Henderson, Julian and Chenery, Simon and Faber, Edward and Kroeger, Jens (2016) The use of electron probe microanalysis and laser ablation-inductively coupled plasma-mass spectrometry for the investigation of 8th–14th century plant ash glasses from the Middle East. Microchemical Journal, 128 . pp. 134-152. ISSN 0026-265X

The use of Electron Probe Microanalysis and Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry for the investigation of 8th-14th century plant ash glasses from the Middle East

Julian Henderson[a1], Simon Chenery[a,b], Edward Faber[a] and Jens Kröger[c]

[a]Department of Archaeology, School of Humanities, University of Nottingham, University Park, Nottingham, NG7 2RD, U.K, (julian.henderson@nottingham.ac.uk); [b]British Geological Survey, Keyworth, Nottinghamshire, NG12 5GG, U.K, (srch@bgs.ac.uk); Geschwister-Scholl-Str. 6, 10117 Berlin, Germany, (jens.sasan.kroeger@gmx.net)

Abstract

This is the first broad survey using major, minor and trace element analysis of 8th-15th AD plant ash glass from the Middle East across a 2000 mile area stretching from Egypt to northern Iran. This was part of the ancient Silk Road that extended from the Middle East, through central Asia to China. Up to now, some compositional distinctions have been identified for such glasses mainly using major and minor element oxides and radiogenic isotopes. Our new trace element characterisation is for glass found in selected cosmopolitan hubs, including one where there is archaeological evidence for primary glass making. It provides not only far clearer provenance definitions for regional centres of production, in the Levant, northern Syria and in Iraq and Iran, but also for sub-regional zones of production. This fingerprinting is provided by trace elements associated with the primary glass making raw materials used: ashed halophytic plants and sands. Even more surprising is a correlation between some of the sub-regional production hubs and the types of glass vessels with diagnostic decoration apparently manufactured in or near the cosmopolitan hubs where the glass was found such as colourless cut and engraved vessels (in Iraq and Iran) and trail-decorated vessels (in the Levant). This therefore provides evidence for centres of specialisation. Our trace element characterisation provides a new way of defining the Silk Road by characterising the glass that was traded or exchanged along it. Taken together this data provides a new decentralised model for ancient glass production.

Key words

[1] Corresponding author. Telephone number 0044-115-951-4849. Email: julian.henderson@nottingham.ac.uk.

Glass technology, trace element analysis, provenance,

1. Introduction

The existence of the Silk Road between the Middle East and China is reflected in the occurrence of a wide range of materials including silk, glass, metals and ceramics particularly found in cosmopolitan hubs. Part of its existence is recognisable from as early as the 4th century BC. Materials may have moved in a range of ways including trade and the resulting distributions are more analogous to a modern day "virtual network" than to a physical road. A peak period of interaction was between the 6th and 9th centuries AD when the Tang Dynasty Chinese and (from 750 AD) the Abbasid caliphate were at political and economic peaks. Between the Mediterranean basin and ancient Persia there were a number of multi-ethnic hubs including Cairo, Damascus, Beirut, Al-Raqqa, Ctesiphon, Samarra and Nishapur. Some of these hubs would have had extensive industrial complexes where glass was fused from raw materials. Either raw glass or the vessels made from it would have been fed into the exchange and trade networks on the land-based Silk Road and the connected water-borne Silk Road, both ultimately leading to south-east Asia.

A range of glass vessel types with characteristic decoration were made between the 8th and 15th centuries [1]. Some of these, including lustre-decorated, scratch-decorated, cameo-decorated, colourless cut and engraved vessels, have been found along the Silk Road as far away as China [2]. One of the best collections of typical west Asia vessels has been found on the famous 9th century Famen temple site in Shaanxi province, northwestern China.

Ancient glass technologies changed over time in the Middle East. The earliest glass (from c. 2400-c. 1000 BC) was made from ashed halophytic plant ashes and crushed quartz or sand (referred to here as plant ash glass [PAG]). Between c. 1000 BC and 800 AD this was followed by the use of an evaporitic alkaline salt, natron, combined with sand. After this date PAG was reintroduced and continued to be used (albeit with other glass compositional types) until c. 17th century AD. Some PAGs dating to between c. 1000 BC and 800 AD have been found, with the Sasanians (3rd to 7th centuries AD), in particular, using the technology, but the Hellenistic Greeks, the Romans, the Byzantines and cultures of early medieval Europe mainly used natron glass.

Scientific research on ancient glass has provided evidence for changing technologies over time and for broad (and sometimes somewhat narrower) geographically defined production zones [3-8]. Analysis of glass using especially Sr and Nd [and B] isotopes has sometimes led to better defined production zones based on a geological provenance [9-11]. Historical references to glass manufacture can provide indications about production [4, 12] and possible broad production zones based on decorative styles and production techniques for Islamic vessels have been suggested on archaeological and art historical grounds [13-15].

