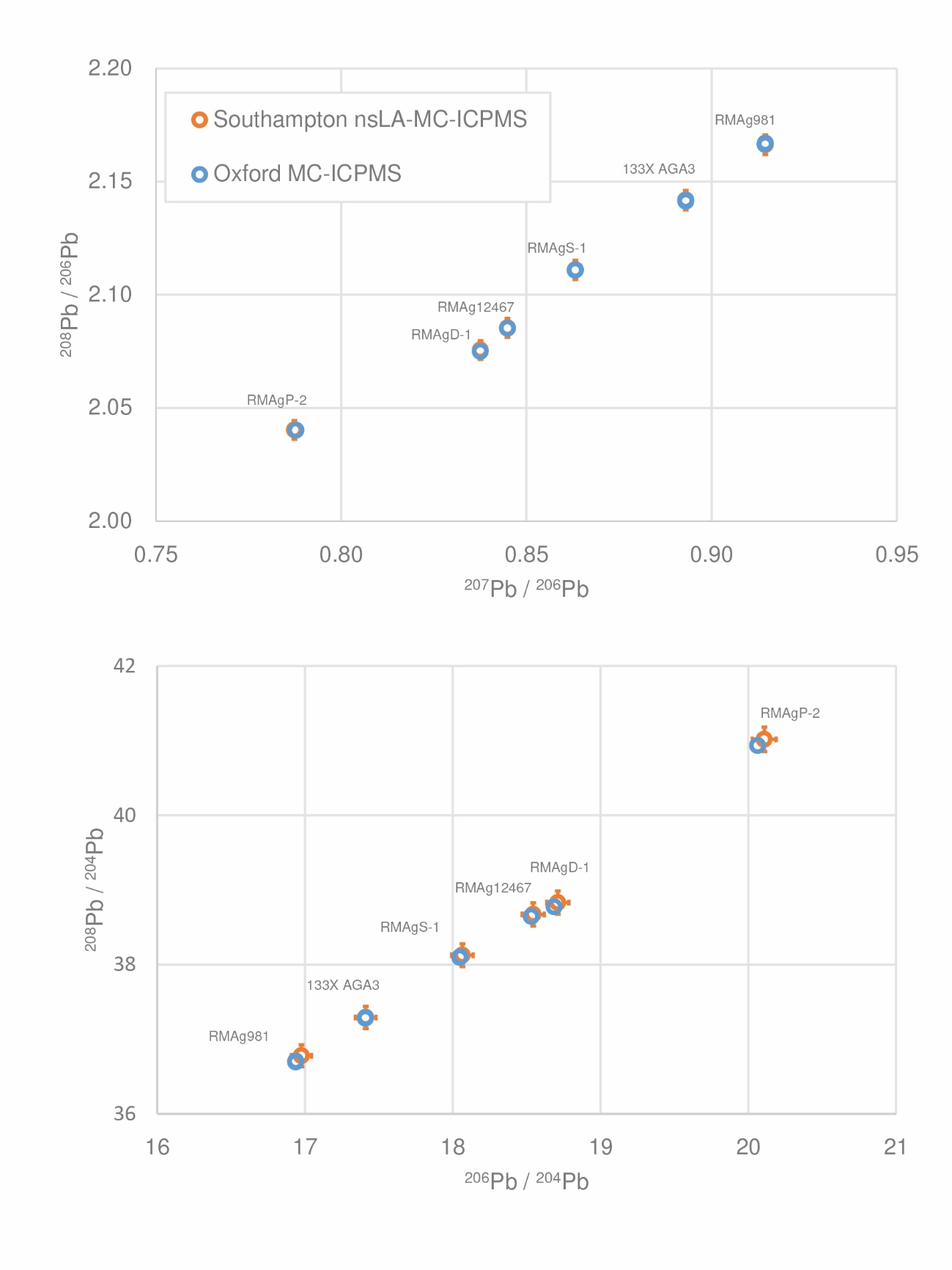
**Figure S1.** **Number of dirhams (n) analysed by decade**.

Orange = Umayyad; blue = Abbasid period *(figure by the authors)*.

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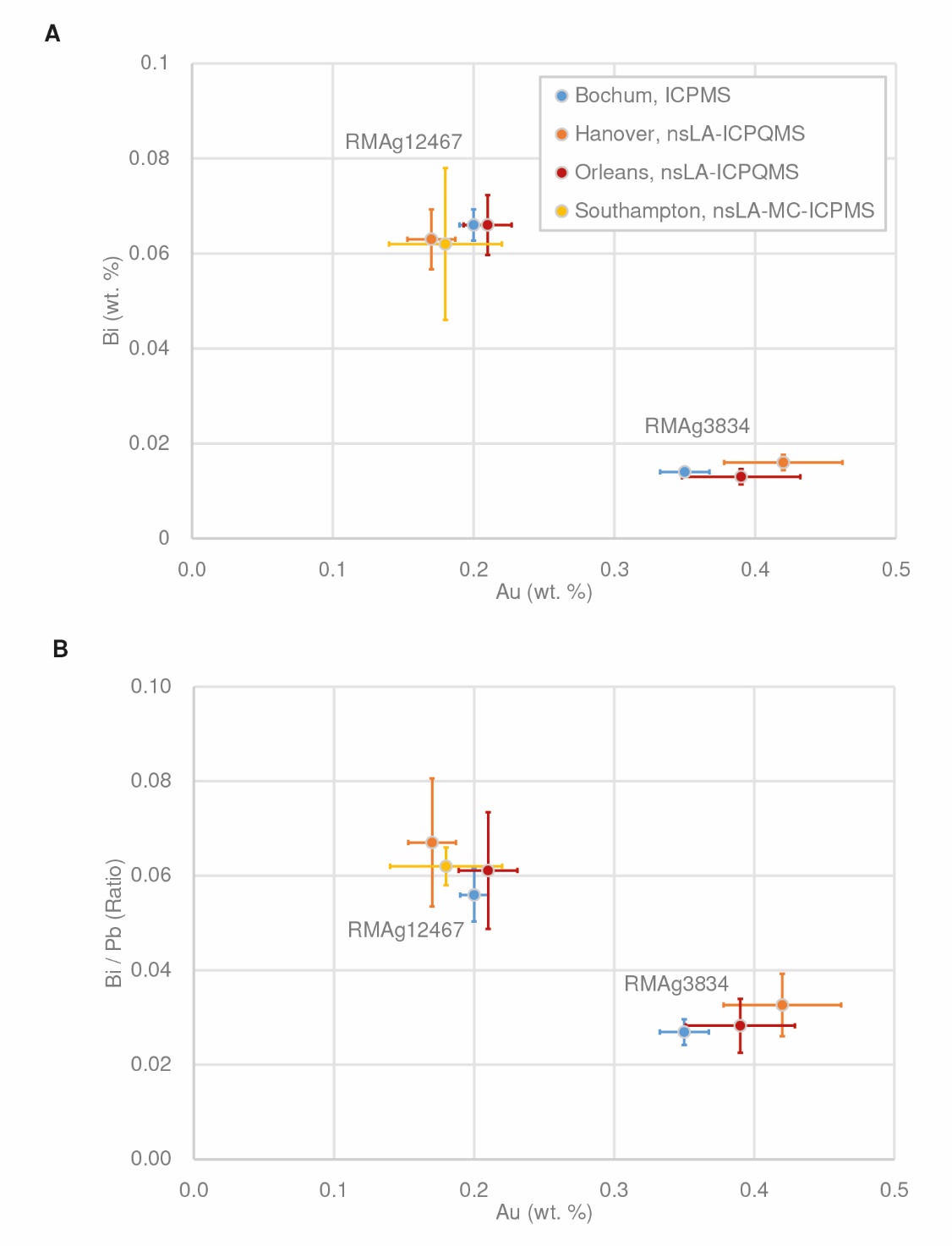
**Figure S2. Comparison of three secondary silver reference materials in four laboratories using different methods**.

The Oxford (this study and Standish *et al*. 2021) and Southampton values (Standish *et al*. 2021) are averages (uncertainties expressed as 2SD of repeat analyses), and the Hanover and Frankfurt-am-Main analyses (Merkel 2016) are single analyses (uncertainties expressed as 2SD of measurement cycles). The analytical uncertainty is smaller than the symbol unless otherwise shown *(figure by the authors)*.

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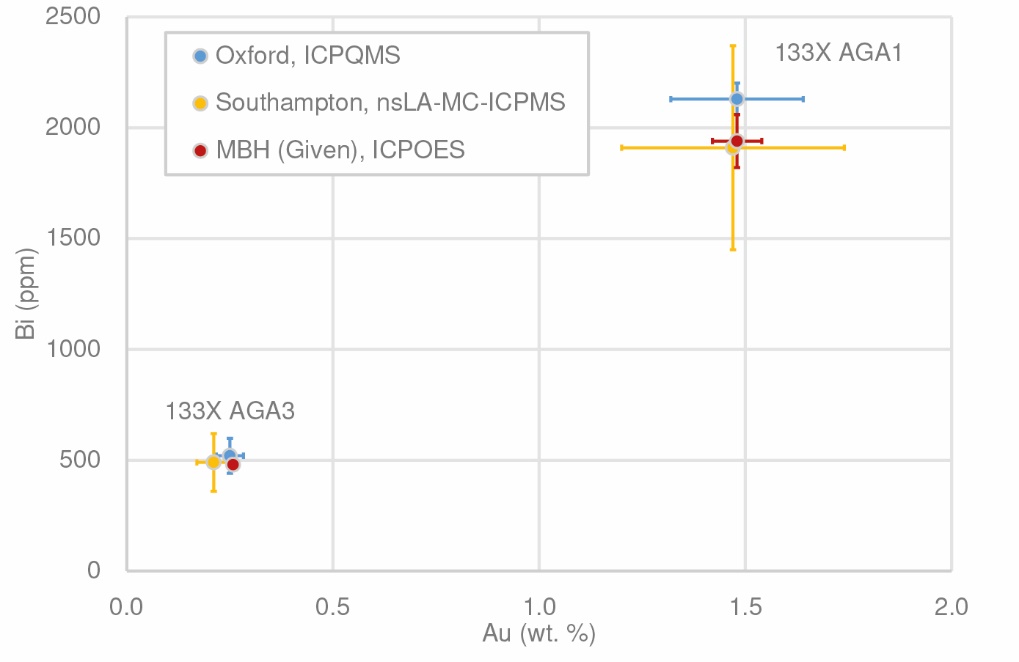
**Figure S3. Comparison of lead isotope ratios from secondary silver reference materials measured in Oxford by MC-ICPMS and in Southampton by nsLA-MC-ICPMS (**Standish *et al*. 2021**)**.

The precisions are shown as 2SD of repeat measurements, which are in many cases smaller than the symbol. The laser ablation analyses are of lower resolution but are within analytical uncertainty (2SD) of the solution measurements *(figure by the authors)*.



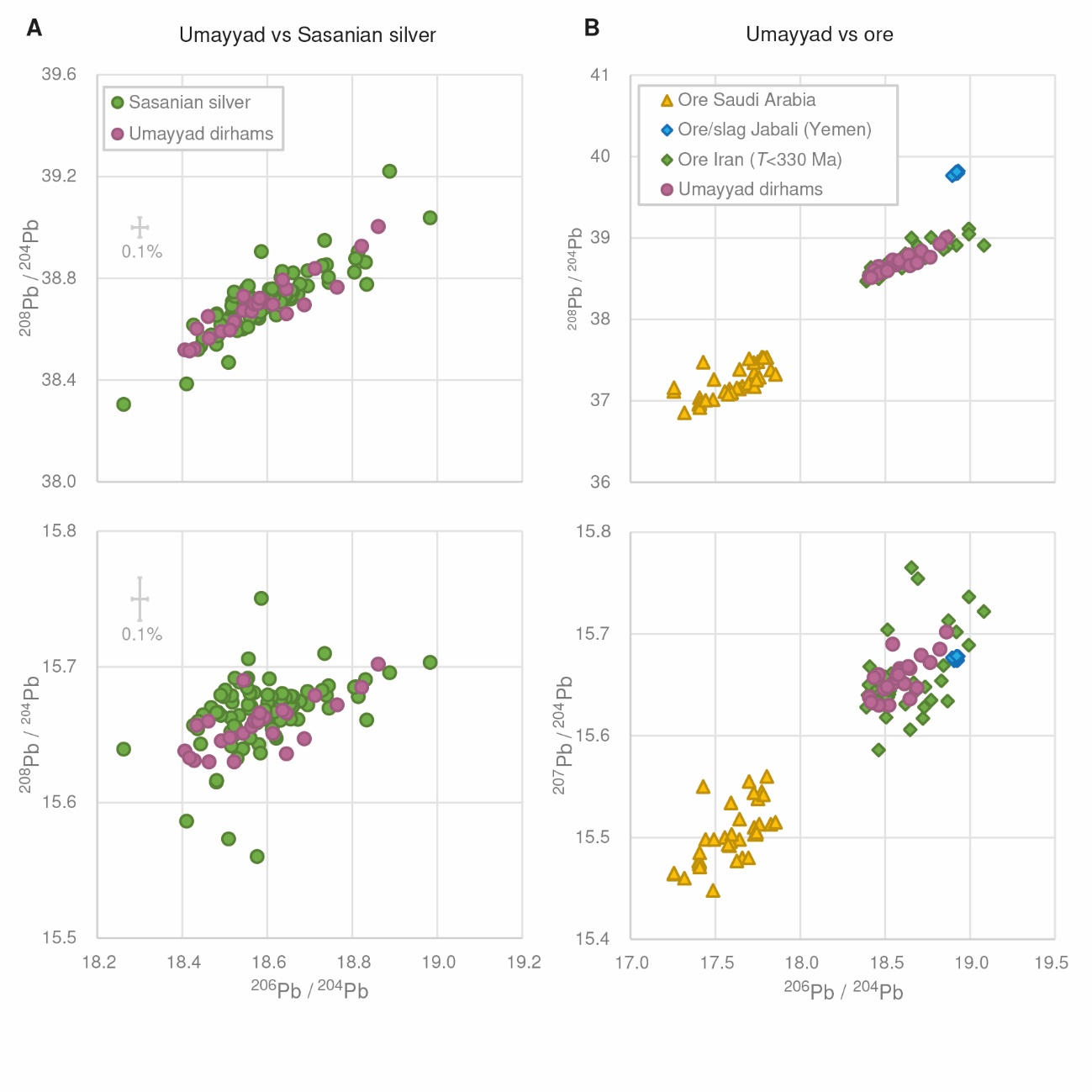
**Figure S4. Comparison of secondary reference materials (archaeological silver samples) measured in four laboratories with different mass spectrometry techniques.**

**(A)** Gold vs. bismuth and **(B)** gold vs. bismuth-to-lead ratio. RMAg3834 and RMAg12467 are Cat. 180 and 187 (Merkel 2016) and objects a and b (Merkel 2019), respectively. Uncertainty for solution ICPMS (Bochum) is estimated to be <5% and <10% for nsLA-ICPQMS (Hanover and Orleans), while for the Southampton analyses the uncertainty is represented as 2SD of replicate analyses (Standish *et al*. 2021) *(figure by the authors)*.



**Figure S5. Comparison of commercial silver reference materials MBH 133X-AGA1 and AGA3.**

Analyses by solution ICPQMS (Oxford) (this study) and by nsLA-MC-ICPMS (Southampton) (Standish *et al*. 2021) are given along with the concentrations determined by ICPOES (MBH Analytical Ltd.). Uncertainties are given as 2SD of three or more replicate analyses *(figure by the authors)*.



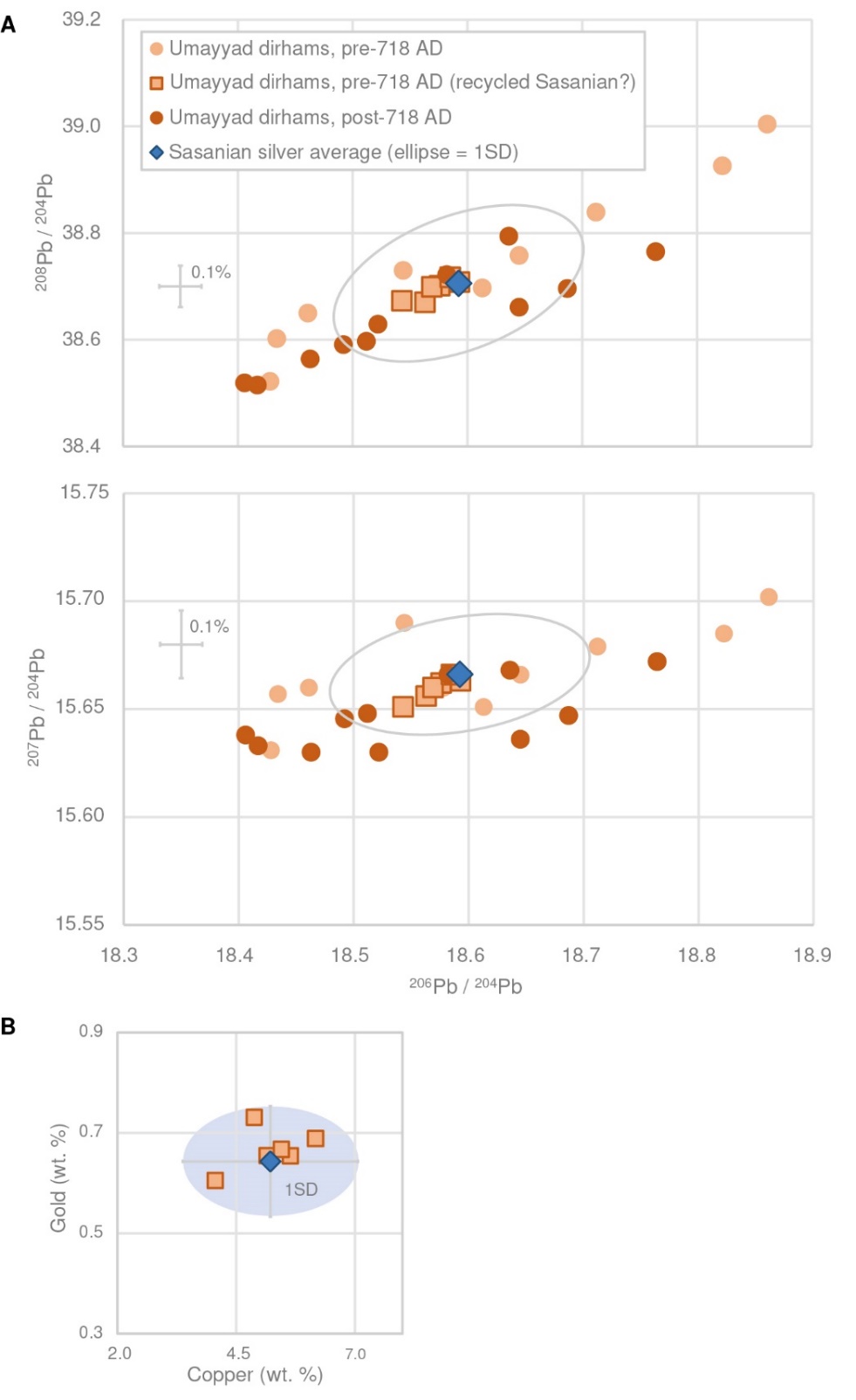
**Figure S6. Umayyad dirham and reference lead isotope datasets normalised to 204Pb.**

Supplementary data for Figure 4A. For reference, 0.1% is equal to or smaller than the symbol unless otherwise stated. For source data, see interpretation of results above *(figure by the authors)*.