Here we present new scientific analyses and interpretation from electron probe microanalysis (EPMA) and laser ablation inductively coupled plasma mass spectrometry (LAICPMS) for glass deriving from the urban centres in an area between Egypt and northern Iran. These centres are 9th century Beirut (the Lebanon), 11th-12th century Damascus (Syria), 9th century Al-Raqqa (Syria), 9th century Samarra (Iraq), 9th-10th century Ctesiphon -Islamic al-Madā'in (Iraq), 9th-10th century Nishapur (Iran) and 14th-15th century Cairo (Egypt). We have also included samples of glass from a late phase (8th-10th century) of the important palatial site of Khirbat al-Minya (Israel). Until now, scientific analysis of Middle Eastern Islamic plant ash glass vessels has largely been the determination of major and minor elements and isotopes [16-20], but not to large-scale trace element analysis or the study of glasses deriving from sites across a broad geographical area.

The main objectives of this work are first to investigate whether variations in the chemical compositions of the glasses form groups that can be correlated to the zones in which they were found or made. A second objective is to assess whether chemical variations in the glasses can be correlated with specific vessel decorative types and/or colours.

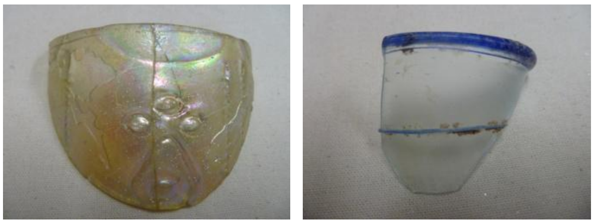
2. Methodology

2.1 Materials

This article focuses on glasses found on the sites listed above. A list of samples is given in Table 1 where the sample number, the site, vessel type and colour is provided. Samples of a range of vessel types and decorations have been analysed so as to investigate any possible links between, their chemical compositions and the locations in which they were found, vessel types and decorations. The vessel types sampled include some that are typical for the period. They include colourless cut and ground vessels mainly found on sites in Iran and Iraq (Nishapur, Samarra and Ctesiphon), vessels with applied decorative strings with green bodies (Nishapur), colourless pinched decorated vessels (Nishapur and Samarra), scratch decorated vessels (Samarra), cameo decorated (Samarra) and enamelled mosque lamps bearing dedications to specific emirs based in Cairo whose reigns are given in Table 1. Although the mosque lamp samples are 200-400 years later than the rest, there is an overall coherence in the results. Undecorated vessels samples analysed include beakers, vases, bottles, bowls, phials, flasks and grenades from Ctesiphon, Beirut, Damascus, Khirbat al-Minya and Al-Raqqa. We have also analysed samples of coloured wall plates from Samarra and window glass from Khirbat al-Minya and Al-Raqqa for comparison. Samples from the only archaeologically proven primary glass making site, where glass furnaces were excavated, are those from Al-Raqqa. We have included samples of raw furnaces glasses of a range of colours. We were careful to make sure that the samples did not derive from a zone of interaction with the furnace floor. Photographs of representative samples are given in Figure 1. The glass samples from Ctesiphon, Khirbat al-Minya, Nishapur and Samarra were taken from vessels housed in the Museum for Islamic Art in Berlin, Germany; the samples from Beirut, the Lebanon derived from excavations directed by Dr Hans Curvers; those from Damascus, Syria derived from the citadel excavations directed by Dr Sophie Bertier; those from Al-Raqqa, Syria from excavations of the industrial complex there directed by the first author; the mosque lamps are housed in the Museum of Islamic Art, Doha, Qatar. The locations where the glass was found are given in Figure 2: it was found in an area covering a distance of some 2000 miles between the Levant and northern Iran.

(a) Facet cut bowl fragments from Ctesiphon in Iraq (samples CTES 15 and 16)

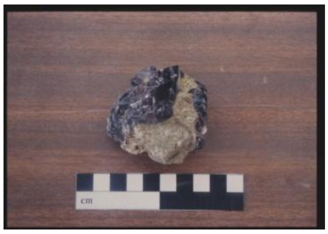
(b) Undecorated flask from Khirbat al-Minya in Israel (sample KAM 11)



(c) Pinch decorated beaker and trail decorated fragments from Nishapur, Iran (samples NISH 9 and 17)

(d) Pinched and scratch decorated bowl rim fragments from Samarra, Iraq (samples SAM 11 and 15)

(e) A cameo decorated bowl fragment and a wall plate from Samarra, Iraq (samples SAM 17 and 35)



(f) A small fragment of glass furnace floor from Al-Raqqa, Syria with raw purple glass attached (sample RAQ 38). Hundreds of other fragments were found there

Figure 1 Photographs of representative fragments of glass from which samples were removed (photographs: J. Henderson)

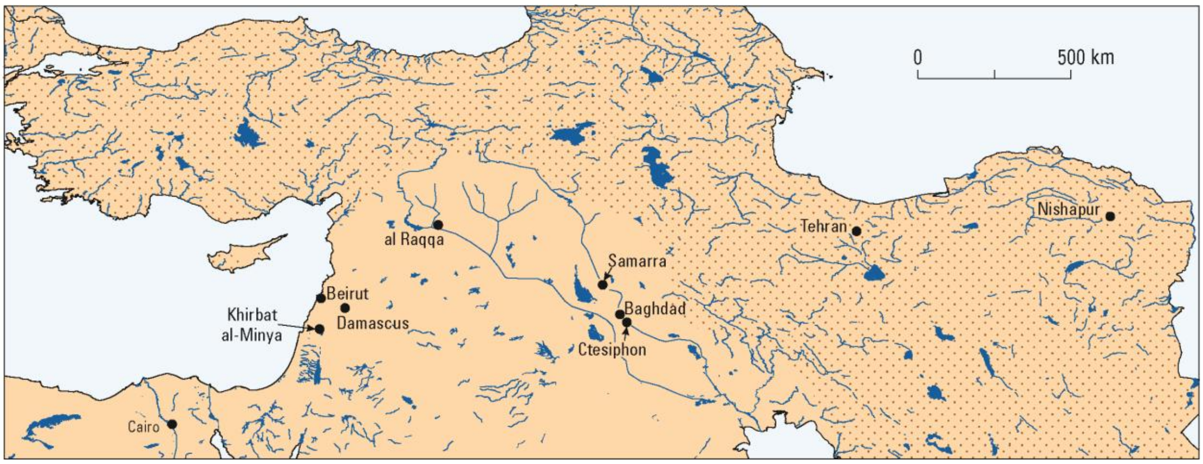

0
500 km
Nishapur
Tehran
al Raqqa
Samarra
Beirut
Damascus
Khirbat
al-Minya
Baghdad
Ctesiphon
Cairo

Fig 2

Table 1 List of samples

NISH= Nishapur, SAM= Samarra, CTES= Ctesiphon, BEI= Beirut, DAM= Damascus, KAM= Khirbat al-Minya, RAQ= Al-Raqqa (Raqqa TZ= Tell Zujaj, Raqqa. Raqqa sample numbers: first number refers to samples in [21], second, in brackets, refer to sample numbers used in publication of electron microprobe data in [18]; *= suggested production centre (mosque lamps dedicated to emirs based in Cairo).

Sample no	Site	Date	Artefact	Colour
NISH1	Nishapur	9th-10th C	Beaker, cut chevrons	Colourless
NISH2	Nishapur	9th-10th C	Beaker, cut chevrons	Colourless
NISH3	Nishapur	9th-10th C	Beaker, cut circles and lines	Colourless
NISH4	Nishapur	9th-10th C	Beaker, cut vertical ribs	Colourless
NISH5	Nishapur	9th-10th C	Beaker, cut circle and lines	Colourless
NISH6	Nishapur	9th-10th C	Jug, pinched	Colourless
NISH7	Nishapur	9th-10th C	Jug, pinched, rim	Colourless
NISH8	Nishapur	9th-10th C	Beaker?, pinched, rim	Colourless
NISH9	Nishapur	9th-10th C	Beaker?, pinched, rim	Colourless
NISH10	Nishapur	9th-10th C	Beaker, applied knobs	Colourless
NISH12	Nishapur	9th-10th C	Beaker, applied knobs	Green
NISH16	Nishapur	9th-10th C	Bowl, thread decorated (green)	Green body
NISH17	Nishapur	9th-10th C	Bowl, thread decorated (blue)	Colourless body
NISH18	Nishapur	9th-10th C	Bowl, thread applied to rim (blue)	Green body
NISH19	Nishapur	9th-10th C	Beaker	Turquoise
SAM1	Samarra	9th-10th C	Bowl, cut lozenge decoration	Colourless
SAM11	Samarra	9th-10th C	Bowl, pinched,	Colourless
SAM12	Samarra	9th-10th C	Bowl, pinched,	Colourless
SAM13	Samarra	9th-10th C	Bowl, pinched,	Green
SAM14	Samarra	9th-10th C	Jug, cut cylindrical	Colourless
SAM15	Samarra	9th-10th C	Bowl, scratched	Blue

SAM16	Samarra	9th-10th C	Bowl, scratched	Purple
SAM17	Samarra	9th-10th C	Bowl, cameo blue	Pale blue
SAM18	Samarra	9th-10th C	Bowl, cameo blue rim	Pale blue
SAM19	Samarra	9th-10th C	Bowl, cameo blue rim	Pale blue
SAM20	Samarra	9th-10th C	Bowl, cameo emerald green	Colourless body
SAM21	Samarra	9th-10th C	Bowl, cameo emerald green rim	Colourless body
SAM22	Samarra	9th-10th C	Bowl, cut	Colourless
SAM23	Samarra	9th-10th C	Bowl, blown and cut	Green
SAM24	Samarra	9th-10th C	Bowl, blown and cut	Green
SAM25	Samarra	9th-10th C	Bowl, blown and cut	Green
SAM27	Samarra	9th-10th C	Bowl, cut, stylised flower	Colourless
SAM28	Samarra	9th-10th C	Bottle, cut, shoulder	Colourless
SAM33	Samarra	9th-10th C	Wall plate	Colourless
SAM34	Samarra	9th-10th C	Wall plate	Deep purple
SAM35	Samarra	9th-10th C	Wall plate	Deep purple
CTES1	Ctesiphon	7th C	Ovoid vessel	Blue
CTES2	Ctesiphon	7th century	Ovoid vessel	Pale green
CTES12	Ctesiphon	9th-10th C	Bowl, facet cut, wheel ground	Pale green
CTES13	Ctesiphon	9th-10th C	Bowl, facet cut, wheel ground	Pale green
CTES14	Ctesiphon	9th-10th C	Bowl, facet cut, wheel ground	Pale green
CTES15	Ctesiphon	9th-10th C	Bowl, facet cut, thick	Colourless
CTES16	Ctesiphon	9th-10th C	Bowl, facet cut	Colourless
CTES17	Ctesiphon	9th-10th C	Bowl, facet cut	Colourless
CTES18	Ctesiphon	9th-10th C	Bowl, facet cut	Colourless
CTES19	Ctesiphon	9th-10th C	Bottle, facet cut base	Colourless
CTES20	Ctesiphon	9th-10th C	Bowl, engraved	Colourless
BEI48	Beirut	12th-14th C	Beaker base	Pale green
BEI49	Beirut	12th-14th C	Bowl rim	Purple
BEI51	Beirut	12th-14th C	Beaker base, pontil	Colourless
BEI53	Beirut	12th-14th C	Beaker base	Pale brown