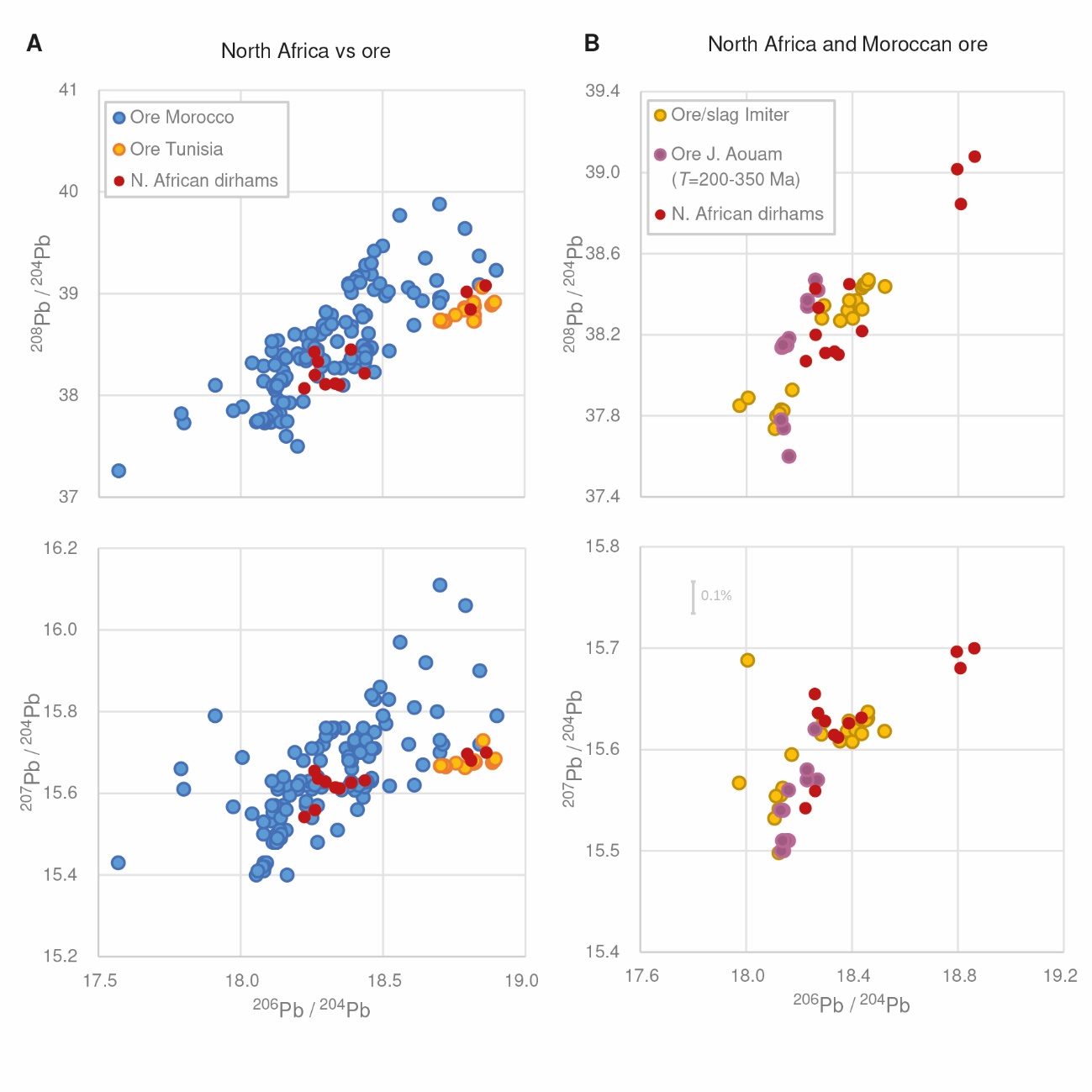
**Figure S7. Scatterplot relating copper content of coins to the minting year.**

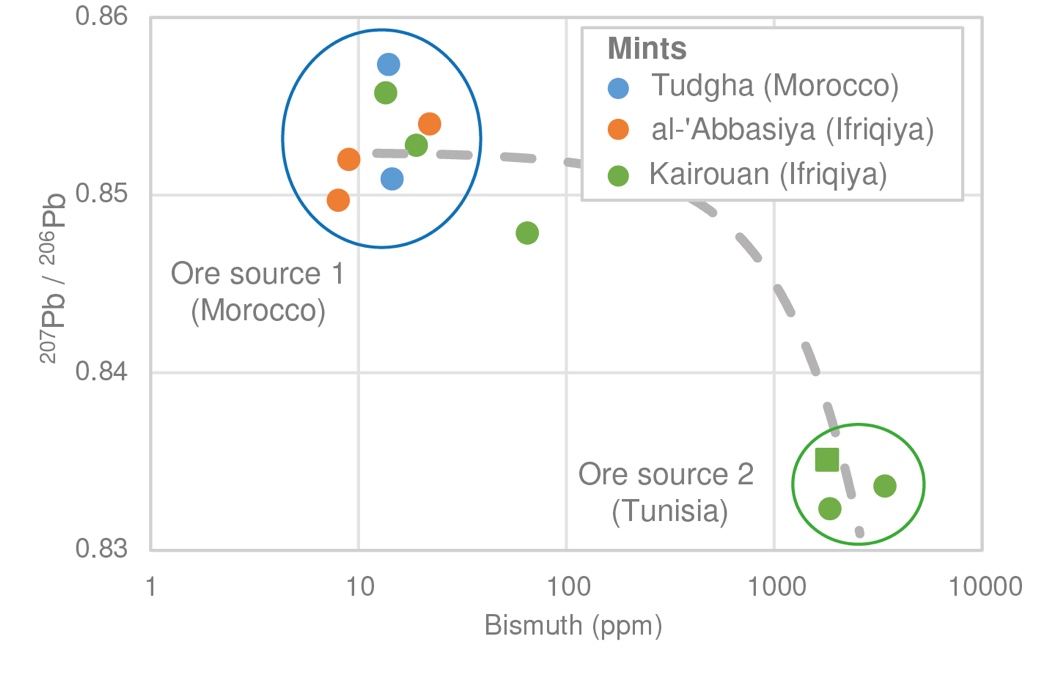
The plot demonstrates the sudden drop in copper contents (= increase in fineness) in silver coins minted at Wasit during the Umayyad period and that the data from this study is consistent with previous studies (Caley 1957; al-Saa’d 1999; Gondonneau & Guerra 2002). This shift marks the change in silver standard from alloyed silver (roughly 6% copper) to fine, unalloyed silver around the year AD 722. Wasit was the dominant Umayyad mint, comprising 67% of Umayyad dirhams of known mint and 88% of dirhams minted after *c*. AD 722 (104 AH) (source: Gert Rispling’s dirham database) *(figure by the authors)*.



**Figure S8. Lead isotope plots of Umayyad dirhams minted before and after AD 718, the year marking the transition to fine silver at the Wasit mint.**

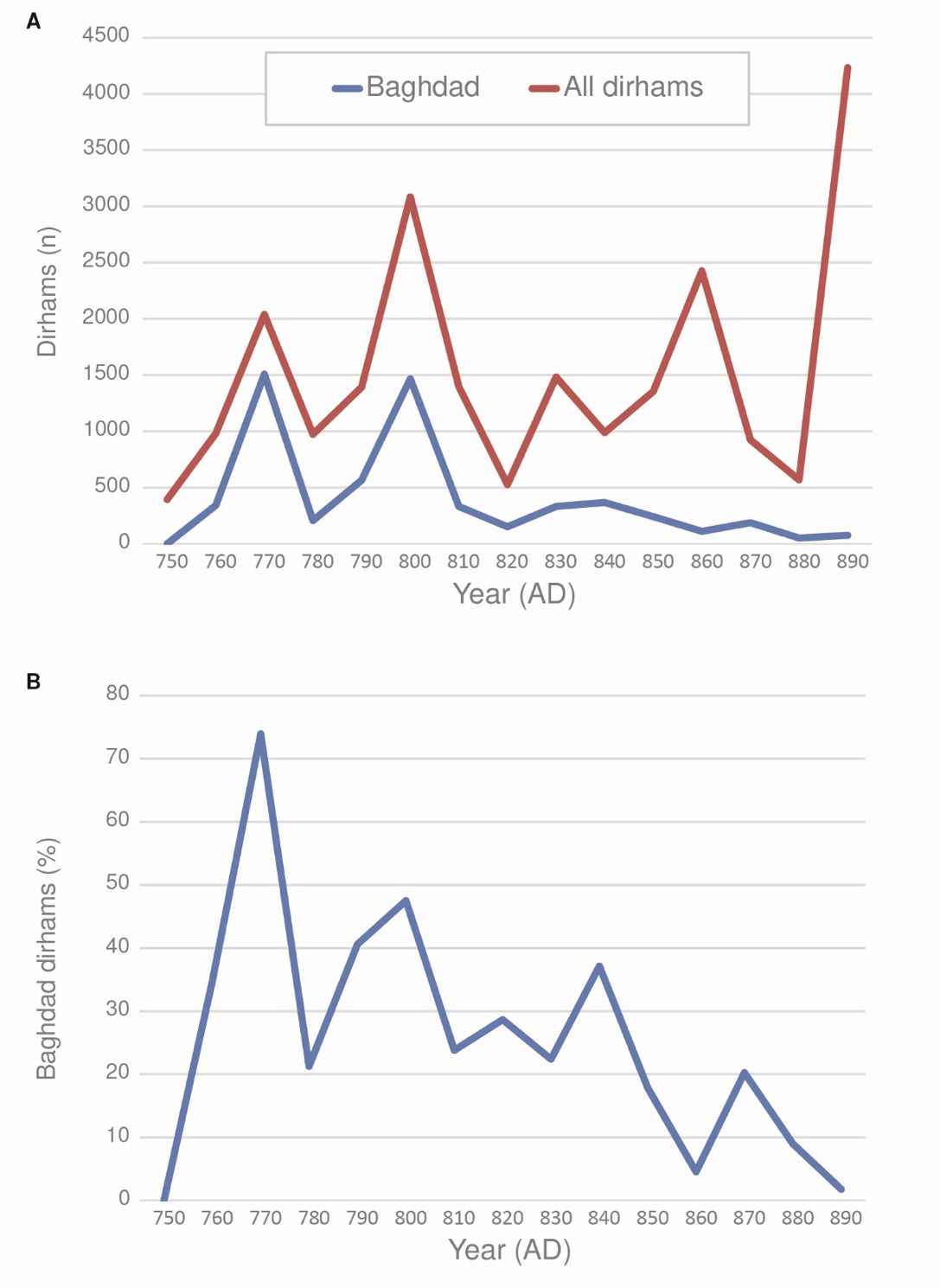
(A) The distribution of lead isotope ratios is constant over the Umayyad period. The average lead isotope ratios of Sasanian silver (Brill & Shields 1972; OXALID Sasanian) are at the centre of the distribution, but also correspond to a cluster of dirhams mostly minted before AD 718, which could reflect the recycling of Sasanian silver. **(B)** These are consistent with average Sasanian elemental compositions (Harper & Meyers 1981; Gondonneau & Guerra 2002); plate below mint quality (i.e. Cu>10%) was excluded *(figure by the authors)*.

**Figure S9. North African dirhams and ore lead isotope datasets normalised to 204Pb.** Supplementary data for Figure 4B. For reference, 0.1% is equal to or smaller than the symbol unless otherwise stated. For source data, see interpretation of results above *(figure by the authors)*.

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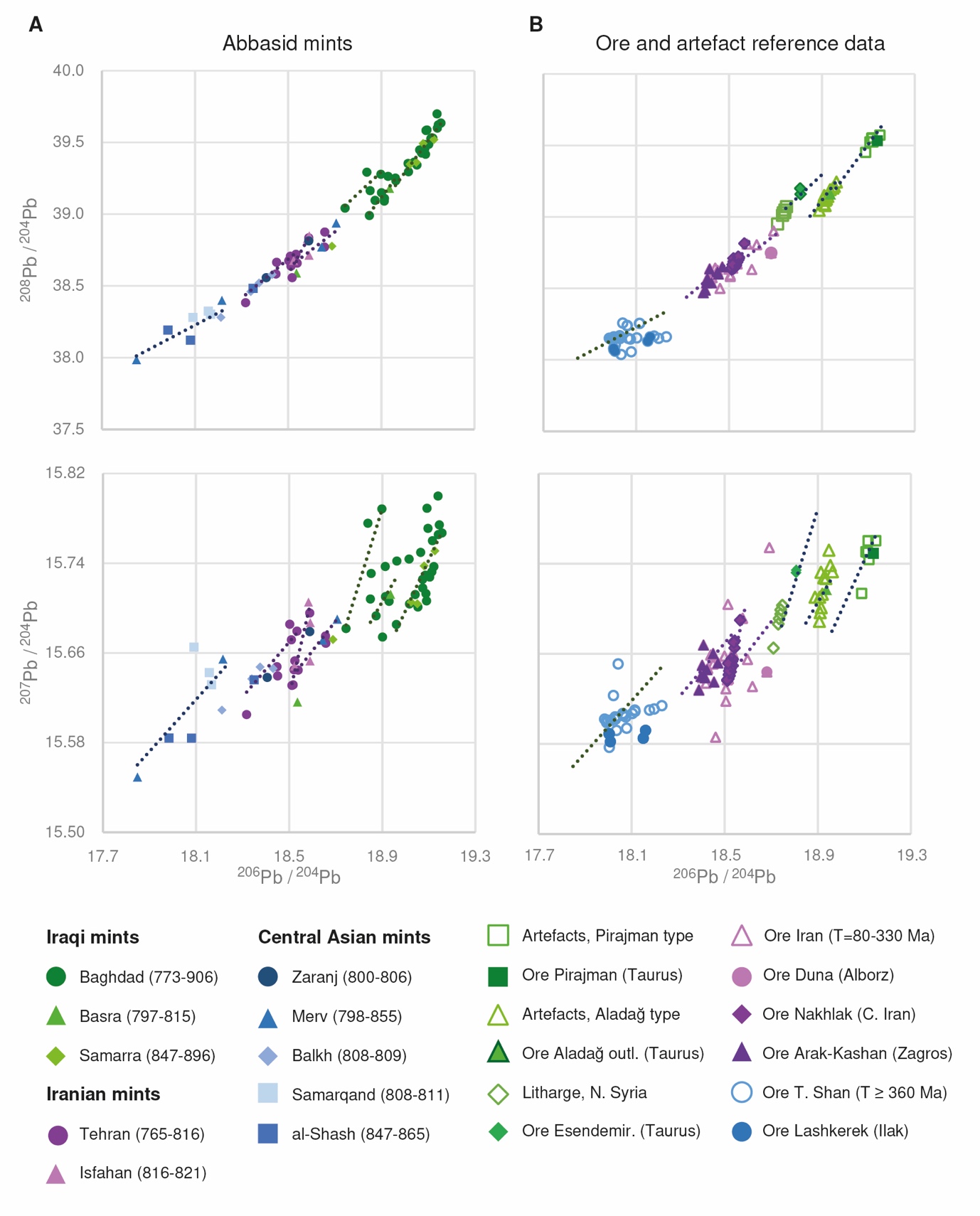
**Figure S10. North African dirhams divide into two groups based on bismuth content and lead isotope ratios**.

The dominant group is characterised by lower bismuth and has lead isotope ratios consistent with sources in Morocco, while a smaller group of dirhams minted in Tunisia has higher bismuth and lead isotope ratios consistent with ore from Tunisia. One dirham from Kairouan mint in Ifriqiya may represent a mixture of the two sources, falling near the hypothetical ‘mixing line’. The square symbol signifies that the bismuth content was measured by pXRF on a metallic surface cleaned by abrasion (see materials and methods above). For all other coins, the bismuth was measured by mass spectrometry *(figure by the authors)*.



**Figure S11. Breakdown of recorded early Abbasid dirhams per decade comparing the number of dirhams minted in Baghdad (Madinat-al-Salam) to all other dirhams.**

(A) Numbers of Baghdad issues in relation to total number of known dirhams per decade. (B) Proportion of Baghdad issues. Information is based on Gert Rispling’s unpublished database of 22,735 dirhams minted AD 750–899, found both within the Islamic lands and in Scandinavia/ Baltic *(figure by the authors)*.



**Figure S12. Abbasid dirhams and reference ore and artefact lead isotope datasets from Iraq, Iran and Central Asia normalised to 204Pb.**

Supplementary data for Figure 4. For reference, 0.1% is equal to or smaller than the symbol. The linear alignments are those of Figure 6A in the main text. For source data, see interpretation of results above *(figure by the authors).*

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| **Table S1. Summary of the data basis for this study**.  Abbreviations: Abb. = Abbasid; Um. = Umayyad; N. Afr. = North Africa; C/E prov. = central and eastern provinces (Iraq, Iran and Central Asia). The study includes lead isotope data for 143 dirhams and elemental data for 142 (all except one Umayyad coin from Syria).  **New samples** | | | | |  |
| **(n=)** | **Description** | **Elemental** | **LIA** | **Source** | **Ref.** |
| 24 | Abb., Iraq/Iran | nsLA-MC-ICPMS | nsLA-MC-ICPMS | Fitzwilliam Museum | This study; Standish *et al*. 2021 |
| 58 | Um., Abb. | ICPQMS | MC-ICPMS | Ox. Fac. Oriental Studies | This study |
| 29 | Abb., N. Afr., C/E prov. | ICPQMS | MC-ICPMS | Coin Chamber Helsinki | This study |
|  |  |  |  |  |  |
| **Previous studies** | | | | |  |
| 1 | Um., Syria | - | TIMS | - | Brill & Shields 1972 |
| 10 | Abb., N. Afr., C/E prov. | LA-ICPQMS | TIMS | - | Sarah 2008 |
| 9 | Um., Abb., Iraq/Iran | ICPMS | MC-ICPMS | - | Bychov 2011 |
| 12 | Abb., N. Afr., C/E prov. | LA-ICPQMS | fsLA-MC-ICPMS | - | Merkel 2016 |
|  |  |  |  |  |  |

**Table S2. List of Umayyad dirhams**.

Abbreviations: Ox FOS = University of Oxford Faculty of Oriental Studies; CC Helsinki = Coin Chamber Helsinki. Analyses: Ox = University of Oxford (this study); A. National Bureau of Standards Boulder (Brill & Shields 1972); B. Moscow (Bychov 2011).

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Nr. | Analytical Ref. Nr. | Museum  ID | Mass (g) | Dynasty | Ruler | Mint | Date (AH) | Date (AD) | Obv. legend | Num. ref. to coin type | Arch context | Source | Analysis |
| 1 | 1024-19 | - | 1.83 | Umayyad | al-Walid | Dimashq | 90 | 708-709 | بسم الله ضرب هذا الدرهم بدمشق سنة تسعون | Klat 2002, no. K7334.1 | unknown | Ox FOS | Ox |
| 2 | 1025-19 | - | 1.27 | Umayyad | al-Walid or Sulayman | Wasit | 89-104 | 707-723 | بسم الله ضرب هذا الدرهم بواسط سنة ا[...] | Klat 2002, nos. 684-697 | unknown | Ox FOS | Ox |
| 3 | 1042-19 | - | 2.00 | Umayyad | Yazid II | al-Andalus | 118 | 734/6-737 | بسم الله ضرب هذا الدرهم بالأندلس سنة ثمان و عشر و مئة | Klat 2002, nos. 129-131 | unknown | Ox FOS | Ox |
| 4 | 1139-19 | - | 2.82 | Umayyad | Hisham | al-Mubarakah (Balkh) | 110 | 728-729 | بسم الله ضرب هذا الدرهم بالمبركة سنة عشر و مئة | Klat 2002, no. 573 | unknown | Ox FOS | Ox |
| 5 | 1140-19 | - | 2.61 | Umayyad | Abd al-Malik | Shaqq al-Taymara | 83 | 702-703 | بسم الله ضرب هذا الدرهم بشق التيمارة سنة ثلث و ثمنين | Klat 2002, no. 205.b | unknown | Ox FOS | Ox |
| 6 | 1141-19 | - | 2.00 | Umayyad | Umar | al-Basra | 100 | 718-719 | بسم الله ضرب هذا الدرهم بالبصرة سنة مئة | Klat 2002, no. 172 | unknown | Ox FOS | Ox |
| 7 | 1142-19 | - | 2.88 | Umayyad | Abd al-Malik | al-Basra | 82 | 701-702 | بسم الله ضرب هذا الدرهم بالبصرة سنة اثنين و ثمانين | Klat 2002, no. 171 | unknown | Ox FOS | Ox |
| 8 | 1143-19 | - | 2.64 | Umayyad | Abd al-Malik | Dimashq | 84 | 703-704 | بسم الله ضرب هذا الدرهم بدمشق سنة اربع و ثمانين | Klat 2002, no. 328 | unknown | Ox FOS | Ox |
| 9 | 1144-19 | - | 2.8 | Umayyad | al-Walid | Dimashq | 92 | 710-711 | بسم الله ضرب هذا الدرهم بدمشق سنة ثنتين و تسعين | Klat 2002, no. 336 | unknown | Ox FOS | Ox |
| 10 | 1145-19 | - | 2.67 | Umayyad | Sulayman or 'Umar | Abrashahr (Nishapur) | 99 | 717-718 | بسم الله ضرب هذا الدرهم بأبرشهر سنة تسع و تسعون | Klat 2002, no. 13 | unknown | Ox FOS | Ox |
| 11 | 1146-19 | - | 2.59 | Umayyad | al-Walid | Nahr Tira | 95 | 713-714 | بسم الله ضرب هذا الدرهم بنهر تيرى سنة خمس و تسعين | Klat 2002, no. 646 | unknown | Ox FOS | Ox |
| 12 | 1147-19 | - | 2.84 | Umayyad | al-Walid or Sulayman | Sabur, Bishapur S. Fars | 97 | 715-716 | بسم الله ضرب هذا الدرهم بسابور فى سنة سبع و تسعين | Klat 2002, no. 428 | unknown | Ox FOS | Ox |
| 13 | 1148-19 | - | 2.89 | Umayyad | Sulayman or 'Umar | Dimashq | 99 | 717-718 | بسم الله ضرب هذا الدرهم بدمشق سنة تسع و تسعين | Klat 2002, no. 343 | unknown | Ox FOS | Ox |
| 14 | 1149-19 Ph46 | - | 2.89 | Umayyad | Hisham | Wasit | 122 | 739-740 | بسم الله ضرب هذا الدرهم بواسط سنة إثنتين و عشرين و مئة | Klat 2002, no. 715 | unknown | Ox FOS | Ox |
| 15 | 1151-19 | - | 1.9 | Umayyad | Hisham | Wasit | 111 | 729-730 | بسم الله ضرب هذا الدرهم بواسط سنة احدى عشرة و مئة | Klat 2002, no. 704 | unknown | Ox FOS | Ox |
| 16 | 1152-19 Ph49 | - | 2.29 | Umayyad | Yazid II | Wasit | 105 | 723-724 | بسم الله ضرب هذا الدرهم بواسط سنة خمس و مئة | Klat 2002, no. 698.b | unknown | Ox FOS | Ox |
| 17 | 1156-19 Ph53 | - | 2.73 | Umayyad | Yazid II | Wasit | 103 | 721-722 | بسم الله ضرب هذا الدرهم بواسط سنة ثلث و مئة | Klat 2002, no. 696 | unknown | Ox FOS | Ox |
| 18 | 1157-19 Ph54 | - | 2.24 | Umayyad | Sulayman or 'Umar | Wasit | 99 | 717-718 | بسم الله ضرب هذا الدرهم بواسط سنة تسع و تسعين | Klat 2002, no. 694.a | unknown | Ox FOS | Ox |
| 19 | 1158-19 Ph58 | - | 1.9 | Umayyad | Hisham | Wasit | 115 | 733-734 | بسم الله ضرب هذا الدرهم بواسط سنة خمس و عشرة و مئة | Klat 2002, no. 708 | unknown | Ox FOS | Ox |
| 20 | 1160-19 | - | 2.59 | Umayyad | al-Walid or Sulayman | Wasit | 97 | 715-716 | بسم الله ضرب هذا الدرهم بواسط سنة سبع و تسعين | Klat 2002, no. 692.b | unknown | Ox FOS | Ox |
| 21 | 1161-19 | - | 2.3 | Umayyad | al-Walid or Sulayman | Wasit | 96 | 714-715 | بسم الله ضرب هذا الدرهم بواسط سنة سيت و تسعين | Klat 2002, no. 691 | unknown | Ox FOS | Ox |
| 22 | 1162-19 Ph59 | - | 2.56 | Umayyad | Abd al-Malik | Wasit | 85 | 704-705 | بسم الله ضرب هذا الدرهم بواسط سنة خمس و ثمانين | Klat 2002, no. 680.c | unknown | Ox FOS | Ox |
| 23 | 1163-19 | - | 2.85 | Umayyad | al-Walid | Wasit | 94 | 712-713 | بسم الله ضرب هذا الدرهم بواسط سنة اربع و تسعين | Klat 2002, no. 689 | unknown | Ox FOS | Ox |
| 24 | 1164-19 | - | 2.82 | Umayyad | Hisham | Dimashq | 110 | 728-729 | بسم الله ضرب هذا الدرهم بدمشق سنة عشرة و مئة | Klat 2002, no. 354 | unknown | Ox FOS | Ox |
| 25 | 1165-19 | - | 2.64 | Umayyad | Hisham | Dimashq | 113 | 731-732 | بسم الله ضرب هذا الدرهم بدمشق سنة ثلث وعشرة و مئة | Klat 2002, no. 357 | unknown | Ox FOS | Ox |
| 26 | 1166-19 | - | 2.85 | Umayyad | al-Walid or Sulayman | Mah | 96 | 714-715 | بسم الله ضرب هذا الدرهم بماهى سنة ست و تسعين | Klat 2002, no. 562.b | unknown | Ox FOS | Ox |
| 27 | 1167-19 | - | 2.86 | Umayyad | al-Walid | Marw | 91 | 709-710 | بسم الله ضرب هذا الدرهم بمرو سنة احدى و تسعين | Klat 2002, no. 588.b | unknown | Ox FOS | Ox |
| 28 | M-11 | - | - | Umayyad | 'Abd al-Malik | al-Kufa | 79-82 | 698-701 |  |  | unknown | - | B |
| 29 | 757 | - | - | Umayyad | ‘Umar or Yazid II | Dimashq | 101-102 | 720 |  |  | unknown | - | A |

**Table S3. List of North African dirhams**.

Abbreviations: NMF = National Museum Finland; WMH = Wikinger Museum Haithabu; BNdF = Bibliothèque nationale de France; Ox FOS = University of Oxford Faculty of Oriental Studies; CC Helsinki = Coin Chamber Helsinki. Analyses: Ox = University of Oxford (this study); B. Moscow (Bychov 2011); C. Orleans (Sarah 2008); D. Hanover (Merkel 2016).

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| Nr. | Analytical Ref. Nr. | Museum ID | Mass (g) | Dynasty | Ruler | Mint | Date (AH) | Date (AD) | Obv. legend | Actual coin published | Num. ref. to coin type | Archaeological context | Source |
| 30 | 1058-19 | NMF RKHY921:106 | 1.98 | Idrisid | Idris I | Tudgha | 174 | 790-791 | بسم الله ضرب هذا الدرهم بتدغة سنة اربع و سبعين و مئة | Granberg 1967, no. 106 | Eustache 1970-1, no. 32 | Svedjelandet Hoard, Åland tpq 837 | CC Helsinki |
| 31 | 1060-19 | NMF RKHY429:157 | 1.32 | Khajirites | Khalaf b. al-Muda' | Tudgha | c. 175 | 791-792 | بسم الله ضرب هذا الدرهم بتدغة سنة خمس و سبعين و مئة | Granberg 1967, no. 264 | Eustache 1970-1:291-3. | Hammarudda Hoard, Åland tpq 857 | CC Helsinki |
| 32 | Han-1 | WMH Hb2007/14062 | 0.4 | Abbasid | al-Mahdi/al-Hadi/al-Rashid | al-'Abbasiya | 160-170 | 776-786 |  |  |  | Metal-detector find, Hedeby | - |
| 33 | Han-2 | WMH Hb2006/12993 | 0.69 | Abbasid | Harun al-Rashid | al-'Abbasiya | 171-175 | 787-792 |  |  |  | Metal-detector find, Hedeby | - |
| 34 | Han-4 | WMH Giekau Coin 34 | 0.47 | Abbasid | Harun al-Rashid | al-'Abbasiya | 170-173 | 786-790 |  | Wiechmann 1996, no. 9.34 |  | Giekau Hoard, Plön tpq 921/2 | - |
| 35 | Han-3 | WMH Hb-LA48/9550 | 0.21 | Abbasid | Harun al-Rashid | Kairouan | 176-177 | 792-794 |  |  |  | Excavated find, Hedeby | - |
| 36 | 1062-19 | NMF RKHY921:65 | 2.78 | Abbasid | al-Mahdi | Ifriqiya (Kairouan) | 166 | 782-783 | بسم الله ضرب هذا الدرهم بإفريقية في سنة سيت و سيتين و مئة | Granberg 1967, no. 65 |  | Svedjelandet Hoard, Åland tpq 837 | CC Helsinki |
| 37 | 1063-19 | NMF RKHY921:72 | 2.66 | Abbasid | Harun al-Rashid | Ifriqiya (Kairouan) | 172 | 788-789 | بسم الله ضرب هذا الدرهم بإفريقية في سنة إثنتين و سباين و مئة | Granberg 1967, no. 72 | Nicol 2012a, 453 var. | Svedjelandet Hoard, Åland tpq 837 | CC Helsinki |
| 38 | L-1.777 | BNdF L-1.777 | - | Abbasid | Harun al-Rashid | Kairouan | 174 | 790-791 |  | Lavoix 1887, no. 777 |  | unknown | - |
| 39 | 1064-19 | NMF RKHY429:66 | 1.38 | Abbasid | al-Mahdi | Kairouan | 167 | 783-784 | بسم الله ضرب هذا الدرهم بإفريقية في سنة سبع و سيتين و مئة | Granberg 1967, no. 173 |  | Hammarudda Hoard, Åland tpq 857 | CC Helsinki |
| 40 | 1065-19 | NMF RKHY1850 | 2.59 | Abbasid | Harun al-Rashid | Ifriqiya (Kairouan) | 174 | 790-791 | بسم الله ضرب هذا الدرهم بإفريقية في سنة اربع و سباين و مئة | Granberg 1967, no. 1470 | Nicol 2012a, 458-459 | Tampere area, stray find ca. 1850. | CC Helsinki |
| 41 | M-10 | - | - | Abbasid | al-Hadi | Kairouan | 169 | 785-786 |  |  |  |  | - |

**Table S4. List of Abbasid-period dirhams from central and eastern mints**. Abbreviations: FM = Fitzwilliam Museum, Cambridge; NMF = National Museum Finland; WMH = Wikinger Museum Haithabu; BNdF = Bibliothèque nationale de France; Ox FOS = University of Oxford Faculty of Oriental Studies; CC Helsinki = Coin Chamber Helsinki. Analyses: Ox = University of Oxford (this study); SH = University of Southampton (this study); B. Moscow (Bychov 2011); C. Orleans (Sarah 2008); D. Hanover (Merkel 2016); E. University of Southampton (Standish *et al*. 2021).

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Nr. | Analytical Ref. Nr. | Museum ID | Mass (g) | Dynasty | Ruler | Mint | Date (AH) | Date (AD) | Obv. legend | Actual coin published | Num. ref. to coin type | Archaeological context | Source |
| 42 | 1026-19 Ph24 | - | 2.65 | Abbasid | al-Mansur | M. al-Salam (Baghdad) | 157 | 773-774 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة سبع و خمسين و مئة |  | Nicol 2012a, 1593-1596 | unknown | Ox FOS |
| 43 | 1046-19 Ph14 | - | 2.92 | Abbasid | Harun al-Rashid | M. al-Salam | 179 | 795-796 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة تسع و سبعين و مئة |  | Nicol 2012a, 1664-1666 | unknown | Ox FOS |
| 44 | 1036-19 | - | 2.56 | Abbasid | Harun al-Rashid | al-Rafiqa | 190 | 805-806 | بسم الله ضرب هذا الدرهم بالرافقة سنة تسعين و مئة |  | Nicol 2012a, 765-766 | unknown | Ox FOS |
| 45 | 1047-19 Ph10 | - | 2.89 | Abbasid | Harun al-Rashid | M. al-Salam | 188 | 803-804 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة ثمان و ثمنين و مئة |  | Nicol 2012a, 1694-1695 | unknown | Ox FOS |
| 46 | Fitz-6 | FM CM.147-1934 | 2.95 | Abbasid | al-Mansur | M. al-Salam | 157 | 773-774 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة سبع و خمسين و مئة |  | Nicol 2012a, 1603-1609 | unknown | Fitzwilliam |
| 47 | 1028-19 Ph28 | - | 1.43 | Abbasid | al-Mahdi | M. al-Salam | 161 | 777-778 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة احدى و ستين و مئة |  | Nicol 2012a, 1622-1627 | unknown | Ox FOS |
| 48 | 1029-19 Ph29 | - | 1.42 | Abbasid | al-Mahdi | M. al-Salam | 163 | 779-780 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة ثلث و ستين و مئة |  | Nicol 2012a, 1632-1633 | unknown | Ox FOS |
| 49 | Han-10 | WMH Hb2003/4191 | 2.7 | Abbasid | al-Mu'tamid | Surra man Ra'ā | 258 | 871/872 |  |  |  |  | - |
| 50 | M-1 | - | - | Abbasid | Harun al-Rashid | M. al-Salam | 172 | 788-789 |  |  |  |  | - |
| 51 | Fitz-12 | FM CM.IS.179-R | 2.7 | Abbasid | Harun al-Rashid | M. al-Salam | 175 | 791-792 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة خمس و سبعين و مئة |  | Nicol 2012a, 1660-1663 | unknown | Fitzwilliam |
| 52 | 1045-19 Ph11 | - | 2.8 | Abbasid | Harun al-Rashid | M. al-Salam | 190-193 | 805-809 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة [...] تسعين و مئة |  | Nicol 2012a, 1698-1706 | unknown | Ox FOS |
| 53 | 1044-19 Ph06 | - | 1.97 | Abbasid | al-Mansur | M. al-Salam | 161 | 777-778 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة احدى و ستين و مئة |  | Nicol 2012a, 1622-1627 | unknown | Ox FOS |
| 54 | Fitz-17 | FM CM.IS.191-R | 2.85 | Abbasid | Harun al-Rashid | M. al-Salam | 193 | 808-809 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة ثلث و تسعين و مئة |  | Nicol 2012a, 1704-1706 | unknown | Fitzwilliam |
| 55 | 1074-19 | NMF RKHY1876:374 | 2.93 | Abbasid | al-Mutawakkil | Surra man Ra'ā | 233 | 847-848 | بسم الله ضرب هذا الدرهم بسر من رأى سنة ثلث و ثلثين و مائتين | Granberg 1967, no. 638 |  | Bertby Hoard, Åland tpq 874 | CC Helsinki |
| 56 | Fitz-13 | FM CM.IS.182-R | 2.9 | Abbasid | Harun al-Rashid | M. al-Salam | 188 | 803-804 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة ثمان و ثمنين و مئة |  | Nicol 2012a, 1694-1695 | unknown | Fitzwilliam |
| 57 | 1039-19 | - | 2.39 | Abbasid | al-Mutadid | Surra man Ra'ā | 282 | 895-896 | بسم الله ضرب هذا الدرهم بسر من رأى سنة ثنين و ثمنين و مائتين |  | Shams Eshragh 2010, no. 1365 | unknown | Ox FOS |
| 58 | Fitz-23 | FM CM.141-2011 | 1.24 | Abbasid | al-Mahdi | M. al-Salam | 162 | 778-779 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة اثنين و ستين و مئة | Blackburn 2011, no. 46 |  | MD find, Torksey | Fitzwilliam |
| 59 | 1073-19 | NMF RKHY1876:384 | 2.6 | Abbasid | al-Mutawakkil | M. al-Salam | 237 | 851-852 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة سبع و ثلثين و مائتين | Granberg 1967, no. 648 |  | Bertby Hoard, Åland tpq 874 | CC Helsinki |
| 60 | 1075-19 | NMF RKHY1876:390 | 2.12 | Abbasid | al-Mutawakkil | Surra man Ra'ā | 239 | 853-854 | بسم الله ضرب هذا الدرهم بسر من رأى سنة تسع و ثلثين و مائتين | Granberg 1967, no. 654 |  | Bertby Hoard, Åland tpq 875 | CC Helsinki |
| 61 | 1072-19 | NMF RKHY921:73 | 3.08 | Abbasid | Harun al-Rashid | M. al-Salam | 180 | 796-797 | بسم الله ضرب هذا الدرهم بمدينة السلام في سنة ثمانين و مئة | Granberg 1967, no. 73 |  | Svedjelandet Hoard, Åland tpq 837 | CC Helsinki |
| 62 | M-2 | - | - | Abbasid | al-Mansur | M. al-Salam? | 154-158 | 770-774 |  |  |  |  | - |
| 63 | M-9 | - | - | Abbasid | Harun al-Rashid | M. al-Salam | 191 | 806 |  |  |  |  | - |
| 64 | Fitz-16 | FM CM.GC.1-R | 2.8 | Abbasid | Harun al-Rashid | M. al-Salam | 193 | 808-809 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة ثلث و تسعين و مئة |  | Nicol 2012a, 1704-1706 | unknown | Fitzwilliam |
| 65 | Fitz-21 | FM CM.76-2011 | 0.81 | Abbasid | al-Mahdi | M. al-Salam | 161 | 777-778 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة احدى و ستين و مئة | Blackburn 2011, no. 45 |  | MD find, Torksey, Lincolnshire | Fitzwilliam |
| 66 | M-7 | - | - | Abbasid | Harun al-Rashid | M. al-Salam? | 190-193 | 805-808 |  |  |  |  | - |
| 67 | 1040-19 Ph23 | - | 2.35 | Abbasid | al-Muktafi | M. al-Salam | 293 | 905-906 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة ثلث و تسعين و مائتين |  | Nicol 2012b, 1028-1029 | unknown | Ox FOS |
| 68 | Fitz-7 | FM CM.IS.168-R | 2.93 | Abbasid | al-Mahdi | M. al-Salam | 160 | 776-777 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة ستين و مئة |  | Nicol 2012a, 1618-1621 | unknown | Fitzwilliam |
| 69 | 1033-19 Ph34 | - | 2.48 | Abbasid | Harun al-Rashid | M. al-Salam | 193 | 808-809 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة ثلث و تسعين و مئة |  | Nicol 2012a, 1704-1706 | unknown | Ox FOS |
| 70 | L-1.779 |  | - | Abbasid | Harun al-Rashid | al-Basra | 181 | 797-798 |  | Lavoix 1887, no. 779 |  |  | - |
| 71 | Fitz-15 | FM CM.IS.187-R | 2.95 | Abbasid | Harun al-Rashid | M. al-Salam | 190 | 805-806 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة تسعين و مئة |  | Nicol 2012a, 1698-1699 | unknown | Fitzwilliam |
| 72 | L-1.861 | - | - | Abbasid | al-Amin | M. al-Salam | 193 | 808-809 |  | Lavoix 1887, no. 861 |  |  | - |
| 73 | 1057-19 | - | 2.53 | Abbasid | al-Muttaqi | M. al-Salam / Basra | 330 | 941-942 | بسم الله ضرب هذا الدرهم [...] سنة ثلثين و ثلثمائة |  | cf. Nicol 2012b, 223 & 225, 1195-1198 | unknown | Ox FOS |
| 74 | 1052-19 Ph15 | - | 2.67 | Abbasid | al-Ma'mun | M. al-Salam | 208 | 823-824 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة ثمان و مئتين |  | Nicol 2012a, 1781-1782 | unknown | Ox FOS |
| 75 | Fitz-20 | FM CM.IS.207-R | 2.94 | Abbasid | al-Ma’mun | M. al-Salam | 203 | 818-819 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة ثلث و مايتين |  | Nicol 2012a, 1755-1761 | unknown | Fitzwilliam |
| 76 | Han-9 | WMH Hb2003/4191 | 0.2 | Abbasid | al-Mutawakkil | M. al-Salam | (23)3 | (84)7 |  |  |  | MD find, Hedeby | - |
| 77 | 1077-19 | NMF RKHY921:24 | 1.05 | Abbasid | ‘Umar ibn al-‘Alā | Tabaristan | 155 | 771 |  | Granberg 1967, no. 24 |  | Svedjelandet Hoard, Åland tpq 837 | CC Helsinki |
| 78 | 1079-19 | NMF RKHY429:2 | 0.73 | Abbasid | ‘Umar ibn al-‘Alā | Tabaristan | 156 | 772 |  | Granberg 1967, no. 109 |  | Svedjelandet Hoard, Åland tpq 837 | CC Helsinki |
| 79 | 1053-19 | - | 3.82 | Abbasid | al-Mutamid | al-Muhammadiya | 251-255 | 866-869 | بسم الله ضرب هذا الدرهم بالمحمدية سنة [...] مئتين |  |  | unknown | Ox FOS |
| 80 | Fitz-14 | FM CM.IS.184-R | 2.63 | Abbasid | Harun al-Rashid | M. al-Salam | 188 | 803-804 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة ثمان و ثمنين و مئة |  | Nicol 2012a, 1694-1695 | unknown | Fitzwilliam |
| 81 | 1030-19 Ph26 | - | 2.48 | Abbasid | al-Mahdi | M. al-Salam | 165 | 781-782 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة خمس و ستين و مئة |  | Nicol 2012a, 1639-1640 | unknown | Ox FOS |
| 82 | 1088-19 | NMF RKHY1876:814 | 2.94 | Abbasid? | - | w/o writing | - | 9th C. | w/o writing | Granberg 1967, no. 1078 |  | Bertby Hoard, Åland tpq 874 | CC Helsinki |
| 83 | Fitz-8 | FM CM.IS.169-R | 2.8 | Abbasid | al-Mahdi | M. al-Salam | 163 | 779-780 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة ثلث و ستين و مئة |  | Nicol 2012a, 1630-1631 | unknown | Fitzwilliam |
| 84 | Fitz-19 | FM CM.IS.206-R | 2.75 | Abbasid | al-Ma’mun | M. al-Salam | 198 | 813-814 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة ثمان و تسعين و مئة |  | Nicol 2012a, 1733-1734 | unknown | Fitzwilliam |
| 85 | 1082-19 | NMF RKHY429:129 | 0.94 | Abbasid | al-Ma'mun | Marw | 199 | 814-815 | بسم الله ضرب هذا الدرهم بمرو سنة تسع و تسعون و مئة | Granberg 1967, no. 236 |  | Hammarudda Hoard, Åland tpq 857 | CC Helsinki |
| 86 | 1076-19 | NMF RKHY1876:367 | 3.05 | Abbasid | al-Mu`tazz | Surra man Ra'ā | 253 | 867 | بسم الله ضرب هذا الدرهم بسر من رأى سنة ثلث و خمسين و مائتين | Granberg 1967, no. 721 | cf. Nicol 2012b, 472 | Bertby Hoard, Åland tpq 874 | CC Helsinki |
| 87 | Fitz-3 | FM CM.IS.147-R | 2.49 | Abbasid | al-Mansur | al-Muhammadiya | 154 | 771 | بسم الله ضرب هذا الدرهم بالمحمدية سنة اربع و خمسين و مئة |  | Nicol 2012a, 1328 | unknown | Fitzwilliam |
| 88 | 1070-19 | NMF RKHY921:32 | 2.82 | Abbasid | al-Saffah | al-Basra | 134 | 751-752 | بسم الله ضرب هذا الدرهم بالبصرة في سنة اربعة و ثلاثون و مئة | Granberg 1967, no. 32 |  | Svedjelandet Hoard, Åland tpq 837 | CC Helsinki |
| 89 | Han-7 | WMH Hb2003/247 | 0.73 | Abbasid | Harun al-Rashid | al-Muhammadiya | 178-187 | 794-803 |  |  |  | MD find, Hedeby | - |
| 90 | 1084-19 | NMF RKHY1876:537 | 3.07 | Abbasid | al-Mutawakkil | Marw | 240 | 854-855 | بسم الله ضرب هذا الدرهم بمرو سنة أربعين و مائتين | Granberg 1967, no. 801 |  | Bertby Hoard, Åland tpq 874 | CC Helsinki |
| 91 | Han-12 | WMH Hb2006/12246 | 0.67 | Saffarid | al-Mu'tamid | Shiraz | 265-270 | 878-884 |  |  |  | MD find, Hedeby | - |
| 92 | 1034-19 | - | 3.01 | Abbasid | al-Ma'mun | Madinat Isfahan | 205 | 820-821 | سم الله ضرب هذا الدرهم بمدينة اصبهان سنة خمس و مئتين |  | Nicol 2012a, 395-400 | unknown | Ox FOS |
| 93 | 1071-19 | NMF RKHY1876:288 | 2.94 | Abbasid | al-Ma'mun | al-Basra | 199 | 814-815 | بسم الله ضرب هذا الدرهم بالبصرة في سنة تسع و تسعون و مئة | Granberg 1967, no. 552 |  | Bertby Hoard, Åland tpq 874 | CC Helsinki |
| 94 | M-5 | - | - | Abbasid | Harun al-Rashid | Zaranj | 184-185 | 800-801 |  |  |  |  | - |
| 95 | Fitz-18 | FM CM.IS.199-R | 2.87 | Abbasid | al-Ma’mun | M. Isbahan | 201 | 816-817 | بسم الله ضرب هذا الدرهم بمدينة اصبهان سنة احدى و مئتين |  | Nicol 2012a, 375-380 | unknown | Fitzwilliam |
| 96 | 1032-19 | - | 2.93 | Abbasid | Harun al-Rashid | al-Muhammadiya | 183 | 799-800 | بسم الله ضرب هذا الدرهم بالمحمدية سنة ثلث و ثمنين و مئة |  | Nicol 2012a, 1440-1445 | unknown | Ox FOS |
| 97 | 1038-19 Ph25 | - | 1.74 | Abbasid | al-Amin | (M. al-Salam) Overstruck | 195 | 810-811 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة خمس و تسعين و مئة |  | Nicol 2012a, 1720-1722 | unknown | Ox FOS |
| 98 | Fitz-11 | FM CM.384-1991 | 0.56 | Abbasid | Harun al-Rashid | al-Muhammadiya | 188-189 | 803-805 | بسم الله ضرب هذا الدرهم بالمحمدية سنة --- |  | Nicol 2012a, 1484-1487, 1489-1491 | MD find Caldecote, Norfolk | Fitzwilliam |
| 99 | Fitz-24 | FM CM.150-2011 | 0.78 | Abbasid | al-Ma'mun | al-Muhammadiya | 200 | 815-816 | بسم الله ضرب هذا الدرهم بالمحمدية سنة مئتين | Blackburn 2011, no. 73 | Nicol 2012a, 1530 | MD find Torksey, Lincolnshire | Fitzwilliam |
| 100 | 1041-19 | - | 3.04 | Abbasid | al-Mansur | al-Rayy (al-Muhammadiya) | 148 | 765-766 | بسم الله ضرب هذا الدرهم بالرى سنة ثمان و أربعين و مئة |  | Nicol 2012a, 784-785 | unknown | Ox FOS |
| 101 | 1080-19 | NMF RKHY921:26 | 1.21 | Abbasid | Hānī | Tabaristan | 173 | 788 |  | Granberg 1967, no. 26 | Malek 2004, 110.4 | Svedjelandet Hoard, Åland tpq 837 | CC Helsinki |
| 102 | 1027-19 | - | 2.63 | Abbasid | al-Mansur | al-Muhammadiya | 149 | 766-767 | بسم الله ضرب هذا الدرهم بالمحمدية سنة تسع و أربعين و مئة |  | Nicol 2012a, 1304-1307 | unknown | Ox FOS |
| 103 | M-4 | - | - | Abbasid | al-Mamun | M. Isbahan | [20]1 | 816-817 |  |  |  |  | - |
| 104 | L-1.859 | - | - | Abbasid | al-Amin | al-Muhammadiya | 194 | 809-810 |  | Lavoix 1887, no. 859 |  |  | - |
| 105 | 1035-19 Ph21 | - | 2.49 | Abbasid | al-Mansur | M. al-Salam | 151 | 768 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة احدى و خمسين و مئة |  | Nicol 2012a, 1566-1569 | unknown | Ox FOS |
| 106 | M-8b | - | - | Abbasid | al-Mamun | Isfahan | 205 | 820-821 |  |  |  |  | - |
| 107 | Fitz-4 | FM CM.IS.152-R | 2.92 | Abbasid | al-Mansur | M. al-Salam | 152 | 769-770 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة اثنتين و خمسين و مئة |  | Nicol 2012a, 1570-1573 | unknown | Fitzwilliam |
| 108 | 1078-19 | - | 0.82 | Abbasid | ‘Umar ibn al-‘Alā | Tabaristan | 162 | 778 | بسم الله ضرب هذا الدرهم بطبرستان سنة اثنين و ستين و مئة | Granberg 1967, no. 25 |  | Svedjelandet Hoard, Åland tpq 837 | Ox FOS |
| 109 | Fitz-5 | FM CM.IS.154-R | 2.76 | Abbasid | al-Mansur | M. al-Salam | 154 | 771 | بسم الله ضرب هذا الدرهم بمدينة السلام سنة اربع و خمسين و مئة |  | Nicol 2012a, 1576-1579 | unknown | Fitzwilliam |
| 110 | Fitz-2 | FM CM.279-1939 | 2.86 | Abbasid | al-Mansur | al-Muhammadiya | 150 | 767-768 | بسم الله ضرب هذا الدرهم بالمحمدية سنة خمسين و مئة |  | Nicol 2012a, 1312-1314 | unknown | Fitzwilliam |
| 111 | Fitz-10 | FM CM.IS.176-R | 2.8 | Abbasid | Harun al-Rashid | al-Muhammadiya | 184 | 800-801 | بسم الله ضرب هذا الدرهم بالمحمدية سنة اربع و ثمنين و مئة |  | Nicol 2012a, 1452-1459 | unknown | Fitzwilliam |
| 112 | Fitz-1 | FM CM.IS.146-R | 2.93 | Abbasid | al-Mansur | al-Muhammadiya | 148 | 765-766 | بسم الله ضرب هذا الدرهم بالمحمدية سنة ثمان و أربعين و مئة |  | Nicol 2012a, 1302-1303 | unknown | Fitzwilliam |
| 113 | Fitz-22 | FM CM.79-2011 | 0.39 | Abbasid | Harun al-Rashid | al-Muhammadiya | c. 186 | c. 802 | بسم الله ضرب هذا الدرهم بالمحمدية سنة ست و ثمنين و مئة | Blackburn 2011, no. 62 |  | MD find Torksey, Lincolnshire | Fitzwilliam |
| 114 | 1043-19 Ph09 | - | 3.1 | Abbasid | Harun al-Rashid | al-Muhammadiya | 182-183 | 798-800 | بسم الله ضرب هذا الدرهم بالمحمدية سنة [...] |  | Nicol 2012a, 1675-1677, 1679-1681 | unknown | Ox FOS |
| 115 | Han-5 | WMH Hb2003/4198 | 0.68 | Abbasid | al-Amin | Balkh | 193-195 | 808-811 |  |  |  | MD find Hedeby | - |
| 116 | 1037-19 Ph27 | - | 2.63 | Abbasid | Harun al-Rashid | Zaranj | 190 | 805-806 | بسم الله ضرب هذا الدرهم بمدينة زرنج سنة تسعين و مئة |  | Nicol 2012a, 821 | unknown | Ox FOS |
| 117 | L-1.787 | - | - | Abbasid | Harun al-Rashid | Balkh | 190 | 805-806 |  | Lavoix 1887, no. 787 |  | unknown | - |
| 118 | Fitz-9 | FM CM.IS.175-R | 2.73 | Abbasid | Harun al-Rashid | al-Muhammadiya | 180 | 796-797 | بسم الله ضرب هذا الدرهم بالمحمدية سنة ثمنين و مئة |  | Nicol 2012a, 1409-1410 | unknown | Fitzwilliam |
| 119 | 1087-19 | NMF RKHY1876:616 | 3.86 | Abbasid | al-Mustai`in | al-Shash | 251 | 865 | بسم الله ضرب هذا الدرهم بالشاش سنة إحدى و خمسين و مائتين | Granberg 1967, no. 880 |  | Bertby Hoard, Åland tpq 874 | CC Helsinki |
| 120 | L-1.781 | - | - | Abbasid | Harun al-Rashid | Balkh | 182 | 798-799 |  | Lavoix 1887, no. 781 |  | unknown | - |
| 121 | L-1.778 | - | - | Abbasid | Harun al-Rashid | Bukhara | 193 | 808-809 |  | Lavoix 1887, no. 778 |  | unknown | - |
| 122 | 1048-19 Ph18 | - | 3.7 | Abbasid | Harun al-Rashid | Balkh | 189 | 804-805 | بسم الله ضرب هذا الدرهم بمدينة بلخ سنة تسع و ثمنين و مئة |  | Nicol 2012a, 692-695 | unknown | Ox FOS |
| 123 | 1049-19 | - | 2.92 | Abbasid | Harun al-Rashid | Tabaristan | 190 | 805-806 | بسم الله ضرب هذا الدرهم بطبرستان سنة تسعين و مئة |  | Nicol 2012a, 933-934 | unknown | Ox FOS |
| 124 | 1081-19 | NMF RKHY429:91 | 2.91 | Abbasid | Harun al-Rashid | Marw | 182 | 798-799 | بسم الله ضرب هذا الدرهم بمرو سنة اثنين و ثمنين و مئة | Granberg 1967, no. 198 |  | Hammarudda Hoard, Åland tpq 857 | CC Helsinki |
| 125 | L-1.803 | - | - | Abbasid | Harun al-Rashid | Samarqand | 193 | 808-809 |  | Lavoix 1887, no. 803 |  | unknown | - |
| 126 | 1965-171 | BNdF 1965-171 | - | Abbasid | Harun al-Rashid | Samarqand | 193 | 808-809 |  |  |  | unknown | - |
| 127 | 1085-19 | NMF RKHY1876:522 | 2.7 | Abbasid | al-Mutawakkil | al-Shash | 233 | 847-848 | بسم الله ضرب هذا الدرهم بالشاش سنة ثلث و ثلثين و مائتين | Granberg 1967, no. 786 |  | Bertby Hoard, Åland tpq 874 | CC Helsinki |
| 128 | 1050-19 Ph03 | - | 2.74 | Abbasid | Harun al-Rashid | Bukhara | 193 | 808-809 | بسم الله ضرب هذا الدرهم بمدينة بخارا سنة ثلث و تسعين و مئة |  | Nicol 2012a, 492-494 | unknown | Ox FOS |
| 129 | 1051-19 Ph08 | - | 2.77 | Abbasid | Harun al-Rashid | Bukhara | 193 | 808-809 | بسم الله ضرب هذا الدرهم بمدينة بخارا سنة ثلث و تسعين و مئة |  | Nicol 2012a, 492-494 | unknown | Ox FOS |
| 130 | 1970-335 | BNdF | - | Abbasid | Harun al-Rashid | Bukhara | 193 | 808-809 |  |  |  | unknown | - |
| 131 | Han-6 | WMH Hb2003/3422 | 0.44 | Abbasid | al-Amin | Balkh | 193-195 | 808-811 |  |  |  | MD find Hedeby | - |
| 132 | Han-8 | WMH Hb2011/14541 | 0.38 | Abbasid | al-Ma'mun | Samarqand | 195 | 810-811 |  |  |  | MD find Hedeby | - |