BEI54	Beirut	12th-14th C	Bottle fragment	Colourless
BEI55	Beirut	12th-14th C	Bowl fragment	Colourless
BEI109	Beirut	12th-14th C	Bottle rim	Green
DAM1	Damascus	12th C	Beaker, poor quality	Green
DAM14	Damascus	12th C	Beaker, poor quality	Green
DAM35	Damascus	12th C	Beaker, poor quality	Green
DAM37	Damascus	12th C	Possible Beaker	Pale purple
DAM38	Damascus	12th C	Dimpled beaker	Colourless
DAM43	Damascus	12th-14th C	Grenade body	Colourless
DAM44	Damascus	12th-14th C	Grenade shoulder	Purple
DAM45	Damascus	12th-14th C	Grenade base	Purple
DAM46	Damascus	12th-14th C	Grenade neck	Purple
Cairo9	Cairo*	c. 1350-65	Mosque lamp, [22] catalogue 7	Colourless
Cairo10	Cairo*	c. 1350-65	Mosque lamp, [22] catalogue 7	Green
Cairo13	Cairo*	c. 1350-65	Mosque lamp, [22] catalogue 7	Opaque red
Cairo14	Cairo*	c. 1300-1340	Mosque lamp, [22] catalogue 4	Blue
Cairo16	Cairo*	c. 1300-1340	Mosque lamp, [22] catalogue 4	Opaque red
Cairo17	Cairo*	c. 1300-1340	Mosque lamp, [22] catalogue 4	Green
Cairo18	Cairo*	c.1412-15	Mosque lamp, [22] catalogue 12	Green
Cairo19	Cairo*	c. 1412-15	Mosque lamp, [22] catalogue 12	Blue
KAM3	Khirbat al-Minya	8th C	Window	Brown
KAM6	Khirbat al-Minya	8th C	Flask straight neck	Green
KAM7	Khirbat al-Minya	8th C	Flask pushed in base	Green
KAM8	Khirbat al-Minya	8th C	Flask neck, white trailed decoration	Purple
KAM11	Khirbat al-Minya	8th C	Flask, tapering with flat base	Green
KAM12	Khirbat al-Minya	8th C	Flask neck with handle	Green

RAQ34 (15)	Al-Raqqa, TZ	9th C	Raw furnace glass	Purple
RAQ35 (31)	Al-Raqqa, TZ	9th C	Raw furnace glass	Green
RAQ36 (16)	Al-Raqqa, TZ	9th C	Raw furnace glass	Purple
RAQ38 (17)	Al-Raqqa, TZ	9th C	Raw furnace glass	Purple
RAQ41 (18)	Al-Raqqa, TZ	9th C	Bowl rim	Colourless
RAQ42 (19)	Al-Raqqa, TZ	9th C	Scrap	Cobalt blue
RAQ43 (20)	Al-Raqqa, TZ	9th C	Scrap	Opaque red
RAQ44 (21)	Al-Raqqa, TZ	9th C	Raw furnace glass	Purple
RAQ45 (22)	Al-Raqqa, TZ	9th C	Raw furnace glass	Brown
RAQ46 (23)	Al-Raqqa, TZ	9th C	Raw furnace glass	Emerald green
RAQ47 (24)	Al-Raqqa, TZ	9th C	Beaker base	Green
RAQ48 (25)	Al-Raqqa, TZ	9th C	Bottle base	Green
RAQ49 (26)	Al-Raqqa, TZ	9th C	Raw furnace glass	Blue
RAQ50 (27)	Al-Raqqa, TZ	9th C	Bottle rim, weathered	Green
RAQ54 (35)	Al-Raqqa, TZ	9th C	Bowl, mould-blown rim	Colourless
RAQ58 (32)	Al-Raqqa, TZ	9th C	Phial base	Green
RAQ59 (33)	Al-Raqqa, TZ	9th C	Raw furnace glass	Purple
RAQ60 (34)	Al-Raqqa, TZ	9th C	Raw furnace glass	Colourless
RAQ61 (46)	Al-Raqqa, Qasr al-Banat	12th C	Bowl	Green
RAQ66 (41)	Al-Raqqa, West palace complex	9th C	Window	Green
RAQ67 (42)	Al-Raqqa, West palace complex	9th C	Window	Blue