**Table S5. Umayyad dirhams LIA results**.

Date = measurement in Oxford.Laboratory Ref: A. National Bureau of Standards Boulder (Brill & Shields 1972); B. Moscow (Bychov 2011).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Lab. Nr. | Mint | AH | AD | 206/204 | 2SD | 207/204 | 2SD | 208/204 | 2SD | 207/206 | 2SD | 208/206 | 2SD | T (Ma) | mu | kappa | Date/Ref. |
| 1024-19 | Dimashq | 90 | 708-709 | 18.461 | 0.001 | 15.660 | 0.002 | 38.650 | 0.004 | 0.84831 | 0.00004 | 2.0936 | 0.00009 | 275 | 9.84 | 4.01 | Dec-19 |
| 1025-19 | Wasit | 89-104 | 707-723 | 18.576 | 0.001 | 15.6621 | 0.0003 | 38.7014 | 0.0004 | 0.84312 | 0.00002 | 2.08338 | 0.00003 | 200 | 9.83 | 3.96 | Nov-19 |
| 1042-19 | al-Andalus | 118? | 734-737 | 18.582 | 0.002 | 15.666 | 0.001 | 38.722 | 0.004 | 0.84310 | 0.00001 | 2.08384 | 0.00008 | 197 | 9.83 | 3.97 | Dec-19 |
| 1139-19 | al-Mubarakah | 110 | 728-729 | 18.636 | 0.002 | 15.668 | 0.002 | 38.794 | 0.006 | 0.84072 | 0.00002 | 2.08166 | 0.00008 | 161 | 9.83 | 3.97 | Mar-21 |
| 1140-19 | Shaqq al-Taymara | 83 | 702-703 | 18.434 | 0.001 | 15.6572 | 0.0004 | 38.602 | 0.002 | 0.84938 | 0.00002 | 2.09410 | 0.00002 | 290 | 9.83 | 4.00 | Mar-21 |
| 1141-19 | al-Basra | 100 | 718-719 | 18.492 | 0.001 | 15.6455 | 0.0004 | 38.591 | 0.002 | 0.84605 | 0.00001 | 2.08688 | 0.00003 | 229 | 9.78 | 3.95 | Mar-20 |
| 1142-19 | al-Basra | 82 | 701-702 | 18.578 | 0.002 | 15.663 | 0.002 | 38.701 | 0.005 | 0.84306 | 0.00002 | 2.08309 | 0.00006 | 198 | 9.83 | 3.96 | Mar-20 |
| 1143-19 | Dimashq | 84 | 703-704 | 18.645 | 0.002 | 15.666 | 0.001 | 38.758 | 0.002 | 0.84024 | 0.00001 | 2.07871 | 0.00002 | 156 | 9.83 | 3.95 | Mar-20 |
| 1144-19 | Dimashq | 92 | 710-711 | 18.613 | 0.003 | 15.651 | 0.002 | 38.697 | 0.005 | 0.84086 | 0.00004 | 2.07902 | 0.00013 | 151 | 9.78 | 3.93 | Mar-20 |
| 1145-19 | Abrashahr | 99 | 717-718 | 18.861 | 0.005 | 15.702 | 0.004 | 39.004 | 0.011 | 0.83247 | 0.00003 | 2.06794 | 0.00006 | 61 | 9.92 | 3.94 | Mar-21 |
| 1146-19 | Nahr Tira | 95 | 713-714 | 18.543 | 0.002 | 15.651 | 0.002 | 38.673 | 0.004 | 0.84407 | 0.00001 | 2.08565 | 0.00003 | 198 | 9.78 | 3.96 | Mar-21 |
| 1147-19 | Sabur | 97 | 715-716 | 18.712 | 0.002 | 15.679 | 0.001 | 38.839 | 0.003 | 0.83787 | 0.00003 | 2.07560 | 0.00014 | 130 | 9.87 | 3.95 | Mar-20 |
| 1148-19 | Dimashq | 99 | 717-718 | 20.325 | 0.003 | 15.846 | 0.002 | 39.171 | 0.006 | 0.77961 | 0.00001 | 1.92723 | 0.00003 | -725 | 10.27 | 3.28 | Mar-20 |
| 1149-19 | Wasit | 122 | 739-740 | 18.764 | 0.002 | 15.672 | 0.001 | 38.765 | 0.002 | 0.83520 | 0.00001 | 2.06587 | 0.00004 | 80 | 9.83 | 3.88 | Mar-20 |
| 1151-19 | Wasit | 111 | 729-730 | 18.522 | 0.001 | 15.630 | 0.001 | 38.629 | 0.002 | 0.84388 | 0.00001 | 2.08557 | 0.00004 | 178 | 9.72 | 3.95 | Mar-20 |
| 1152-19 | Wasit | 105 | 723-724 | 18.406 | 0.002 | 15.638 | 0.002 | 38.519 | 0.005 | 0.84965 | 0.00002 | 2.09281 | 0.00003 | 281 | 9.78 | 3.97 | Mar-20 |
| 1156-19 | Wasit | 103 | 721-722 | 18.463 | 0.001 | 15.630 | 0.001 | 38.564 | 0.003 | 0.84660 | 0.00002 | 2.08880 | 0.00001 | 223 | 9.73 | 3.96 | Mar-20 |
| 1157-19 | Wasit | 99 | 717-718 | 18.563 | 0.001 | 15.656 | 0.001 | 38.670 | 0.003 | 0.84338 | 0.00002 | 2.08317 | 0.00001 | 198 | 9.81 | 3.95 | Mar-20 |
| 1158-19 | Wasit | 115 | 733-734 | 18.417 | 0.002 | 15.633 | 0.001 | 38.515 | 0.004 | 0.84883 | 0.00001 | 2.09121 | 0.00002 | 262 | 9.75 | 3.96 | Mar-20 |
| 1160-19 | Wasit | 97 | 715-716 | 18.593 | 0.003 | 15.663 | 0.002 | 38.708 | 0.006 | 0.84240 | 0.00002 | 2.08187 | 0.00005 | 189 | 9.83 | 3.96 | Mar-20 |
| 1161-19 | Wasit | 96 | 714-715 | 18.5781 | 0.0004 | 15.6600 | 0.0002 | 38.700 | 0.002 | 0.84293 | 0.00002 | 2.08307 | 0.00009 | 194 | 9.82 | 3.96 | Mar-20 |
| 1162-19 | Wasit | 85 | 704-705 | 18.569 | 0.002 | 15.660 | 0.003 | 38.699 | 0.007 | 0.84335 | 0.00004 | 2.08402 | 0.00011 | 201 | 9.83 | 3.97 | Mar-20 |
| 1163-19 | Wasit | 94 | 712-713 | 18.5851 | 0.0002 | 15.666 | 0.001 | 38.717 | 0.001 | 0.84294 | 0.00002 | 2.08323 | 0.00004 | 201 | 9.85 | 3.97 | Mar-20 |
| 1164-19 | Dimashq | 110 | 728-729 | 18.645 | 0.004 | 15.636 | 0.004 | 38.661 | 0.009 | 0.83859 | 0.00002 | 2.07353 | 0.00008 | 95 | 9.71 | 3.89 | Mar-20 |
| 1165-19 | Dimashq | 113 | 731-732 | 18.687 | 0.003 | 15.647 | 0.002 | 38.696 | 0.005 | 0.83731 | 0.00002 | 2.07078 | 0.00005 | 86 | 9.75 | 3.88 | Mar-20 |
| 1166-19 | Mah | 96 | 714-715 | 18.428 | 0.002 | 15.631 | 0.002 | 38.522 | 0.007 | 0.84823 | 0.00004 | 2.09048 | 0.00018 | 249 | 9.74 | 3.96 | Mar-20 |
| 1167-19 | Marw | 91 | 709-710 | 18.822 | 0.004 | 15.685 | 0.004 | 38.926 | 0.009 | 0.83333 | 0.00001 | 2.06810 | 0.00003 | 62 | 9.87 | 3.93 | Mar-20 |
| M-11 | al-Kufa | 79-82 | 698-701 | 18.544 | 0.004 | 15.690 | 0.003 | 38.730 | 0.008 | 0.8461 | - | 2.0886 | - | 271 | 9.93 | 4.01 | B |
| 757 | Dimashq | 101-102 | 720 | 18.512 | 0.019 | 15.648 | 0.016 | 38.597 | 0.039 | 0.8453 | - | 2.0850 | - | 215 | 9.78 | 3.94 | A |

**Table S6. North African dirham LIA results**.

Date = measurement in Oxford. Laboratory Ref: B. Moscow (Bychov 2011); C. Orleans (Sarah 2008); D. Hanover (Merkel 2016). **\***Poor blank (0.25%), could not be repeated.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Lab. Nr. | Mint | AH | AD | 206/204 | 2SD | 207/204 | 2SD | 208/204 | 2SD | 207/206 | 2SD | 208/206 | 2SD | T (Ma) | mu | kappa | Date/Ref. |
| 1058-19 | Tudgha | 174 | 790-791 | 18.260 | 0.001 | 15.655 | 0.001 | 38.428 | 0.004 | 0.85735 | 0.00002 | 2.10449 | 0.00008 | 414 | 9.86 | 4.02 | Dec-19 |
| 1060-19 | Tudgha | c. 175 | 791-792 | 18.347 | 0.002 | 15.611 | 0.001 | 38.108 | 0.003 | 0.85088 | 0.00003 | 2.07707 | 0.00008 | 267 | 9.67 | 3.78 | Aug-20 |
| Han-1 | al-'Abbasiya | 160-170 | 776-786 | 18.298 | 0.004 | 15.628 | 0.005 | 38.11 | 0.01 | 0.8540 | 0.0001 | 2.0841 | 0.0003 | 336 | 9.75 | 3.82 | D |
| Han-2 | al-'Abbasiya | 171-175 | 787-792 | 18.388 | 0.004 | 15.626 | 0.004 | 38.45 | 0.01 | 0.8497 | 0.0001 | 2.0925 | 0.0002 | 265 | 9.72 | 3.94 | D |
| Han-4 | al-'Abbasiya | 170-173 | 786-790 | 18.224 | 0.101 | 15.542 | 0.074 | 38.070 | 0.150 | 0.8528 | 0.0007 | 2.0904 | 0.0033 | 225 | 9.42 | 3.82 | D |
| Han-3 | Ifriqiya | 176-177 | 792-794 | 18.261 | 0.061 | 15.559 | 0.058 | 38.200 | 0.130 | 0.8520 | 0.0005 | 2.0933 | 0.0008 | 231 | 9.48 | 3.87 | D |
| 1062-19 | Ifriqiya | 166 | 782-783 | 18.328 | 0.000 | 15.609 | 0.000 | 38.105 | 0.002 | 0.85167 | 0.00001 | 2.07912 | 0.00008 | 284 | 9.68 | 3.79 | Jan-20\* |
| 1063-19 | Ifriqiya | 172 | 788-789 | 18.274 | 0.001 | 15.638 | 0.001 | 38.346 | 0.003 | 0.85575 | 0.00001 | 2.09836 | 0.00006 | 372 | 9.79 | 3.96 | Aug-20 |
| L-1.777 | Ifriqiya | 174 | 790-791 | 18.436 | 0.022 | 15.631 | 0.025 | 38.218 | 0.084 | 0.8479 | - | 2.0730 | - | 239 | 9.73 | 3.79 | C |
| 1064-19 | Ifriqiya | 167 | 783-784 | 18.866 | 0.001 | 15.703 | 0.001 | 39.096 | 0.001 | 0.83237 | 0.000004 | 2.07233 | 0.00003 | 60 | 9.92 | 3.98 | Aug-20 |
| 1065-19 | Ifriqiya | 174 | 790-791 | 18.796 | 0.002 | 15.696 | 0.001 | 39.017 | 0.002 | 0.83509 | 0.00003 | 2.07579 | 0.00010 | 98 | 9.91 | 3.99 | Dec-19 |
| M-10 | Ifriqiya | 169 | 785-786 | 18.810 | 0.004 | 15.680 | 0.003 | 38.845 | 0.008 | 0.8336 | - | 2.0652 | - | 56 | 9.84 | 3.89 | B |

**Table S7**. **Abbasid-period dirhams from central and eastern mints LIA results**.

Laboratory Ref: Date = measurement in Oxford; SH = University of Southampton (this study); B. Moscow (Bychov 2011); C. Orleans (Sarah 2008); D. Hanover (Merkel 2016); E. Southampton (Standish *et al*. 2021). **\***Poor blank (0.25%), measurement could not be repeated.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Lab. Nr. | Mint | AH | AD | 206/204 | 2SD | 207/204 | 2SD | 208/204 | 2SD | 207/206 | 2SD | 208/206 | 2SD | T (Ma) | mu | kappa | Date/Ref. |
| 1026-19 | M. al-Salam (Baghdad) | 157 | 773-774 | 19.113 | 0.001 | 15.732 | 0.001 | 39.526 | 0.002 | 0.82313 | 0.00002 | 2.06799 | 0.00009 | -65 | 9.99 | 4.05 | Dec-19 |
| 1046-19 | M. al-Salam | 179 | 795-796 | 19.090 | 0.003 | 15.706 | 0.003 | 39.417 | 0.009 | 0.82274 | 0.00002 | 2.06479 | 0.00009 | -93 | 9.91 | 4.00 | Jan-20 |
| 1036-19 | al-Rafiqa | 190 | 805-806 | 19.094 | 0.002 | 15.712 | 0.002 | 39.445 | 0.004 | 0.82284 | 0.00002 | 2.06573 | 0.00005 | -93 | 9.91 | 4.01 | Dec-19 |
| 1047-19 | M. al-Salam | 188 | 803-804 | 19.122 | 0.002 | 15.737 | 0.002 | 39.530 | 0.005 | 0.82298 | 0.00001 | 2.06722 | 0.00005 | -63 | 10.00 | 4.04 | Dec-19 |
| Fitz-6 | M. al-Salam | 157 | 773-774 | 19.156 | 0.036 | 15.767 | 0.029 | 39.635 | 0.077 | 0.8230 | 0.0002 | 2.0691 | 0.0018 | -28 | 10.11 | 4.08 | SH |
| 1028-19 | M. al-Salam | 161 | 777-778 | 19.088 | 0.002 | 15.713 | 0.002 | 39.458 | 0.005 | 0.82320 | 0.00002 | 2.06711 | 0.00004 | -85 | 9.92 | 4.02 | Dec-19 |
| 1029-19 | M. al-Salam | 163 | 779-780 | 19.104 | 0.001 | 15.728 | 0.001 | 39.487 | 0.003 | 0.82327 | 0.00003 | 2.06689 | 0.00005 | -68 | 9.97 | 4.03 | Dec-19 |
| Han-10 | Surra man Ra'ā | 258 | 871/872 | 19.126 | 0.009 | 15.751 | 0.008 | 39.52 | 0.03 | 0.8235 | 0.0002 | 2.0684 | 0.0007 | -37 | 10.06 | 4.04 | D |
| M-1 | M. al-Salam | 172 | 788-789 | 19.141 | 0.004 | 15.766 | 0.003 | 39.600 | 0.008 | 0.8237 | - | 2.0688 | - | -20 | 10.11 | 4.08 | B |
| Fitz-12 | M. al-Salam | 175 | 791-792 | 19.145 | 0.036 | 15.774 | 0.029 | 39.623 | 0.077 | 0.8239 | 0.0002 | 2.0697 | 0.0018 | -6 | 10.14 | 4.09 | SH |
| 1045-19 | M. al-Salam | 190-193 | 805-809 | 19.053 | 0.001 | 15.701 | 0.001 | 39.343 | 0.004 | 0.82405 | 0.00001 | 2.06485 | 0.00007 | -84 | 9.88 | 3.98 | Dec-19 |
| 1044-19 | M. al-Salam | 161 | 777-778 | 19.074 | 0.001 | 15.718 | 0.001 | 39.444 | 0.004 | 0.82406 | 0.00003 | 2.06789 | 0.00014 | -65 | 9.94 | 4.03 | Dec-19 |
| Fitz-17 | M. al-Salam | 193 | 808-809 | 19.115 | 0.036 | 15.760 | 0.029 | 39.532 | 0.077 | 0.8244 | 0.0002 | 2.0672 | 0.0018 | -12 | 10.09 | 4.06 | SH |
| 1074-19 | Surra man Ra'ā | 233 | 847-848 | 19.050 | 0.001 | 15.704 | 0.001 | 39.361 | 0.001 | 0.82433 | 0.00001 | 2.06616 | 0.00006 | -69 | 9.91 | 4.00 | Jan-20 |
| Fitz-13 | M. al-Salam | 188 | 803-804 | 19.073 | 0.036 | 15.726 | 0.029 | 39.426 | 0.077 | 0.8245 | 0.0002 | 2.0672 | 0.0018 | -49 | 9.97 | 4.02 | SH |
| 1039-19 | Surra man Ra'ā | 282 | 895-896 | 19.079 | 0.002 | 15.738 | 0.001 | 39.494 | 0.005 | 0.82484 | 0.00001 | 2.06991 | 0.00007 | -30 | 10.01 | 4.05 | Dec-19 |
| Fitz-23 | M. al-Salam | 162 | 778-779 | 19.140 | 0.036 | 15.800 | 0.029 | 39.699 | 0.077 | 0.8251 | 0.0002 | 2.0710 | 0.0018 | 48 | 10.24 | 4.14 | SH |
| 1073-19 | M. al-Salam | 237 | 851-852 | 19.041 | 0.003 | 15.712 | 0.002 | 39.363 | 0.005 | 0.82514 | 0.00002 | 2.06723 | 0.00004 | -48 | 9.94 | 4.01 | Mar-20 |
| 1075-19 | Surra man Ra'ā | 239 | 853-854 | 19.024 | 0.003 | 15.705 | 0.002 | 39.348 | 0.006 | 0.82557 | 0.00001 | 2.06839 | 0.00004 | -46 | 9.92 | 4.01 | Jan-20 |
| 1072-19 | M. al-Salam | 180 | 796-797 | 19.017 | 0.001 | 15.704 | 0.001 | 39.296 | 0.001 | 0.82577 | 0.00002 | 2.06635 | 0.00006 | -44 | 9.91 | 3.99 | Jan-20\* |
| M-2 | M. al-Salam? | 154-158 | 770-774 | 19.096 | 0.004 | 15.771 | 0.003 | 39.587 | 0.008 | 0.8259 | - | 2.0730 | - | 24 | 10.14 | 4.10 | B |
| M-9 | M. al-Salam | 191 | 806 | 19.065 | 0.004 | 15.750 | 0.003 | 39.447 | 0.008 | 0.8261 | - | 2.0691 | - | 4 | 10.06 | 4.05 | B |
| Fitz-16 | M. al-Salam | 193 | 808-809 | 19.092 | 0.036 | 15.789 | 0.029 | 39.583 | 0.077 | 0.8267 | 0.0003 | 2.0715 | 0.0018 | 61 | 10.21 | 4.11 | SH |
| Fitz-21 | M. al-Salam | 161 | 777-778 | 18.961 | 0.036 | 15.685 | 0.029 | 39.251 | 0.076 | 0.8275 | 0.0003 | 2.0702 | 0.0018 | -47 | 9.83 | 3.99 | SH |
| M-7 | M. al-Salam? | 190-193 | 805-808 | 19.015 | 0.004 | 15.744 | 0.003 | 39.354 | 0.008 | 0.8280 | - | 2.0696 | - | 29 | 10.05 | 4.03 | B |
| 1040-19 | M. al-Salam | 293 | 905-906 | 19.085 | 0.001 | 15.729 | 0.001 | 39.486 | 0.004 | 0.82414 | 0.00002 | 2.06883 | 0.00007 | -51 | 9.98 | 4.04 | Dec-19 |
| Fitz7 | M. al-Salam | 160 | 776-777 | 18.901 | 0.036 | 15.674 | 0.029 | 39.150 | 0.076 | 0.8293 | 0.0003 | 2.0715 | 0.0018 | -24 | 9.80 | 3.98 | SH |
| 1033-19 | M. al-Salam | 193 | 808-809 | 18.929 | 0.001 | 15.706 | 0.001 | 39.263 | 0.003 | 0.82972 | 0.00003 | 2.07415 | 0.00009 | 18 | 9.92 | 4.03 | Dec-19 |
| L- 1.779 | al-Basra | 181 | 797-798 | 18.936 | 0.023 | 15.712 | 0.025 | 39.180 | 0.086 | 0.8298 | - | 2.0691 | - | 26 | 9.94 | 3.98 | C |
| Fitz-15 | M. al-Salam | 190 | 805-806 | 18.962 | 0.036 | 15.742 | 0.029 | 39.233 | 0.076 | 0.8301 | 0.0003 | 2.0692 | 0.0018 | 64 | 10.05 | 4.00 | SH |
| L-1.861 | M. al-Salam | 193 | 808-809 | 18.914 | 0.023 | 15.710 | 0.025 | 39.110 | 0.086 | 0.8306 | - | 2.0678 | - | 38 | 9.94 | 3.96 | C |
| 1057-19 | M. al-Salam/Basra | 330 | 941-942 | 18.869 | 0.002 | 15.685 | 0.001 | 39.033 | 0.003 | 0.83125 | 0.00002 | 2.06862 | 0.00012 | 28 | 9.87 | 3.95 | Jan-20 |
| 1052-19 | M. al-Salam | 208 | 823-824 | 18.873 | 0.002 | 15.693 | 0.002 | 39.096 | 0.003 | 0.83150 | 0.00000 | 2.07145 | 0.00003 | 34 | 9.88 | 3.98 | Dec-19 |
| Fitz-20 | M. al-Salam | 203 | 818-819 | 18.913 | 0.036 | 15.737 | 0.029 | 39.091 | 0.076 | 0.8320 | 0.0003 | 2.0671 | 0.0018 | 91 | 10.04 | 3.96 | SH |
| Han-9 | M. al-Salam | (23)3 | (84)7 | 18.849 | 0.007 | 15.708 | 0.004 | 38.99 | 0.01 | 0.8333 | 0.0001 | 2.0698 | 0.0002 | 82 | 9.94 | 3.94 | D |
| 1077-19 | Tabaristan | 155 | 771 | 18.746 | 0.001 | 15.638 | 0.001 | 38.966 | 0.002 | 0.83423 | 0.00001 | 2.07867 | 0.00008 | 20 | 9.69 | 3.97 | Aug-20 |
| 1079-19 | Tabaristan | 156 | 772 | 18.715 | 0.003 | 15.633 | 0.003 | 38.914 | 0.009 | 0.83536 | 0.00005 | 2.07931 | 0.00012 | 39 | 9.69 | 3.97 | Mar-20 |
| 1053-19 | al-Muhammadiya | 251-255 | 866-869 | 18.789 | 0.001 | 15.687 | 0.001 | 39.062 | 0.001 | 0.83490 | 0.00002 | 2.07895 | 0.00007 | 84 | 9.87 | 4.01 | Dec-19 |
| Fitz-14 | M. al-Salam | 188 | 803-804 | 18.852 | 0.036 | 15.731 | 0.029 | 39.164 | 0.076 | 0.8344 | 0.0003 | 2.0776 | 0.0018 | 123 | 10.03 | 4.04 | SH |
| 1030-19 | M. al-Salam | 165 | 781-782 | 18.744 | 0.000 | 15.682 | 0.001 | 39.042 | 0.002 | 0.83661 | 0.00004 | 2.0828 | 0.0001 | 108 | 9.86 | 4.03 | Dec-19 |
| 1088-19 | w/o writing | - | 9th C. | 18.717 | 0.002 | 15.675 | 0.001 | 39.032 | 0.004 | 0.83746 | 0.00001 | 2.0854 | 0.0001 | 121 | 9.86 | 4.04 | Jan-20 |
| Fitz-8 | M. al-Salam | 163 | 779-780 | 18.898 | 0.036 | 15.788 | 0.029 | 39.278 | 0.076 | 0.8354 | 0.0003 | 2.0786 | 0.0018 | 199 | 10.24 | 4.08 | SH |
| Fitz-19 | M. al-Salam | 198 | 813-814 | 18.838 | 0.036 | 15.776 | 0.029 | 39.292 | 0.076 | 0.8372 | 0.0003 | 2.0838 | 0.0018 | 217 | 10.21 | 4.13 | SH |
| 1082-19 | Marw | 199 | 814-815 | 18.706 | 0.002 | 15.690 | 0.002 | 38.938 | 0.004 | 0.83874 | 0.00000 | 2.08151 | 0.00002 | 152 | 9.90 | 4.00 | Aug-20 |
| 1076-19 | Surra man Ra'ā | 253 | 867 | 18.688 | 0.001 | 15.672 | 0.001 | 38.777 | 0.003 | 0.83861 | 0.00001 | 2.07494 | 0.00001 | 130 | 9.83 | 3.93 | Mar-21 |
| Fitz-3 | al-Muhammadiya | 154 | 771 | 18.658 | 0.035 | 15.669 | 0.029 | 38.876 | 0.076 | 0.8397 | 0.0003 | 2.0837 | 0.0018 | 146 | 9.83 | 4.00 | E |
| 1070-19 | al-Basra | 134 | 751-752 | 18.661 | 0.001 | 15.673 | 0.001 | 38.813 | 0.002 | 0.83990 | 0.00002 | 2.07992 | 0.00011 | 158 | 9.86 | 3.97 | Mar-20 |
| Han-7 | al-Muhammadiya | 178-187 | 794-803 | 18.656 | 0.005 | 15.675 | 0.005 | 38.77 | 0.01 | 0.8401 | 0.0001 | 2.0798 | 0.0004 | 160 | 9.85 | 3.95 | D |
| 1084-19 | Marw | 240 | 854-855 | 18.644 | 0.001 | 15.671 | 0.001 | 38.772 | 0.004 | 0.84055 | 0.00002 | 2.07960 | 0.00006 | 162 | 9.84 | 3.95 | Aug-20 |
| Han-12 | Shiraz | 265-270 | 878-884 | 18.636 | 0.005 | 15.685 | 0.005 | 38.78 | 0.02 | 0.8416 | 0.0001 | 2.0825 | 0.0005 | 194 | 9.89 | 3.97 | D |
| 1034-19 | Madinat Isfahan | 205 | 820-821 | 18.590 | 0.001 | 15.653 | 0.001 | 38.714 | 0.002 | 0.84203 | 0.00002 | 2.08250 | 0.00004 | 166 | 9.78 | 3.95 | Dec-19 |
| 1071-19 | al-Basra | 199 | 814-815 | 18.535 | 0.002 | 15.616 | 0.001 | 38.590 | 0.004 | 0.84250 | 0.00001 | 2.08197 | 0.00001 | 142 | 9.67 | 3.92 | Jan-20 |
| M-5 | Zaranj | 184-185 | 800-801 | 18.589 | 0.004 | 15.679 | 0.003 | 38.813 | 0.008 | 0.8435 | - | 2.0880 | - | 217 | 9.88 | 4.01 | B |
| Fitz-18 | Madinat Isbahan | 201 | 816-817 | 18.591 | 0.035 | 15.687 | 0.029 | 38.849 | 0.076 | 0.8436 | 0.0003 | 2.0879 | 0.0018 | 231 | 9.91 | 4.03 | SH |
| 1032-19 | al-Muhammadiya | 183 | 799-800 | 18.539 | 0.001 | 15.645 | 0.001 | 38.659 | 0.003 | 0.84390 | 0.00001 | 2.08526 | 0.00005 | 188 | 9.76 | 3.96 | Dec-19 |
| 1038-19 | (M. al-Salam) Ov. | 195 | 810-811 | 18.531 | 0.002 | 15.640 | 0.001 | 38.664 | 0.003 | 0.84398 | 0.00002 | 2.08640 | 0.00003 | 185 | 9.74 | 3.96 | Dec-19 |
| Fitz-11 | al-Muhammadiya | 188-189 | 803-805 | 18.517 | 0.035 | 15.631 | 0.029 | 38.557 | 0.075 | 0.8441 | 0.0003 | 2.0821 | 0.0018 | 179 | 9.71 | 3.91 | E |
| Fitz-24 | al-Muhammadiya | 200 | 815-816 | 18.588 | 0.035 | 15.696 | 0.029 | 38.835 | 0.075 | 0.8443 | 0.0003 | 2.0886 | 0.0018 | 249 | 9.95 | 4.03 | E |
| 1041-19 | al-Rayy Muhammadiya | 148 | 765-766 | 18.512 | 0.002 | 15.631 | 0.002 | 38.638 | 0.006 | 0.84437 | 0.00002 | 2.08713 | 0.00009 | 182 | 9.71 | 3.96 | Dec-19 |
| 1080-19 | Tabaristan | 172 | 788 | 18.504 | 0.001 | 15.626 | 0.001 | 38.621 | 0.001 | 0.84448 | 0.00001 | 2.08718 | 0.00006 | 185 | 9.71 | 3.96 | Jan-20 |
| 1027-19 | al-Muhammadiya | 149 | 766-767 | 18.521 | 0.001 | 15.645 | 0.001 | 38.676 | 0.002 | 0.84471 | 0.00000 | 2.08817 | 0.00003 | 202 | 9.76 | 3.98 | Dec-19 |
| M-4 | Madinat Isbahan | [20]1 | 816-817 | 18.523 | 0.004 | 15.648 | 0.003 | 38.677 | 0.008 | 0.8448 | - | 2.0881 | - | 207 | 9.77 | 3.98 | B |
| L-1.859 | al-Muhammadiya | 194 | 809-810 | 18.525 | 0.022 | 15.653 | 0.025 | 38.672 | 0.085 | 0.8450 | - | 2.0876 | - | 214 | 9.79 | 3.97 | C |
| 1035-19 | M. al-Salam | 151 | 768 | 18.527 | 0.002 | 15.657 | 0.002 | 38.625 | 0.004 | 0.84509 | 0.00002 | 2.08475 | 0.00009 | 221 | 9.81 | 3.95 | Dec-19 |
| M-8b | Isfahan | 205 | 820-821 | 18.583 | 0.004 | 15.705 | 0.003 | 38.831 | 0.008 | 0.8451 | - | 2.0896 | - | 271 | 9.99 | 4.04 | B |
| Fitz-4 | M. al-Salam | 152 | 769-770 | 18.546 | 0.035 | 15.677 | 0.029 | 38.708 | 0.075 | 0.8453 | 0.0003 | 2.0873 | 0.0018 | 245 | 9.88 | 3.99 | SH |
| 1078-19 | Tabaristan | 162 | 778 | 18.494 | 0.001 | 15.637 | 0.001 | 38.672 | 0.003 | 0.84554 | 0.00002 | 2.09107 | 0.00006 | 208 | 9.74 | 3.99 | Aug-20 |
| Fitz-5 | M. al-Salam | 154 | 771 | 18.559 | 0.035 | 15.701 | 0.029 | 38.737 | 0.075 | 0.8460 | 0.0003 | 2.0874 | 0.0018 | 280 | 9.97 | 4.00 | Shm |
| Fitz-2 | al-Muhammadiya | 150 | 767-768 | 18.534 | 0.035 | 15.679 | 0.029 | 38.720 | 0.075 | 0.8459 | 0.0003 | 2.0892 | 0.0018 | 258 | 9.89 | 4.00 | E |
| Fitz-10 | al-Muhammadiya | 184 | 800-801 | 18.510 | 0.035 | 15.672 | 0.029 | 38.707 | 0.075 | 0.8466 | 0.0003 | 2.0913 | 0.0018 | 262 | 9.87 | 4.01 | E |
| Fitz-1 | al-Muhammadiya | 148 | 765-766 | 18.451 | 0.035 | 15.639 | 0.029 | 38.665 | 0.075 | 0.8476 | 0.0003 | 2.0957 | 0.0018 | 244 | 9.76 | 4.02 | E |
| Fitz-22 | al-Muhammadiya | c. 186 | c. 802 | 18.502 | 0.035 | 15.685 | 0.029 | 38.676 | 0.075 | 0.8477 | 0.0003 | 2.0902 | 0.0018 | 293 | 9.93 | 4.00 | E |
| 1043-19 | al-Muhammadiya | 182-183 | 798-800 | 18.448 | 0.001 | 15.648 | 0.001 | 38.583 | 0.002 | 0.84822 | 0.00002 | 2.09143 | 0.00015 | 262 | 9.79 | 3.98 | Dec-19 |
| Han-5 | Balkh | 193-195 | 808-811 | 18.431 | 0.005 | 15.646 | 0.006 | 38.58 | 0.01 | 0.8488 | 0.0001 | 2.0945 | 0.0004 | 271 | 9.79 | 3.99 | D |
| 1037-19 | Zaranj | 190 | 805-806 | 18.406 | 0.002 | 15.638 | 0.002 | 38.557 | 0.005 | 0.84961 | 0.00002 | 2.09476 | 0.00004 | 274 | 9.76 | 3.99 | Dec-19 |
| L-1.787 | Balkh | 190 | 805-806 | 18.3749 | 0.022 | 15.647 | 0.025 | 38.520 | 0.085 | 0.8516 | - | 2.0963 | - | 315 | 9.80 | 3.99 | C |
| Fitz-9 | al-Muhammadiya | 180 | 796-797 | 18.317 | 0.035 | 15.605 | 0.029 | 38.383 | 0.075 | 0.8519 | 0.0003 | 2.096 | 0.002 | 278 | 9.65 | 3.94 | E |
| 1087-19 | al-Shash | 251 | 865 | 18.350 | 0.001 | 15.636 | 0.001 | 38.482 | 0.003 | 0.85210 | 0.00002 | 2.0972 | 0.0001 | 319 | 9.79 | 3.99 | Jan-20 |
| L-1.781 | Balkh | 182 | 798-799 | 18.339 | 0.022 | 15.637 | 0.025 | 38.461 | 0.085 | 0.8527 | - | 2.0972 | - | 322 | 9.77 | 3.98 | C |
| L-1.778 | Bukhara | 193 | 808-809 | 18.365 | 0.022 | 15.665 | 0.025 | 38.588 | 0.085 | 0.8530 | - | 2.1012 | - | 356 | 9.88 | 4.04 | C |
| 1048-19 | Balkh | 189 | 804-805 | 18.211 | 0.002 | 15.609 | 0.001 | 38.281 | 0.003 | 0.85709 | 0.00000 | 2.10196 | 0.00002 | 364 | 9.69 | 3.96 | Dec-19 |
| 1049-19 | Tabaristan | 190 | 805-806 | 18.230 | 0.001 | 15.632 | 0.001 | 38.260 | 0.004 | 0.85752 | 0.00002 | 2.09873 | 0.00004 | 394 | 9.78 | 3.95 | Dec-19 |
| 1081-19 | Marw | 182 | 798-799 | 18.215 | 0.001 | 15.654 | 0.001 | 38.400 | 0.002 | 0.85940 | 0.00002 | 2.1081 | 0.0001 | 445 | 9.87 | 4.04 | Aug-20 |
| L-1.803 | Samarqand | 193 | 808-809 | 18.167 | 0.022 | 15.632 | 0.025 | 38.303 | 0.084 | 0.8605 | - | 2.1084 | - | 439 | 9.79 | 4.01 | C |
| 1965-171 | Samarqand | 193 | 808-809 | 18.157 | 0.022 | 15.642 | 0.025 | 38.325 | 0.084 | 0.8615 | - | 2.1107 | - | 466 | 9.84 | 4.04 | C |
| 1085-19 | al-Shash | 233 | 847-848 | 18.081 | 0.001 | 15.584 | 0.001 | 38.122 | 0.002 | 0.86192 | 0.00002 | 2.1084 | 0.0001 | 415 | 9.62 | 3.96 | Dec-19 |
| 1050-19 | Bukhara | 193 | 808-809 | 18.101 | 0.001 | 15.609 | 0.002 | 38.175 | 0.004 | 0.86232 | 0.00004 | 2.1090 | 0.0002 | 451 | 9.73 | 3.98 | Nov-19 |
| 1051-19 | Bukhara | 193 | 808-809 | 18.076 | 0.002 | 15.600 | 0.002 | 38.144 | 0.005 | 0.86304 | 0.00001 | 2.11014 | 0.00002 | 449 | 9.69 | 3.98 | Dec-19 |
| 1970-335 | Bukhara | 193 | 808-809 | 18.050 | 0.022 | 15.612 | 0.025 | 38.197 | 0.084 | 0.8649 | - | 2.1161 | - | 490 | 9.75 | 4.03 | C |
| Han-6 | Balkh | 193-195 | 808-811 | 18.114 | 0.004 | 15.672 | 0.004 | 38.31 | 0.01 | 0.8651 | 0.0001 | 2.1167 | 0.0003 | 550 | 9.97 | 4.07 | D |
| Han-8 | Samarqand | 195 | 810-811 | 18.091 | 0.004 | 15.665 | 0.005 | 38.28 | 0.01 | 0.8658 | 0.0001 | 2.1175 | 0.0004 | 554 | 9.95 | 4.06 | D |
| 1086-19 | al-Shash | 239 | 853-854 | 17.984 | 0.002 | 15.584 | 0.002 | 38.192 | 0.005 | 0.86655 | 0.00001 | 2.1237 | 0.0001 | 488 | 9.65 | 4.06 | Aug-20 |
| 1083-19 | Marw | 225 | 839-840 | 17.848 | 0.002 | 15.549 | 0.001 | 37.986 | 0.002 | 0.87120 | 0.00001 | 2.12830 | 0.00008 | 532 | 9.57 | 4.04 | Jan-20 |
| 1068-19 | Ma’dan Bajunais | 195 | 810-811 | 18.951 | 0.001 | 15.677 | 0.001 | 39.028 | 0.003 | 0.82723 | 0.00004 | 2.05946 | 0.00010 | -49 | 9.82 | 3.89 | Jan-20 |
| 1069-19 | Ma’dan Bajunais | 204 | 819-820 | 18.942 | 0.002 | 15.696 | 0.002 | 39.006 | 0.005 | 0.82864 | 0.00003 | 2.05922 | 0.00009 | -4 | 9.90 | 3.89 | Jan-20 |
| 1067-19 | Ma’dan Bajunais | 191 | 806-807 | 18.906 | 0.002 | 15.691 | 0.002 | 38.983 | 0.004 | 0.82996 | 0.00003 | 2.06189 | 0.00011 | 14 | 9.89 | 3.90 | Jan-20 |
| 1031-19 | M. al-Salam | 299 | 911-912 | 18.916 | 0.002 | 15.701 | 0.002 | 38.931 | 0.006 | 0.83003 | 0.00003 | 2.05810 | 0.00015 | 18 | 9.90 | 3.87 | Dec-19 |
| 1054-19 | Surra man Ra'ā | 289? | 901-902 | 18.916 | 0.002 | 15.701 | 0.002 | 38.935 | 0.004 | 0.83000 | 0.00001 | 2.05828 | 0.00004 | 24 | 9.92 | 3.88 | Jan-20 |
| 1055-19 | M. al-Salam | 299 | 911-912 | 18.915 | 0.001 | 15.701 | 0.001 | 38.934 | 0.002 | 0.83010 | 0.00001 | 2.05835 | 0.00003 | 19 | 9.90 | 3.87 | Dec-19 |
| 1056-19 | M. al-Salam | 300 | 912-913 | 18.907 | 0.003 | 15.695 | 0.003 | 38.915 | 0.007 | 0.83017 | 0.00002 | 2.05825 | 0.00005 | 14 | 9.88 | 3.87 | Dec-19 |
| 1066-19 | Arminiya | 252 | 866-867 | 18.811 | 0.003 | 15.679 | 0.003 | 38.835 | 0.007 | 0.83353 | 0.00002 | 2.06454 | 0.00003 | 61 | 9.86 | 3.89 | Jan-20 |
| Han-11 | Panjhir | 262 | 875-876 | 18.819 | 0.017 | 15.72 | 0.007 | 39.18 | 0.04 | 0.83520 | 0.00050 | 2.08330 | 0.00030 | 127 | 9.99 | 4.06 | D |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Table S8. Umayyad dirhams elemental results acquired by ICPMS techniques.**