2.2 Methods

Electron probe microanalysis

Electron probe microanalysis is one of the most accurate techniques for the analysis of silicates [23]. The analysis of 1-2mm samples was performed using EPMA-WDS using a JEOL JXA-8200 electron microprobe in the Department of Archaeology, University of Nottingham as described elsewhere [24]. A defocused 50µm electron beam was used. Twenty six elements were sought, presented as oxide weight percentage: Na_2O, MgO, Al_2O_3, SiO_2, P_2O_5, SO_3, Cl, K_2O, CaO, TiO_2, V_2O_3, Cr_2O_3, MnO, FeO, CoO, NiO, CuO, ZnO, As_2O_5, SrO, ZrO_2, Ag_2O, SnO_2, Sb_2O_5, BaO and PbO. Three areas of interest at ×1000 were analysed for the main glass phase of each sample and the results were averaged. Quantification of detected oxides was performed with a PRZ correction routine. The following relative analytical accuracies were obtained using the Corning B standard as unknown: 3% for Na_2O; 2.5% for SiO_2; 1.5% for K_2O; 1.5% for CaO and 2% for PbO. For minor elements the accuracy was 5% for MgO, 2.5% for Al_2O_3, 15.5% for P_2O_5, 6.5% for FeO, 5% CuO and up to 13% for Cl. A fuller consideration of analytical errors in the EPMA analyses of ancient glasses is published elsewhere [24]. The following elements were sought but not detected: V, Cr, Ni, Ba, Sn, Zn, Sr, Ag, As, Zr. Table 2 provides a comparison between the quoted and measured values for detected oxides in the Corning B glass standard, with associated standard deviations.

Table 2: The recommended composition for the Corning B standard [25] compared to average analytical results (n=20) and associated standard deviations using the electron microprobe.

	SiO_2	Al_2O_3	Na_2O	K_2O	CaO	TiO_2	*FeO	MnO	MgO	CoO	CuO	P_2O_5	Sb_2O_3
Measured	62.33	4.41	17.45	1.07	8.77	0.11	0.29	0.23	1.1	0.05	3.14	0.60	0.49
Quoted	61.55	4.36	17.0	1.0	8.56	0.089	0.31	0.25	1.03	0.046	2.66	0.82	0.46
St. Dev.	0.46	0.07	0.14	0.02	0.09	0.03	0.03	0.02	0.07	0.02	0.11	0.05	0.04

Note: * FeO composition for Corning B calculated from published value for Fe_2O_3

Laser ablation inductively coupled plasma mass spectrometry

The use of LA-ICP-MS for the trace element analysis of glass is a now widely accepted practice, even within the naturally conservative forensic community [26].

Trace element determinations were carried out using by laser ablation-inductively coupled plasma mass spectrometry (LAICP-MS). The same samples were used as for EPMA. Prior to analysis the samples were cleaned by rubbing a tissue soaked in dilute acid over the surface for a few seconds. The laser ablation unit was a NewWave (Electro Scientific Industries, Inc.) UP193 nm excimer system. The sample was placed in a simple single volume ablation cell with a 0.8 $Lmin^{-1}$ He flow. In addition to the sample block NIST glass standards SRM610 and 612 were placed in the chamber. The laser was normally fired at 5 Hz for 60s using a beam diameter of 70 µm. Fluence and irradiance as measured by the internal monitor were typically 3 J/cm^2 and 0.85 GW/cm^2 respectively. Prior to introduction into the ICP-MS the He flow was mixed, via a Y-junction, with a 0.85 $Lmin^{-1}$Ar and 0.04 $Lmin^{-1}$ N2 gas flows supplied by a Cetac Aridus desolvating nebuliser. The Aridus allowed introduction of ICP-MS tuning solutions and optimisation of the Aridus sweep gas (nominal 4$Lmin^{-1}$Ar). During solids analysis by the laser, the Aridus only aspirated air. The ICP-MS used in this study was an Agilent 7500cs series instrument. The instrument was set for 100 sweeps of the 47 isotopes of interest per integration. The dwell time for each isotope was 1 ms giving an integration time of 5s. Data were collected in a continuous time resolved analysis (TRA) fashion. Prior to laser firing a period of at least 120s of 'gas blank' were collected, then 3 ablations being made on the SRM610; 3 ablations on the SRM612; 3 ablations on up to 8 samples and a final 3 ablations on the SRM610. The SRM612 was used to calibrate the system whilst the SRM610 was used as a quality control (QC) material; aggregated results for each element-isotope concentration are given in Table 3. All calculations and data reduction were performed manually in Excel spreadsheets and statistical analysis using MiniTab v13. The nature of laser ablation means there is some variability in ablation volume and transport efficiency with different materials (matrix effects). Therefore, accepted practice is to normalise results to an internal standard element, in the current study Si was chosen for this purpose with its concentration being known in the NIST glasses and provided by the EPMA data for the study glasses.