‘-’ means below the detection limit, ‘nm’ means not measured. Total *100* *(Italics)* means normalised total. Laboratory Ref: B. Moscow (Bychov 2011).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Mint | Date (AD) | Ag(%) | Pb(%) | Cu (%) | Au | Cr | Fe | Co | Ni | Zn | As | In | Se | Pd | Sb | Te | Pt | Hg | Bi | Sn | Total (%) | Lab |
| 1024-19 | Dimashq | 708-709 | 94.3 | 1.54 | 3.39 | 7576 | 0.9 | 12 | 0.2 | 2.8 | 19 | 12 | - | 3 | 1.8 | 2.6 | 3.8 | 3.6 | - | 545 | 36 | 102.7 | Ox |
| 1025-19 | Wasit | 707-723 | 94.4 | 0.91 | 4.06 | 6053 | - | 8 | 0.3 | 13 | 71 | 5.7 | - | 3 | 1.6 | 1.8 | 1.5 | 1.8 | - | 289 | 102 | 97.5 | Ox |
| 1042-19 | al-Andalus | 734-737 | 93.9 | 1.09 | 3.39 | 7674 | 0.9 | 666 | 0.1 | 4.4 | 17 | 7.7 | 0.08 | 5 | 1.8 | 7.7 | 2.3 | - | - | 336 | 47 | 100.0 | Ox |
| 1139-19 | al-Mubarakah | 728-729 | 94.2 | 1.89 | 3.32 | 5602 | - | - | 0.1 | 2.6 | 64 | - | 0.08 | 5 | 1.7 | - | 1.5 | 2.1 | - | 132 | 18 | 95.6 | Ox |
| 1140-19 | Shaq al-Taymara | 702-703 | 95.9 | 1.62 | 2.24 | 309 | - | - | 3.8 | 68 | 18 | 22 | 0.10 | 4 | 0.4 | - | 0.5 | 0.2 | - | 1577 | 56 | 96.8 | Ox |
| 1141-19 | al-Basra | 718-719 | 96.4 | 0.62 | 2.49 | 4601 | - | - | 0.2 | 8.1 | 70 | 4.1 | 0.10 | 5 | 1.2 | 2.0 | 1.3 | 1.1 | - | 369 | 75 | 87.2 | Ox |
| 1142-19 | al-Basra | 701-702 | 91.8 | 1.05 | 6.28 | 7734 | - | - | 1.1 | 63 | 202 | 18 | 0.13 | 7 | 1.9 | 5.8 | 2.7 | 2.1 | - | 293 | 216 | 94.9 | Ox |
| 1143-19 | Dimashq | 703-704 | 90.6 | 1.47 | 7.06 | 8204 | 0.5 | - | 0.3 | 10 | 68 | 3.2 | 0.14 | 15 | 1.8 | 4.0 | 2.4 | 1.8 | - | 220 | 65 | 90.0 | Ox |
| 1144-19 | Dimashq | 710-711 | 94.7 | 0.86 | 3.41 | 9853 | 0.7 | - | 0.1 | 1.4 | 41 | - | 0.07 | 7 | 2.1 | 2.7 | 2.3 | 3.1 | - | 149 | 86 | 89.8 | Ox |
| 1145-19 | Abrashahr | 717-718 | 95.0 | 0.88 | 3.06 | 10634 | - | - | 0.1 | 0.4 | 35 | - | 0.19 | 8 | 2.2 | - | 2.0 | 3.1 | - | 26 | - | 90.8 | Ox |
| 1146-19 | Nahr Tira | 713-714 | 92.3 | 2.05 | 4.88 | 7311 | - | - | 0.8 | 18 | 61 | 4.3 | - | 5 | 1.7 | 1.6 | 2.4 | 1.2 | - | 193 | 125 | 95.9 | Ox |
| 1147-19 | Sabur | 715-716 | 92.4 | 1.52 | 5.28 | 7185 | - | - | 0.1 | 4.6 | 37 | 4.7 | 0.10 | 5 | 1.8 | 1.4 | 2.0 | 1.9 | - | 203 | 15 | 91.2 | Ox |
| 1148-19 | Dimashq | 717-718 | 91.4 | 1.86 | 6.49 | 2566 | - | - | 0.1 | 1.1 | 20 | - | 0.12 | 9 | 6.8 | 30 | 1.5 | 0.6 | - | 5.9 | 4.3 | 90.4 | Ox |
| 1149-19 Ph46 | Wasit | 739-740 | 98.5 | 0.80 | 0.30 | 1342 | 0.1 | 11 | 0.1 | 0.9 | 40 | - | - | 3 | 0.6 | - | 0.2 | 0.4 | 0.7 | 1989 | 653 | 95.7 | Ox |
| 1151-19 | Wasit | 729-730 | 98.2 | 0.83 | 0.64 | 2735 | - | - | 0.2 | 1.2 | 33 | 2.0 | 0.27 | 8 | 0.6 | - | 0.3 | 0.7 | 1.8 | 48 | 12 | 97.6 | Ox |
| 1152-19 Ph49 | Wasit | 723-724 | 98.7 | 0.25 | 0.37 | 6581 | - | - | 0.2 | 1.5 | 25 | - | 0.08 | 3 | 2.1 | - | - | 2.2 | 0.4 | 0.5 | - | 95.8 | Ox |
| 1156-19 Ph53 | Wasit | 721-722 | 98.5 | 0.33 | 0.49 | 6663 | - | - | 0.2 | 1.4 | 34 | - | 0.16 | 6 | 2.1 | - | - | 2.1 | 1.5 | 4.6 | - | 97.4 | Ox |
| 1157-19 Ph54 | Wasit | 717-718 | 92.3 | 1.34 | 5.64 | 6545 | - | 29 | 0.3 | 15 | 85 | 8.9 | 0.15 | 7 | 1.7 | 3.7 | 2.1 | 2.1 | - | 272 | 89 | 90.0 | Ox |
| 1158-19 Ph58 | Wasit | 733-734 | 98.5 | 0.14 | 0.64 | 7310 | 0.3 | - | 0.1 | 0.5 | 42 | - | 0.23 | 6 | 2.3 | - | - | 2.2 | - | 74 | - | 90.1 | Ox |
| 1160-19 | Wasit | 715-716 | 91.9 | 1.20 | 6.17 | 6888 | - | - | 0.2 | 14 | 89 | 7.8 | 0.15 | 8 | 1.9 | 3.8 | 2.1 | 1.9 | - | 289 | 83 | 90.0 | Ox |
| 1161-19 | Wasit | 714-715 | 92.8 | 0.89 | 5.45 | 7833 | - | - | 0.1 | 3.3 | 48 | - | 0.15 | 8 | 2.0 | 1.8 | 2.0 | 2.1 | 0.7 | 237 | 39 | 90.1 | Ox |
| 1162-19 Ph59 | Wasit | 704-705 | 92.4 | 1.71 | 5.15 | 6548 | - | - | 0.2 | 14 | 93 | 10 | 0.02 | 7 | 1.7 | 6.3 | 1.9 | 1.9 | - | 274 | 128 | 89.2 | Ox |
| 1163-19 | Wasit | 712-713 | 92.8 | 1.00 | 5.45 | 6673 | 0.1 | 53 | 0.3 | 16 | 140 | 11 | 0.03 | 5 | 2.0 | 3.9 | 2.1 | 2.0 | - | 246 | 138 | 89.5 | Ox |
| 1164-19 | Dimashq | 728-729 | 97.1 | 0.30 | 1.83 | 7194 | 0.3 | - | 0.1 | 0.7 | 36 | - | 0.13 | 4 | 2.1 | - | 0.8 | 2.3 | - | 71 | 25 | 85.2 | Ox |
| 1165-19 | Dimashq | 731-732 | 97.7 | 0.45 | 1.37 | 4248 | - | - | 0.1 | 1.5 | 40 | - | 0.14 | 2 | 1.2 | - | 0.3 | 1.4 | - | 38 | 9.4 | 90.4 | Ox |
| 1166-19 | Mah | 714-715 | 96.5 | 0.52 | 2.58 | 1671 | - | - | 1.8 | 69 | 16 | 5.7 | 0.18 | 6 | 0.6 | 0.7 | 1.1 | 0.2 | - | 2177 | 13 | 89.2 | Ox |
| 1167-19 | Marw | 709-710 | 96.2 | 0.92 | 2.01 | 8968 | - | - | 0.1 | 2.8 | 19 | 12 | - | 3 | 1.8 | 2.6 | 0.8 | 2.6 | - | 26 | 8.4 | 90.2 | Ox |
| M-11 | al-Kufa | 698-701 | 93.7 | 0.56 | 4.57 | 11680 | - | nm | 4 | - | - | nm | nm | nm | nm | nm | nm | nm | nm | 225 | - | *100* | B |

**Table S9.** **North African dirhams elemental results acquired by ICPMS techniques**.

The full range of elements was not measured in two samples due to lack of sufficient sample material. \*Analyses in parentheses are pXRF analyses on cleaned (abraded) surfaces. ‘-’ means below the detection limit, ‘nm’ means not measured. Total *100* *(Italics)* means normalised total. Laboratory Ref: B. Moscow (Bychov 2011); C. Orleans (Sarah 2008); D. Hanover (Merkel 2016).

\*Due to insufficient sample material, we report the bismuth and copper concentrations measured by pXRF for two dirhams (1062-19 and 1065-19). Since all the dirhams analysed by (bulk) ICPQMS at the School of Geography, University of Oxford, were also analysed by pXRF (Thermo Scientific Niton™ XL3T Analyzer) after abrasive cleaning, it is possible to compare the data directly. Copper was strongly correlated (r2= 0.92). The comparison indicated that the detection limit for bismuth was between 300-400ppm and above this concentration, the values are strongly correlated (r2=0.94) and this is independent of the lead content. The analytical resolution for bismuth contents above 400ppm are adequate and we report no issues with spectral peak overlap or interference for bismuth above this concentration.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Lab. Nr. | Mint | Date (AD) | Ag(%) | Pb(%) | Cu (%) | Au | Cr | Fe | Co | Ni | Zn | As | In | Se | Pd | Sb | Te | Pt | Hg | Bi | Sn | Total(%) | Lab |
| 1058-19 | Tudgha | 790-791 | 97.4 | 1.86 | 0.72 | 11 | - | - | 0.3 | 4.4 | 36 | - | 0.5 | 8.4 | 1.0 | - | - | - | 1 | 14 | - | 99 | Ox |
| 1060-19 | Tudgha | 791-792 | 92.5 | 0.87 | 6.63 | - | - | - | 0.1 | 1.4 | 10 | - | 0.2 | 5.5 | 0.8 | - | - | - | - | 15 | - | 100 | Ox |
| Han-1 | al-'Abbasiya | 776-786 | 95.4 | 0.62 | 4.56 | 4 | nm | - | 0.6 | 8.6 | 6 | - | 0.2 | 24 | 3.0 | 3.1 | nm | - | 187 | 22 | 1 | 101 | D |
| Han-2 | al-'Abbasiya | 787-792 | 97.9 | 1.28 | 2.04 | 13 | nm | - | 0.6 | 16.4 | 20 | 1.3 | - | 19 | 1.4 | 2.0 | nm | - | 211 | 8 | 3 | 101 | D |
| Han-4 | al-'Abbasiya | 786-790 | 97.8 | 0.74 | 2.17 | 24 | nm | - | 0.1 | 4.7 | 41 | 1.3 | - | 18 | 1.4 | 128 | nm | - | 195 | 19 | 3 | 101 | D |
| Han-3 | Ifriqiya | 792-794 | 94.0 | 1.03 | 6.01 | 1 | nm | - | - | 1.9 | - | 5.1 | - | - | 3.6 | 6.3 | nm | - | 303 | 9 | 2 | 101 | D |
| 1062-19 | Ifriqiya | 782-783 | 94.3 | 0.72 | (4.9) | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | (<400) | nm | 92 | Ox |
| 1063-19 | Ifriqiya | 788-789 | 95.1 | 2.58 | 2.33 | - | - | - | 0.2 | 1.3 | 50 | - | 0.4 | 15 | 1.2 | 52 | 0.6 | - | - | 14 | - | 95 | Ox |
| L-1.777 | Ifriqiya | 790-791 | 79.7 | 1.48 | 18.2 | 11 | nm | 25 | nm | 18 | 10 | 42 | 0.1 | - | 2.3 | 765 | 0.2 | 0.04 | 4598 | 65 | 14 | *100* | C |
| 1064-19 | Ifriqiya | 783-784 | 97.0 | 2.26 | 0.58 | 23 | - | - | 0.2 | 1.2 | 30 | - | 0.3 | 4.6 | 0.8 | 8.1 | 0.4 | 0.30 | - | 1853 | - | 96 | Ox |
| 1065-19 | Ifriqiya | 790-791 | 97.3 | 2.09 | (0.7) | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | (1800) | nm | 98 | Ox |
| M-10 | Ifriqiya | 785-786 | 97.6 | 0.25 | 1.57 | 1 | - | nm | - | - | 1810 | nm | nm | nm | nm | nm | nm | nm | nm | 3411 | - | *100* | B |

**Table S10.** **Abbasid-period dirhams from central and eastern mints - elemental results acquired by ICPMS techniques**.

‘-’ means below the detection limit, ‘nm’ means not measured. Total *100* *(Italics)* means normalised total. Laboratory Ref: Ox = University of Oxford (this study); SH = University of Southampton (this study); B. Moscow (Bychov 2011); C. Orleans (Sarah 2008); D. Hanover (Merkel 2016); E. Southampton (Standish *et al*. 2021).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Lab. Nr. | Mint | AD | Ag  (%) | Pb  (%) | Cu  (%) | Au | Cr | Fe | Co | Ni | Zn | As | In | Se | Pd | Sb | Te | Pt | Hg | Bi | Sn | Total  (%) | Lab |
| 1026-19 | M. al-Salam | 773-774 | 99.3 | 0.26 | 0.17 | 2505 | 0.1 | 280 | 0.1 | 1.1 | 31 | - | - | 1.2 | 0.9 | 3.1 | 1.2 | 0.5 | - | 54 | 200 | 98.3 | Ox |
| 1046-19 | M. al-Salam | 795-796 | 98.0 | 0.17 | 1.50 | 1827 | - | - | 0.1 | 1237 | 21 | - | 0.16 | 5.1 | 0.3 | - | 0.2 | 0.1 | 0.2 | 14 | - | 103.6 | Ox |
| 1036-19 | al-Rafiqa | 805-806 | 99.5 | 0.25 | 0.09 | 1357 | - | - | 0.2 | 2.4 | 24 | 23 | 0.15 | 3.7 | 0.9 | 13 | 0.2 | 0.6 | - | 1.4 | - | 92.1 | Ox |
| 1047-19 | M. al-Salam | 803-804 | 99.5 | 0.30 | 0.08 | 687 | - | 513 | 0.1 | 2.3 | 21 | 20 | 0.07 | 3.2 | 0.4 | 28 | 0.2 | 0.9 | - | 4.4 | 24 | 94.0 | Ox |
| Fitz-6 | M. al-Salam | 773-774 | 0.0 | 0.17 | nm | 3000 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 10.3 | nm | nm | SH |
| 1028-19 | M. al-Salam | 777-778 | 99.6 | 0.10 | 0.09 | 2289 | - | 16 | 0.05 | 2.1 | 16 | - | 0.04 | 2.3 | 0.9 | 2.9 | - | 0.7 | - | 10 | 8.8 | 98.5 | Ox |
| 1029-19 | M. al-Salam | 779-780 | 99.5 | 0.17 | 0.11 | 2234 | - | 104 | 0.1 | 1.0 | 32 | - | 0.06 | 3.4 | 1.4 | 4.3 | 0.2 | 0.5 | 0.1 | 94 | 11 | 97.2 | Ox |
| Han-10 | Surra man Ra'ā | 871/872 | 99.0 | 0.33 | 0.62 | 2521 | nm | - | 0.2 | 0.4 | 1086 | 1.2 | - | 2.7 | 1.1 | 0.8 | nm | 0.9 | 59 | 12 | 16 | 100.3 | D |
| M-1 | M. al-Salam | 788-789 | 98.5 | 0.26 | 0.20 | 10330 | - | nm | - | - | - | nm | nm | nm | nm | nm | nm | nm | nm | 6.0 | 7.0 | *100* | B |
| Fitz-12 | M. al-Salam | 791-792 | nm | 2.30 | nm | 9600 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 200 | nm | nm | SH |
| 1045-19 | M. al-Salam | 805-809 | 99.1 | 0.66 | 0.08 | 1733 | - | 14 | 0.1 | 2.3 | 21 | 25 | 0.08 | 2.0 | 0.7 | 15 | - | 0.6 | 0.1 | 4.2 | - | 93.7 | Ox |
| 1044-19 | M. al-Salam | 777-778 | 99.6 | 0.07 | 0.12 | 2044 | - | - | 0.4 | 2.2 | 30 | - | 0.15 | 8.3 | 1.1 | 2.1 | - | 0.7 | - | 24 | 9.4 | 97.5 | Ox |
| Fitz-17 | M. al-Salam | 808-809 | nm | 1.85 | nm | 1600 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 4.0 | nm | nm | SH |
| 1074-19 | Surra man Ra'ā | 847-848 | 98.3 | 0.17 | 1.03 | 5431 | - | - | 0.2 | 0.8 | 45 | 15 | 0.25 | 15 | 1.0 | - | - | 0.9 | - | 7.5 | - | 98.2 | Ox |
| Fitz-13 | M. al-Salam | 803-804 | nm | 0.42 | nm | 1400 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 1.0 | nm | nm | SH |
| 1039-19 | Surra man Ra'ā | 895-896 | 97.0 | 1.00 | 1.56 | 3803 | - | 13 | 0.1 | 3.8 | 52 | - | 0.16 | 12 | 1.0 | 4.8 | 1.4 | 4.3 | 3.3 | 269 | 30 | 89.5 | Ox |
| Fitz-23 | M. al-Salam | 778-779 | nm | 0.23 | nm | 3400 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 50 | nm | nm | SH |
| 1073-19 | M. al-Salam | 851-852 | 98.3 | 0.14 | 1.04 | 4719 | - | - | 0.2 | 0.4 | 37 | 2.9 | 0.37 | 8.1 | 1.0 | - | - | 0.7 | 0.2 | 12 | - | 95.5 | Ox |
| 1075-19 | Surra man Ra'ā | 853-854 | 98.9 | 0.16 | 0.58 | 2699 | - | - | 0.2 | 0.6 | 30 | 3.6 | - | 2.6 | 0.6 | 0.8 | - | 0.6 | 26 | 24 | 497 | 77.9 | Ox |
| 1072-19 | M. al-Salam | 796-797 | 96.2 | 0.44 | 2.48 | 8160 | - | - | 0.3 | 1.3 | 80 | - | 0.46 | 18 | 1.1 | 24 | 1.0 | 0.5 | 62 | 87 | - | 95.7 | Ox |
| M-2 | M. al-Salam? | 770-774 | 99.3 | 0.11 | 0.08 | 3770 | - | - | - | - | 1080 | nm | nm | nm | nm | nm | nm | nm | nm | 149 | - | *100* | B |
| M-9 | M. al-Salam | 806 | 99.0 | 0.55 | 0.08 | 3570 | - | - | - | - | - | nm | nm | nm | nm | nm | nm | nm | nm | 8.0 | - | *100* | B |
| Fitz-16 | M. al-Salam | 808-809 | nm | 2.64 | nm | 700 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 1.0 | nm | nm | SH |
| Fitz-21 | M. al-Salam | 777-778 | nm | 0.15 | nm | 2000 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 29 | nm | nm | SH |
| M-7 | M. al-Salam? | 805-808 | 99.1 | 0.54 | 0.08 | 3100 | - | - | - | - | - | nm | nm | nm | nm | nm | nm | nm | nm | 4.0 | - | *100* | B |
| 1040-19 | M. al-Salam | 905-906 | 96.4 | 2.45 | 0.83 | 2369 | - | 27 | 0.1 | 2.3 | 30 | 2.4 | 0.07 | 1.9 | 0.7 | - | 1.3 | 0.5 | 0.1 | 736 | 4.0 | 98.9 | Ox |
| Fitz-7 | M. al-Salam | 776-777 | nm | 0.26 | nm | 1600 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 9.3 | nm | nm | SH |
| 1033-19 | M. al-Salam | 808-809 | 97.7 | 1.65 | 0.54 | 451 | - | - | 0.1 | 9 | 128 | 86 | 0.20 | 10 | 0.6 | 136 | - | 0.3 | - | 89 | 15 | 98.1 | Ox |
| L-1.779 | al-Basra | 797-798 | 98.8 | 0.39 | 0.20 | 3656 | nm | 72 | nm | - | 19 | 18 | 0.03 | - | 1.3 | 3.2 | 0.27 | 1.0 | 1748 | 2.7 | 2.9 | *100* | C |
| Fitz-15 | M. al-Salam | 805-806 | nm | 0.59 | nm | 3400 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 2.0 | nm | nm | SH |
| L-1.861 | M. al-Salam | 808-809 | 98.5 | 1.12 | 0.20 | 1895 | nm | 92 | nm | 2.94 | 25 | 27 | 0.03 | - | 0.7 | 14 | 0.16 | 0.5 | 498 | 1.22 | 1.29 | *100* | C |
| 1057-19 | M. al-Salam/Basra | 941-942 | 96.6 | 1.12 | 1.86 | 3485 | - | 67 | 0.2 | 2 | 49 | 14 | 0.06 | 2.5 | 0.7 | 0.7 | 2.7 | 0.6 | 0.1 | 836 | 29 | 93.1 | Ox |
| 1052-19 | M. al-Salam | 823-824 | 99.3 | 0.11 | 0.17 | 2876 | 0.1 | 223 | 0.5 | 1472 | 17 | 7.2 | 0.03 | 1.5 | 0.9 | 2.2 | 0.1 | 0.9 | 0.6 | 6.2 | 12 | 100.8 | Ox |
| Fitz-20 | M. al-Salam | 818-819 | nm | 2.13 | nm | 3700 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 190 | nm | nm | SH |
| Han-9 | M. al-Salam | (84)7 | 94.7 | 0.25 | 5.30 | 10 | nm | - | 3.4 | 12.1 | 9.0 | 1.5 | 0.30 | 11.6 | 3.4 | 2.4 | nm | - | 124 | 204 | 17 | 100.3 | D |
| 1077-19 | Tabaristan | 771 | 92.1 | 1.08 | 6.74 | 121 | - | - | 1.7 | 83 | 35 | 14 | 0.26 | 13 | 0.6 | 3.1 | 1.7 | 0.4 | - | 689 | 18 | 97.1 | Ox |
| 1079-19 | Tabaristan | 772 | 90.7 | 0.90 | 7.90 | 3795 | - | - | 2.7 | 120 | 71 | 95 | 0.25 | 23 | 0.6 | 27 | 3 | 0.4 | - | 327 | 179 | 100.1 | Ox |
| 1053-19 | al-Muhammadiya | 866-869 | 93.8 | 1.66 | 3.27 | 1385 | - | 219 | 0.4 | 16 | 133 | 63 | 0.05 | 4.6 | 0.6 | 9.0 | 6.7 | 0.3 | - | 11176 | 82 | 98.8 | Ox |
| Fitz-14 | M. al-Salam | 803-804 | nm | 0.56 | nm | 1700 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 80 | nm | nm | SH |
| 1030-19 | M. al-Salam | 781-782 | 97.5 | 0.32 | 1.81 | 788 | 0.1 | 597 | 5.5 | 16 | 89 | 10 | - | 2.9 | 0.4 | 5.0 | 0.7 | 0.3 | - | 2500 | 119 | 96.1 | Ox |
| 1088-19 | w/o writing | 9th C. | 99.0 | 0.35 | 0.27 | 642 | - | - | 0.2 | 0.8 | 55 | 4.7 | 0.10 | 5.6 | 0.4 | - | 0.4 | 0.3 | - | 2850 | 20 | 96.3 | Ox |
| Fitz-8 | M. al-Salam | 779-780 | nm | 0.04 | nm | 1900 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 19 | nm | nm | SH |
| Fitz-19 | M. al-Salam | 813-814 | nm | 1.81 | nm | 3500 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 830 | nm | nm | SH |
| 1082-19 | Marw | 814-815 | 97.3 | 0.59 | 1.53 | 5794 | - | - | 0.4 | 2.0 | 78 | 7.0 | 0.53 | 16 | 1.0 | 6 | - | 0.7 | 0.9 | 100 | - | 99.2 | Ox |
| 1076-19 | Surra man Ra'ā | 867 | 78.3 | 1.23 | 20.00 | 2880 | - | 34 | 0.9 | 84 | 386 | 679 | 0.18 | 12 | 0.7 | 128 | 7.9 | 0.6 | - | 171 | 63 | 101.7 | Ox |
| Fitz-3 | al-Muhammadiya | 771 | nm | 0.19 | nm | 1800 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 220 | nm | nm | E |
| 1070-19 | al-Basra | 751-752 | 91.2 | 1.71 | 5.76 | 13272 | - | - | 0.5 | 2.2 | 98 | - | 0.47 | 35 | 2.1 | - | 3.7 | 1.7 | - | 219 | - | 98.7 | Ox |
| Han-7 | al-Muhammadiya | 794-803 | 98.8 | 1.24 | 1.04 | 489 | nm | - | 0.1 | 1.0 | 40 | - | - | 15.3 | 1.0 | 0.3 | nm | 0.2 | 180 | 450 | 2 | 101.2 | D |
| 1084-19 | Marw | 854-855 | 94.5 | 1.01 | 3.94 | 3932 | - | - | 0.3 | 13 | 174 | 142 | - | 6.4 | 0.9 | 18 | 1.9 | 0.8 | - | 718 | 906 | 97.1 | Ox |
| Han-12 | Shiraz | 878-884 | 97.0 | 0.92 | 2.68 | 2338 | nm | - | 0.3 | 3.1 | 306 | 36.5 | 0.70 | 5.1 | 2.4 | 13.4 | nm | 0.7 | 192 | 737 | 200 | 101.0 | D |
| 1034-19 | Madinat Isfahan | 820-821 | 97.7 | 1.59 | 0.42 | 2761 | 2.4 | 56 | 0.1 | 1.9 | 0.9 | 6.3 | - | 4.5 | 0.7 | - | - | 0.8 | - | 43 | 2.0 | 100.2 | Ox |
| 1071-19 | al-Basra | 814-815 | 98.4 | 0.18 | 0.91 | 5358 | - | - | 0.2 | 0.3 | 27 | - | 0.29 | - | 1.3 | - | 0.9 | 0.7 | 0.3 | 3.5 | - | 95.5 | Ox |
| M-5 | Zaranj | 800-801 | 98.1 | 1.01 | 0.58 | 1400 | - | - | nm | - | - | nm | nm | nm | nm | nm | nm | nm | nm | 2258 | - | *100* | B |
| Fitz-18 | Madinat. Isbahan | 816-817 | nm | 1.49 | nm | 2400 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 20 | nm | nm | SH |
| 1032-19 | al-Muhammadiya | 799-800 | 97.8 | 1.46 | 0.63 | 269 | - | - | 0.1 | 1.4 | 22 | - | 0.11 | 4.6 | 0.4 | - | 0.6 | 0.2 | - | 738 | - | 97.8 | Ox |
| 1038-19 | (M. al-Salam) Ov. | 810-811 | 98.7 | 0.91 | 0.17 | 1733 | 0.2 | 401 | 0.1 | 1.0 | 16 | 1 | 0.07 | 2.9 | 0.6 | 3.1 | 0.2 | 1.1 | 11 | 2 | 12 | 99.9 | Ox |
| Fitz-11 | al-Muhammadiya | 803-805 | nm | 0.06 | nm | 200 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 17 | nm | nm | E |
| Fitz-24 | al-Muhammadiya | 815-816 | nm | 2.33 | nm | 300 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 230 | nm | nm | E |
| 1041-19 | al-Rayy (Muham.) | 765-766 | 98.3 | 1.12 | 0.28 | 2485 | - | 329 | 0.03 | 0.7 | 43 | - | 0.09 | 2.1 | 0.8 | 0.7 | 0.4 | 1.0 | 4.8 | 153 | 6.1 | 98.9 | Ox |
| 1080-19 | Tabaristan | 788 | 93.3 | 0.58 | 6.00 | 701 | - | - | 1.1 | 13 | 65 | 6.8 | 0.37 | 15 | 0.9 | 3.2 | - | 0.4 | - | 389 | - | 94.4 | Ox |
| 1027-19 | al-Muhammadiya | 766-767 | 56.4 | 0.68 | 42.70 | 2328 | 1.2 | - | 0.1 | 3.0 | 28 | - | 0.11 | 4.3 | 1.7 | 3.1 | 0.5 | 0.6 | - | 26 | 16 | 96.0 | Ox |
| M-4 | M. Isbahan | 816-817 | 99.4 | 0.14 | 0.06 | 4210 | - | - | nm | - | - | nm | nm | nm | nm | nm | nm | nm | nm | 13 | - | *100* | B |
| L-1.859 | al-Muhammadiya | 809-810 | 99.7 | 0.07 | 0.10 | 330 | nm | 98 | nm | 2.3 | 72 | 0.6 | 0.03 | - | 0.3 | 0.1 | 0.7 | 0.2 | 374 | 42 | 1.1 | *100* | C |
| 1035-19 | M. al-Salam | 768 | 99.3 | 0.19 | 0.13 | 3306 | - | - | 0.1 | 2.3 | 22 | - | 0.09 | 3.4 | 1.3 | 2.4 | 0.4 | 0.6 | - | 20 | 12 | 97.2 | Ox |
| M-8b | Isfahan | 820-821 | 97.5 | 0.75 | 1.31 | 4170 | - | - | nm | - | - | nm | nm | nm | nm | nm | nm | nm | nm | 29 | - | *100* | B |
| Fitz-4 | M. al-Salam | 769-770 | nm | 0.07 | nm | 3500 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 14 | nm | nm | SH |
| 1078-19 | Tabaristan | 778 | 91.6 | 1.03 | 6.96 | 3245 | - | - | 0.5 | 18 | 63 | 23 | 0.43 | 10 | 0.6 | 13 | 1.4 | 0.4 | - | 594 | 121 | 99.4 | Ox |
| Fitz-5 | M. al-Salam | 771 | nm | 0.03 | nm | 1600 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 12 | nm | nm | SH |
| Fitz-2 | al-Muhammadiya | 767-768 | nm | 0.63 | nm | 2000 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 990 | nm | nm | E |
| Fitz-10 | al-Muhammadiya | 800-801 | nm | 1.39 | nm | 400 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 540 | nm | nm | E |
| Fitz-1 | al-Muhammadiya | 765-766 | nm | 1.57 | nm | 1300 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 540 | nm | nm | E |
| Fitz-22 | al-Muhammadiya | c. 802 | nm | 1.25 | nm | 300 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 680 | nm | nm | E |
| 1043-19 | al-Muhammadiya | 798-800 | 98.5 | 0.86 | 0.49 | 412 | - | 43 | 0.1 | 3.9 | 44 | - | 0.12 | 2.8 | 0.4 | - | 0.6 | 0.1 | 0.2 | 1405 | - | 92.4 | Ox |
| Han-5 | Balkh | 808-811 | 95.6 | 1.00 | 4.18 | 385 | nm | - | 3.0 | 9.1 | 44 | 48 | 0.30 | 14 | 2.8 | 22 | nm | - | 160 | 1470 | 4 | 101.0 | D |
| 1037-19 | Zaranj | 805-806 | 98.1 | 1.07 | 0.69 | 562 | 5.4 | 65 | 0.2 | 2.2 | 28 | - | 0.14 | 5.2 | 0.2 | 2.0 | 1.4 | 0.5 | 0.2 | 1114 | 13 | 91.9 | Ox |
| L-1.787 | Balkh | 805-806 | 99.2 | 0.42 | 0.20 | 252 | nm | 3.6 | nm | - | 0.5 | 0.1 | - | - | 0.24 | 0.01 | 0.13 | 0.1 | 411 | 885 | 1.9 | *100* | C |
| Fitz-9 | al-Muhammadiya | 796-797 | nm | 0.34 | nm | 500 | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | nm | 760 | nm | nm | E |
| 1087-19 | al-Shash | 865 | 96.1 | 1.27 | 1.80 | 5442 | - | - | 0.3 | 1.2 | 46 | - | 0.19 | 14 | 0.5 | 5.7 | 4.0 | 0.2 | - | 2409 | - | 98.2 | Ox |
| L-1.781 | Balkh | 798-799 | 96.2 | 0.91 | 2.70 | 323 | nm | - | nm | 3.2 | 0.8 | 6.8 | 0.22 | - | 0.82 | 1.4 | 0.27 | 0.04 | 635 | 1177 | 6.4 | *100* | C |
| L-1.778 | Bukhara | 808-809 | 99.4 | 0.24 | 0.10 | 212 | nm | 10 | nm | - | 0.4 | - | - | - | 0.18 | 0.01 | 0.23 | - | 391 | 1969 | 0.33 | *100* | C |
| 1048-19 | Balkh | 804-805 | 99.1 | 0.49 | 0.18 | 199 | - | 17 | 0.1 | 6.0 | 30 | - | 0.10 | 2.0 | 0.2 | - | 0.3 | 0.03 | 0.1 | 1845 | - | 89.7 | Ox |
| 1049-19 | Tabaristan | 805-806 | 99.5 | 0.30 | 0.17 | 228 | - | 12 | 0.1 | 5.8 | 57 | - | 0.18 | 4.5 | 1 | - | - | 0.3 | 0.2 | 71 | - | 96.2 | Ox |
| 1081-19 | Marw | 798-799 | 96.6 | 0.97 | 1.96 | 4146 | - | - | 1.8 | 3.5 | 36 | 3 | 0.34 | 10 | 0.5 | - | 0.6 | 0.2 | - | 571 | 11 | 97.4 | Ox |
| L-1.803 | Samarqand | 808-809 | 98.9 | 0.44 | 0.30 | 247 | nm | 2.6 | nm | - | 0.9 | 0.8 | 0.01 | - | 0.26 | 0.06 | 1.4 | 0.03 | 940 | 2332 | 0.41 | *100* | C |
| 1965-171 | Samarqand | 808-809 | 98.8 | 0.46 | 0.20 | 273 | nm | 15 | nm | - | 0.9 | 0.23 | - | - | 0.29 | 0.73 | 0.02 | 0.02 | 2942 | 2763 | 1.4 | 100.1 | Ox |
| 1085-19 | al-Shash | 847-848 | 99.3 | 0.38 | 0.13 | 131 | - | - | 0.1 | 1.7 | 36 | - | 0.24 | 7.7 | 0.4 | - | 1.2 | 0.03 | - | 2018 | - | 99.8 | Ox |
| 1050-19 | Bukhara | 808-809 | 99.0 | 0.63 | 0.18 | 168 | - | 84 | 0.1 | 1.1 | 8.9 | - | 0.06 | 1.1 | 0.1 | - | 0.4 | 0.03 | 0.3 | 1822 | - | 93.9 | Ox |
| 1051-19 | Bukhara | 808-809 | 98.6 | 0.80 | 0.16 | 185 | 0.7 | 2310 | 0.8 | 2.7 | 9.4 | - | - | 7.0 | 0.1 | 5.6 | 0.6 | 1.0 | 2.7 | 1665 | 5.2 | 95.0 | Ox |
| 1970-335 | Bukhara | 808-809 | 98.9 | 0.44 | 0.30 | 219 | nm | 1.6 | nm | - | 0.4 | 0.05 | - | - | 0.29 | 0.17 | 1.7 | 0.1 | 1013 | 2250 | - | *100* | C |
| Han-6 | Balkh | 808-811 | 99.3 | 0.45 | 0.63 | 738 | nm | - | 0.1 | 0.8 | 83 | - | - | 13.4 | 0.6 | 0.3 | nm | 0.2 | 158 | 40 | - | 100.5 | D |
| Han-8 | Samarqand | 810-811 | 99.3 | 0.63 | 0.43 | 1059 | nm | - | 0.1 | 0.5 | 650 | - | - | 10.7 | 0.6 | 0.2 | nm | 0.2 | 126 | 553 | - | 100.6 | D |
| 1086-19 | al-Shash | 853-854 | 96.9 | 0.88 | 1.43 | 5262 | - | - | 0.1 | 0.3 | 42 | - | 0.21 | 13 | 0.4 | 2.2 | 8.4 | 0.1 | - | 2916 | - | 97.5 | Ox |
| 1083-19 | Marw | 839-840 | 98.7 | 0.08 | 0.71 | 2844 | - | - | 0.3 | 0.9 | 55 | 9 | 0.13 | 6.2 | 0.3 | - | 1.7 | 0.1 | - | 2204 | - | 96.9 | Ox |
| 1068-19 | M. Bajunais | 810-811 | 96.6 | 0.90 | 1.75 | 19 | - | - | 0.1 | 0.9 | 102 | 4 | 0.32 | 10 | 1.8 | 1.8 | 18 | 0.8 | 0.6 | 6903 | 4.2 | 96.8 | Ox |
| 1069-19 | M. Bajunais | 819-820 | 96.8 | 2.89 | 0.21 | 6.5 | - | - | 0.2 | 0.9 | 53 | - | 0.31 | 11 | 0.5 | - | 0.5 | 0.1 | 0.8 | 1137 | 10 | 96.8 | Ox |
| 1067-19 | M. Bajunais | 806-807 | 96.5 | 3.26 | 0.16 | 4.4 | - | - | 0.1 | 0.3 | 48 | - | 0.18 | 4.7 | 0.3 | - | 0.3 | 0.01 | 3.9 | 589 | - | 97.5 | Ox |
| 1031-19 | M. al-Salam | 911-912 | 95.3 | 2.38 | 1.85 | 1982 | - | 47 | 0.1 | 3.9 | 42 | - | 0.09 | 5.8 | 0.6 | 1.1 | 7.1 | 0.6 | - | 2153 | 8.4 | 98.9 | Ox |
| 1054-19 | Surra man Ra'ā | 901-902 | 94.8 | 2.22 | 2.49 | 3132 | 0.6 | 39 | 0.3 | 15 | 44 | 9 | 0.15 | 3.0 | 0.6 | 0.9 | 2.9 | 0.5 | - | 1655 | - | 98.6 | Ox |
| 1055-19 | M. al-Salam | 911-912 | 96.0 | 2.01 | 1.51 | 2269 | - | 416 | 0.3 | 6.3 | 18 | - | - | 7.1 | 0.6 | 1.7 | 6.2 | 33.6 | 0.2 | 1903 | 554 | 96.8 | Ox |
| 1056-19 | M. al-Salam | 912-913 | 95.4 | 2.26 | 2.07 | 507 | - | 667 | 0.1 | 3.0 | 55 | 7 | 0.03 | 3.3 | 0.7 | 12 | 7.1 | 0.5 | - | 1703 | 53 | 94.7 | Ox |
| 1066-19 | Arminiya | 866-867 | 67.3 | 1.21 | 30.67 | 5899 | - | - | 4.4 | 144 | 76 | 1135 | 1.30 | 31 | 1 | 400 | 13 | 0.6 | - | 115 | 59 | 94.5 | Ox |
| Han-11 | Panjhir | 875-876 | 98.7 | 0.36 | 0.12 | 3.0 | nm | - | 0.1 | 0.8 | 20 | 5.4 | 0.10 | 7.9 | - | 6.5 | nm | 0.2 | 132 | 11788 | 4.0 | 100.4 | D |