Table 3: Summary quality control (QC) data for analysis of glass samples

Sample: SRM610 Number of analyses=72 Number of analytical session = 5

Element	Measured Isotope	Expected Concentration (mg/kg)	Mean Concentration (mg/kg)	s.d.	RSD%	Error %
Li	7	468	498	25	5	6

B	11	350	361	28	8	3
Na	23	99407	103151	3430	3	4
Mg	24	432	577	20	3	34
Al	27	10320	10937	500	5	6
Si	28	327977	***Internal Standard***			
P	31	413	403	275	68	-2
K	39	464	460	79	17	-1
Ca	42	81475	82641	3082	4	1
Ti	47	452	496	21	4	10
V	51	450	459	15	3	2
Cr	52	408	414	25	6	1
Mn	55	444	455	36	8	3
Fe	56	458	511	47	9	12
Co	59	410	422	15	4	3
Ni	60	459	472	21	4	3
Cu	63	441	433	22	5	-2
Zn	66	460	440	26	6	-4
As	75	325	353	21	6	9
Rb	85	425	427	15	4	0
Sr	88	516	524	23	4	2
Y	89	462	467	32	7	1
Zr	90	448	455	27	6	1
Nb	93	465	492	20	4	6
Mo	95	417	443	16	4	6
Sn	120	430	385	72	19	-10
Sb	121	396	447	18	4	13
Cs	133	366	377	13	4	3
Ba	138	452	464	20	4	3
La	139	440	449	26	6	2
Ce	140	463	468	19	4	1
Pr	141	448	454	24	5	1
Nd	146	430	450	26	6	5
Sm	147	463	472	28	6	2
Eu	153	447	454	24	5	2
Gd	157	449	453	32	7	1
Tb	159	437	470	52	11	8
Dy	163	437	456	29	6	4
Ho	165	449	496	60	12	10
Er	166	455	465	32	7	2
Tm	169	435	495	58	12	14
Yb	172	450	473	32	7	5
Lu	175	439	481	51	11	9
Hf	178	435	424	31	7	-3
Pb	208	426	443	21	5	4
Th	232	457	508	62	12	11
U	238	462	508	57	11	10

Appendix A provides a comparison between our LA-ICP-MS analysis of the Corning B standard, the expected composition [25] and Wagner et al.'s analytical assessment [27].Typical uncertainties (2s.e.m.) for sample analyses used in Figure 4-6 error bars were estimated using an analysis of variance (ANOVA) to separate the within-sample variance from the between sample variance. This ANOVA was based on the elemental concentration or ratio of the original 3 replicate ablation analyses for each of 10 colourless Nishapur glasses. The 3 replicates being combined into a mean for plotting in the Figures.

A number of bi-plots for both 2 sets of oxides and for ratios were created for both major/minor and trace element results, including for rare earth elements. Those provided here are considered to be the most instructive for the present study.

3. Results

Major, minor and trace element analysis has been carried out on 97 samples of plant ash glasses in order to examine relationships between glass compositions, dates, vessel types and provenance. Electron microprobe results are given in Appendix B and trace element results in Appendices C.1 to C.8. As noted above broad geographical provenances for Islamic plant ash glasses have been suggested before. The suggested areas have been 'Syria', 'Mesopotamia' and 'the Levant' mainly based on major and minor oxide concentrations such as sodium, calcium, magnesium, aluminium, iron and strontium [4], [17-19], [28].

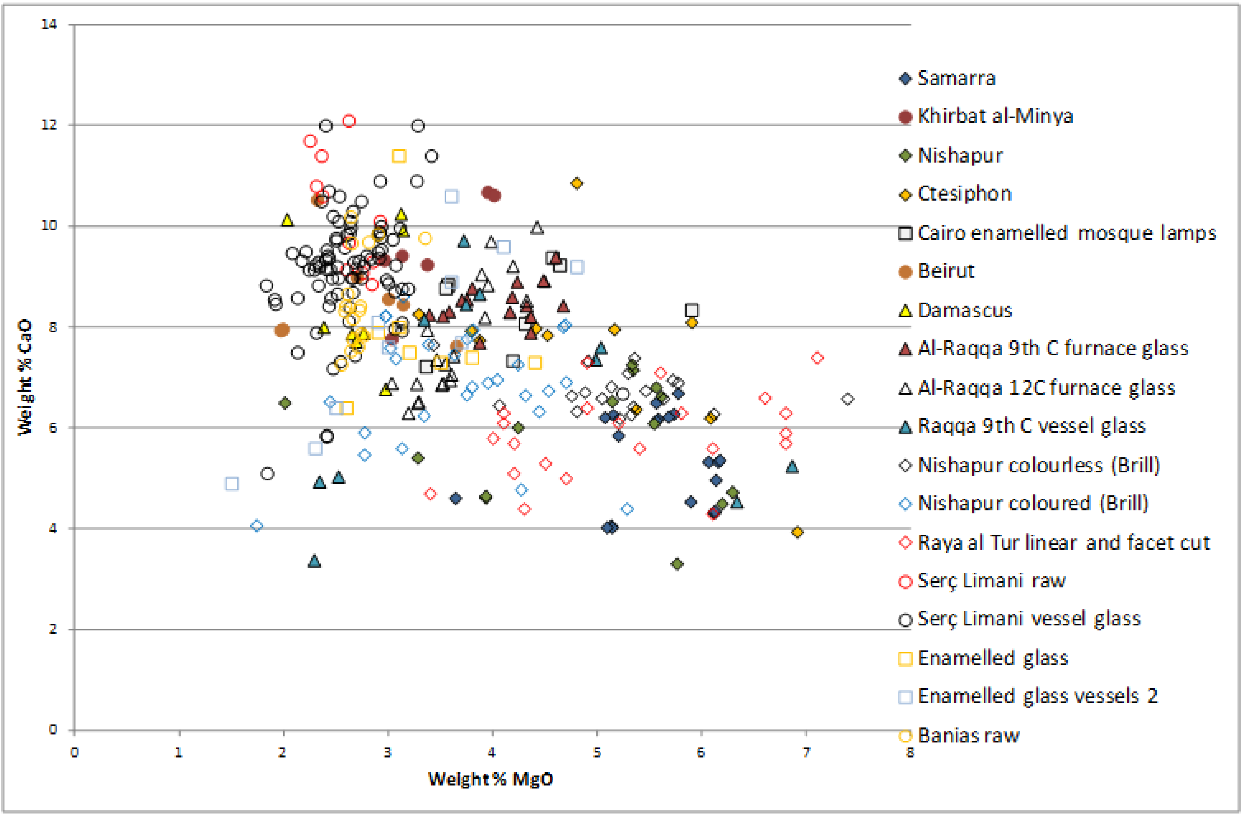


Figure 3

. This plot is provided so as to compare the electron microprobe results of glass samples that form the focus of this paper with other, mainly well dated, glasses mainly deriving from the same broad geographical area. In Figure 3 the glass samples that form the focus of this study have solid symbols (some additional 9th century Al-Raqqa furnace glass results have been plotted too); the balance of plotted data is represented by open symbols. Comparable furnace glass from a second (12th century) site in Al-Raqqa are plotted and results for raw glass from the Turkish early 11th century Serç Limani shipwreck and from the 8th-9th century Israeli secondary glass working site of Banias. Data for cut and ground colourless and coloured glass from (9th-10th century) Nishapur [16] and linear cut and facet cut colourless glass from the 9th-10th century Raya and Al Tur area, Egypt [19] are also included here for comparison. Two data sets for vessel body compositions of enamelled Ayyubid (11th century) and Mamluk (12th-14th century) vessels are presented here to provide a comparison with our results for the 14th-15th century enamelled mosque lamps [29-30]: they form a relatively coherent correlation defined by the parallel lines in Figure 3. The symbols used are intended to highlight a broad compositional trend that has been noted before [4]: glasses found and apparently made in Iraq and Iran (lozenges) have amongst the highest MgO levels and the lowest CaO levels; the furnace glasses from Al-Raqqa (triangles) fall between 'Levantine' glasses (circles) and the Iraqi/

Iranian glasses. The ratio of weight % MgO to CaO therefore changes according to the location moving from east to west. The compositional results for furnace glasses provide a degree of confidence for this interpretation because they have a fixed provenance but there are a number of instances where a provenance attribution is difficult to assign. Levantine and Iraqi/ Iranian glasses are well distinguishable from each other in the Figure 3 but it becomes more difficult to have confidence in the attribution of glasses plotting with Syrian furnace glasses. Examples are some Nishapur coloured glasses and the enamelled vessel samples. It is possible that some of these were made in other areas, such as Egypt.