**Table S11.** **Statistical tests comparing different categories of dirhams: Umayyad (*c*. AD 698–740), Abbasid-era North African (*c*. AD 776–794), Iranian (Tehran AD 765–869), Iraqi (Baghdad AD 773–906), and Central Asia (AD 798–865).**

The Mann-Whitney U Test was used to compare two datasets, and, using the Bonferroni correction, the significance limit for vertical columns is p<0.005 and for horizontal rows p<0.0167. The three variables used are the LIRI (lead isotope ratio index, see D’Imporanzo *et al*. 2021), the two most important source related elements, gold and bismuth. The values in italics fail the vertical significance test and those in bold fail horizontally. Those failing the statistical test indicate that the two datasets are not significantly different.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sample 1 | Sample 2 | LIRI | Au | Bi |
| Umayyad | N. Africa | ***0.15272*** | <0.00001 | ***0.1010*** |
| Umayyad | Iran | ***0.08544*** | <0.00001 | ***0.11876*** |
| Umayyad | Iraq | <0.00001 | <0.00001 | 0.00030 |
| Umayyad | C. Asia | <0.00001 | <0.00001 | <0.00001 |
| N. Africa | Iran | ***0.78716*** | <0.00001 | ***0.06876*** |
| N. Africa | Iraq | <0.00001 | <0.00001 | ***0.25848*** |
| N. Africa | C. Asia | 0.00158 | <0.00001 | 0.00480 |
| Iran | Iraq | <0.00001 | 0.00026 | 0.00014 |
| Iran | C. Asia | 0.00016 | ***0.65272*** | 0.00228 |
| Iraq | C. Asia | <0.00001 | *0.00804* | <0.00001 |

**Table S12. Oxford Geography solution-based ICPQMS analyses of silver reference materials.**

MBH-133X-AGA3 and MBH 133X-AGA1 compared to the given values. Elements are in ppm unless otherwise stated. Ag given values are calculated assuming it makes up the rest. The standard deviations of the Oxford analyses are two or more measurements from different digestions in different sessions. n.g. means not given and n.d. means not detected.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| AGA3 | Ag(%) | Pb(%) | Cu (%) | Au(%) | Cr | Fe | Co | Ni | Zn | As | In | Se | Pd | Sb | Te | Pt | Hg | Bi | Sn | Total (%) |
| **Measured** | **86.3** | **2.13** | **5.03** | **0.250** | **85** | **240** | **53** | **417** | **8559** | **68** | **154** | **45** | **273** | **3914** | **28** | **349** | **n.d.** | **520** | **8068** | **96.0** |
| Measured SD | ±1.1 | - | ±0.11 | ±0.16 | ±9 | ±29 | ±2 | ±3 | ±88 | - | - | ±4 | ±111 | ±400 | - | ±1 | - | ±39 | - | - |
| **Given** | ***91.0*** | **1.89** | **4.91** | **0.258** | **86** | **150** | **50** | **450** | **8160** | **80** | **134** | **44** | **156** | **4590** | **54** | **256** | **n.g.** | **480** | **9210** | ***100*** |
| Given Uncertainty | n.g. | ±0.05 | ±0.08 | ±0.002 | ±17 | n.g. | ±1 | ±47 | ±100 | ±2 | ±2 | ±1 | ±1 | ±20 | n.g. | ±4 | n.g. | ±10 | ±70 | n.g. |
| Recovery | 95% | 113% | 102% | 97% | 88% | 88% | 103% | 92% | 104% | 85% | 115% | 103% | 103% | 85% | 52% | 136% | - | 108% | 88% | - |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| AGA1 | Ag(%) | Pb(%) | Cu (%) | Au(%) | Cr | Fe | Co | Ni | Zn | As | In | Se | Pd | Sb | Te | Pt | Hg | Bi | Sn | Total (%) |
| **Measured** | **79.1** | **0.193** | **19.27** | **1.48** | **40** | **338** | **401** | **115** | **2055** | **243** | **40** | **166** | **69** | **474** | **250** | **73** | **0.4** | **2129** | **2388** | **100.9** |
| Measured SD | ±0.1 | ±0.01 | ±0.8 | ±0.08 | ±24 | ±160 | ±34 | ±8 | ±79 | ±1 | - | ±20 | ±29 | ±22 | ±4 | ±3 | ±<0.1 | ±36 | ±193 | - |
| **Given** | ***77.4*** | **0.207** | **19.95** | **1.48** | **20** | **390** | **406** | **118** | **2110** | **255** | **37** | **169** | **54** | **500** | **271** | **67** | **n.g.** | **1940** | **2910** | ***100*** |
| *Given Uncertainty* | n.g. | ±0.007 | ±0.21 | ±0.03 | ±2 | ±10 | ±7 | ±3 | ±50 | ±9 | ±4 | ±5 | ±<1 | ±10 | n.g. | ±1 | n.g. | ±60 | ±100 | n.g. |
| Recovery | 102% | 93% | 97% | 100% | 198% | 87% | 99% | 98% | 97% | 95% | 108% | 98% | 128% | 95% | 92% | 109% | - | 110% | 82% | - |

**Table S13. Oxford Earth Sciences lead isotope analyses of NIST981 and NIST982 lead isotope standards**.

These are average values during the measurement sessions. NIST981 are the measured values and the NIST982 are adjusted values after normalising to the NIST981 values of Todt *et al*. 1996. NIST982 was not measured in Mar-21.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Date | 206Pb/204Pb | 2SD | 207Pb/204Pb | 2SD | 208Pb/204Pb | 2SD | 207Pb/206Pb | 2SD | 208Pb/206Pb | 2SD |
| NIST981 | Sep-19 | 16.933 | 0.002 | 15.485 | 0.002 | 36.678 | 0.005 | 0.91449 | 0.00010 | 2.16615 | 0.00032 |
|  | Nov-19 | 16.932 | 0.002 | 15.485 | 0.002 | 36.681 | 0.006 | 0.91457 | 0.00004 | 2.16641 | 0.00019 |
|  | Dec-19 | 16.932 | 0.002 | 15.485 | 0.002 | 36.680 | 0.008 | 0.91453 | 0.00006 | 2.16629 | 0.00034 |
|  | Jan-20 | 16.932 | 0.002 | 15.485 | 0.002 | 36.682 | 0.007 | 0.91454 | 0.00005 | 2.16640 | 0.00026 |
|  | Mar-20 | 16.932 | 0.002 | 15.485 | 0.002 | 36.683 | 0.005 | 0.91453 | 0.00003 | 2.16642 | 0.00008 |
|  | Aug-20 | 16.934 | 0.002 | 15.487 | 0.002 | 36.689 | 0.005 | 0.91454 | 0.00002 | 2.16658 | 0.00007 |
|  | Mar-21 | 16.938 | 0.003 | 15.492 | 0.002 | 36.706 | 0.006 | 0.91464 | 0.00006 | 2.16703 | 0.00009 |
| NIST982 | Sep-19 | 36.724 | 0.003 | 17.154 | 0.001 | 36.735 | 0.002 | 0.46710 | 0.00002 | 1.00029 | 0.00007 |
|  | Nov-19 | 36.731 | 0.005 | 17.152 | 0.002 | 36.727 | 0.006 | 0.46696 | 0.00002 | 0.99988 | 0.00006 |
|  | Dec-19 | 36.728 | 0.006 | 17.153 | 0.002 | 36.730 | 0.003 | 0.46701 | 0.00004 | 1.00003 | 0.00013 |
|  | Jan-20 | 36.729 | 0.002 | 17.151 | 0.001 | 36.726 | 0.002 | 0.46696 | 0.00001 | 0.99991 | 0.00003 |
|  | Mar-20 | 36.735 | 0.004 | 17.154 | 0.002 | 36.733 | 0.005 | 0.46697 | 0.00002 | 0.99995 | 0.00005 |
|  | Aug-20 | 36.730 | 0.003 | 17.155 | 0.001 | 36.734 | 0.003 | 0.46707 | 0.00001 | 1.00012 | 0.00004 |

**Table S14. List of secondary silver reference materials**.

Analyses are by solution ICPQMS measured at the Oxford School of Geography unless otherwise stated. Uncertainties estimated based on repeat measurements of reference materials (15% 2RSD). \* given MBH values, \*\*Multi-laboratory averages (Merkel 2019), uncertainties represent 2SD of multiple analyses, \*\*\*Lead contents were estimated using pXRF on fresh metal surface, uncertainty is the given instrumental error during measurement.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Reference Material | Description/Production | Pb (%) | Cu (%) | Au (ppm) | Bi (ppm) |
| AgD-1 | Ag, produced from smelting and cupelling silver ore and argentiferous galena | 0.39 ± 0.06 | 0.12 ± 0.02 | < 10 | < 10 |
| RMAg981-1\*\*\* | Ag, commercial MBH 131X AGP4 melted with metal NIST981 and cast into water | ≈ 1.7 ± 0.2 | nm | nm | nm |
| RMAg981-3 | Ag, commercial MBH 131X AGP4 melted with metal NIST981 and cast into water | 0.86 ± 0.13 | 0.03 ± 0.01 | < 10 | < 10 |
| MBH-133x-AGA3\* | Ag, commercial reference material with 5% Cu and minor and trace elements | 1.89 ± 0.01 | 4.91 ± 0.08 | 2580 ± 40 | 480 ± 20 |
| RMAgS-1 | Ag, produced from smelting and cupelling argentiferous galena | 2.49 ± 0.37 | 0.03 ± 0.01 | < 10 | < 10 |
| RMAg3834\*\* | Ag, archaeological silver sample (= object a) | 0.49 ± 0.02 | 3.4 ± 0.6 | 3870 ± 270 | 145 ± 12 |
| RMAg12467\*\* | Ag, archaeological silver sample (= object b) | 1.07 ± 0.10 | 5.5 ± 1.5 | 1920 ± 195 | 650 ± 14 |
| RMAgP-2\*\*\* | Ag, silver melted with lead and cast into water | ≈ 0.5 ± 0.1 | nm | nm | nm |

**Table S15. Published analyses of RMAg3834 (Object a) and RMAg12467 (Object b)** (Merkel 2019).

Laboratory references: A. Goethe-University Frankfurt/Main, LIA internal measurement precision (2SD); B. DBM Bochum, reported precision are 1–6% 2RSD, 5% used here; C. Leibniz-University Hanover, LIA internal measurement precision (2SD), precision of elemental results is the 95% confidence interval; D. Orleans, reported precision are <10% for these elements.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Method | 206/204 | 207/204 | 208/204 | 207/206 | 208/206 | Au (wt. %) | Bi (wt. %) | Pb (wt. %) | Lab Ref |
| RMAg12467 | Solution MC-ICPMS\* | 18.533±6 | 15.660±6 | 38.650±10 | 0.84490±10 | 2.0854±3 | - | - | - | A |
|  | Solution ICPMS | - | - | - | - | - | 0.20±1 | 0.066±3 | 1.18±6 | B |
|  | fs-LA MC-ICPMS | 18.535±4 | 15.662±4 | 38.660±10 | 0.84490±10 | 2.0856±3 | - | - | - | C |
|  | ns-LA ICPQMS | - | - | - | - | - | 0.17±1 | 0.063±3 | 0.94±4 | C |
|  | ns-LA ICPQMS | - | - | - | - | - | 0.21±2 | 0.066±6 | 1.08±11 | D |
| RMAg3834 | Solution MC-ICPMS | 18.452±4 | 15.639±4 | 38.480±20 | 0.84750±10 | 2.0855±4 | - | - | - | A |
|  | Solution ICPMS | - | - | - | - | - | 0.35±2 | 0.014±1 | 0.52±3 | B |
|  | fs-LA MC-ICPMS | 18.457±17 | 15.643±16 | 38.490±40 | 0.84750±40 | 2.0855±11 | - | - | - | C |
|  | ns-LA ICPQMS | - | - | - | - | - | 0.42±4 | 0.016±1 | 0.49±2 | C |
|  | ns-LA ICPQMS | - | - | - | - | - | 0.39±4 | 0.013±1 | 0.46±5 | D |

**Table S16. Oxford Earth Sciences lead isotope analyses of secondary reference materials**.

The values represent averages of three replicate analyses from the same stock solution.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Name | 206/204 | 2SD | 207/204 | 2SD | 208/204 | 2SD | 207/206 | 2SD | 208/206 | 2SD | Measured | Matrix |
| RMAg3834 | 18.447 | 0.002 | 15.634 | 0.002 | 38.466 | 0.005 | 0.84749 | 0.00001 | 2.0851 | 0.0001 | Dec-19 | w/o |
| RMAg3834 | 18.447 | 0.001 | 15.633 | 0.002 | 38.461 | 0.004 | 0.84745 | 0.00004 | 2.0850 | 0.0001 | Mar-21 | w/o |
| RMAg12467 | 18.532 | 0.001 | 15.657 | 0.001 | 38.644 | 0.002 | 0.84490 | 0.00002 | 2.0852 | 0.0001 | Dec-19 | w/o |
| RMAg12467 | 18.533 | 0.002 | 15.659 | 0.002 | 38.646 | 0.005 | 0.84492 | 0.00001 | 2.0853 | 0.0001 | Mar-21 | w/o |
| RMAg981-3 | 16.938 | 0.002 | 15.490 | 0.001 | 36.706 | 0.004 | 0.91452 | 0.00002 | 2.1670 | 0.0001 | Dec-19 | w/o |
| RMAg981-3 | 16.937 | 0.0001 | 15.488 | 0.0001 | 36.694 | 0.001 | 0.91445 | 0.00002 | 2.1665 | 0.0001 | Nov-19 | w/o |
| RMAgD-1 | 18.686 | 0.001 | 15.651 | 0.002 | 38.774 | 0.005 | 0.83758 | 0.00003 | 2.0750 | 0.0002 | Dec-19 | w/o |
| RMAgS-1 | 18.051 | 0.001 | 15.582 | 0.001 | 38.104 | 0.002 | 0.86328 | 0.00008 | 2.1110 | 0.0003 | Sep-19 | Ag |
| RMAgS-1 | 18.048 | 0.004 | 15.579 | 0.003 | 38.096 | 0.008 | 0.86321 | 0.00002 | 2.1108 | 0.0001 | Dec-19 | w/o |
| MBH-133x-AGA-3 | 17.409 | 0.001 | 15.545 | 0.001 | 37.280 | 0.005 | 0.89304 | 0.00005 | 2.1413 | 0.0001 | Sep-19 | Ag |
| MBH-133x-AGA-3 | 17.411 | 0.002 | 15.549 | 0.002 | 37.291 | 0.006 | 0.89304 | 0.00003 | 2.1418 | 0.0002 | Nov-19 | w/o |
| RMAgP-2 | 20.077 | 0.004 | 15.820 | 0.003 | 40.984 | 0.007 | 0.78797 | 0.00002 | 2.04131 | 0.00011 | Mar-21 | w/o |

**Table S17. Southampton lead isotope analyses and Pb, Au and Bi contents/ratios of secondary reference materials** (Standish *et al*. 2021). Precision is 2SD of repeat analyses in the last decimal place.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Reference Material | 206/204 | 207/204 | 208/204 | 207/206 | 208/206 | Au (%) | Bi (%) | Pb (%) | Au/Pb | Bi/Pb |
| RMAg981-1 | 16.976±41 | 15.525±39 | 36.779±120 | 0.9145±6 | 2.1663±43 | - | - | 1.52±61 | - | - |
| RMAg12467 | 18.544±29 | 15.668±25 | 38.672±68 | 0.8449±2 | 2.0854±16 | 0.18±4 | 0.062±16 | 0.96±25 | 0.179±20 | 0.062±4 |
| RMAgD-1 | 18.711±8 | 15.672±4 | 38.831±10 | 0.8376±1 | 2.0756±3 | - | - | 0.44±7 | - | - |
| RMAgS-1 | 18.065±12 | 15.591±8 | 38.126±23 | 0.8632±2 | 2.1110±7 | - | - | 3.07±32 | - | - |
| RMAgP-2 | 20.108±31 | 15.832±30 | 41.017±84 | 0.7874±1 | 2.0403±6 | - | - | 0.44±6 | - | - |
| 133X AGA3 | 17.411±16 | 15.549±14 | 37.292±26 | 0.8930±1 | 2.1418±2 | 0.211±41 | 0.049±13 | 1.57±34 | 0.137±10 | 0.031±2 |

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