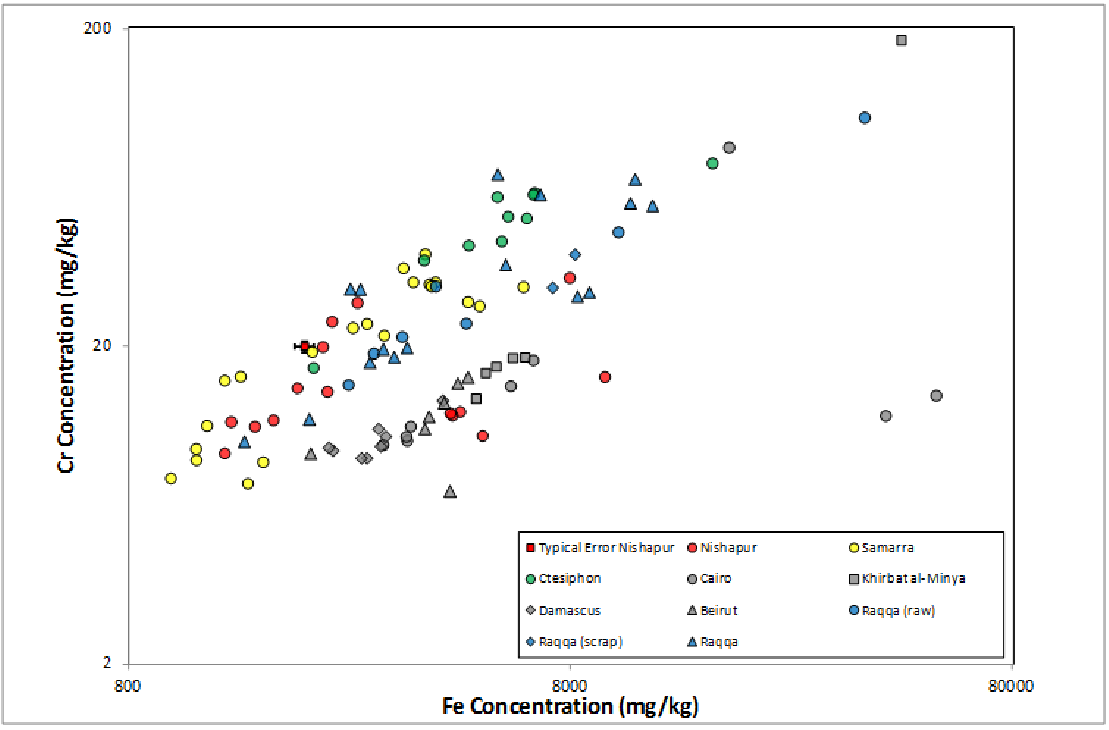


Fig 4

This is an important start but clearly the use of a more sensitive technique such as LA-ICP-MS for a wide range of elements is the next logical step. The data plotted in Figures 4-6 reflect the use of plant ashes and sands with varying geochemical characteristics to make the soda-lime-silica glasses. Figure 4, a plot of Cr versus Fe shows a clear distinction between glasses made in the Levant (including southern Syria) and Egypt on the one hand and northern Syrian/ Iraqi and Iranian glasses on the other; these trace elements are often associated with sand raw materials. With four exceptions, the eastern samples clearly have significantly more Cr for a given amount of Fe compared to the western samples. A cluster of seven Ctesiphon samples falls in the middle of the Fe concentration range. These are results for colourless or pale green facet cut vessels. Significantly, almost all Al-

Raqqa samples, including raw furnace glasses, fall on a linear correlation suggesting a dilution trend. When this plot is compared to slightly earlier Sasanian glasses [31-32] most have higher Cr and Fe with the majority having a higher proportion of Cr.

in a majority of cases have lower 1000Zr/Ti ratios [31-32].

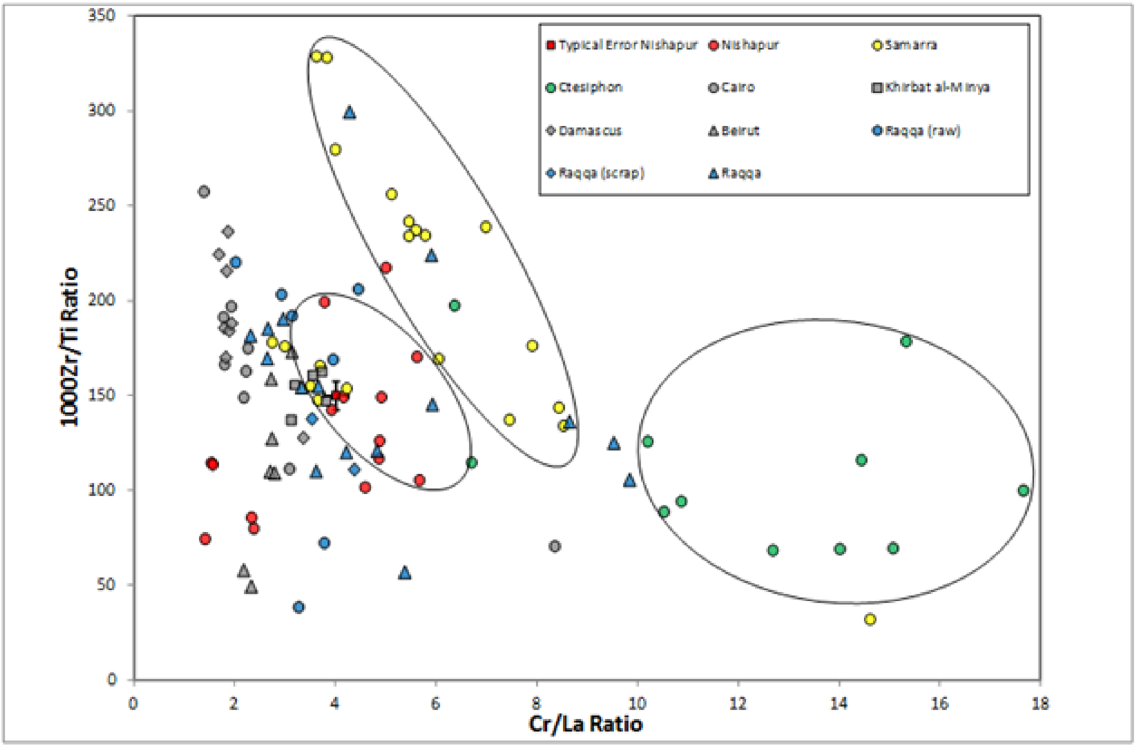


Fig 5

The issue of differential dilution of diagnostic contaminants by the silica component can be overcome by the use of ratio: ratio plots. In Figure 5 Levantine glasses tend to have lower Cr/La ratios than eastern glasses. The ellipses in Figures 5 (and 6) are provided as a visual means of emphasising the clustering of data from individual sites in the eastern zone. Amongst the eastern glasses in Figure 5 Nishapur samples are most like western ones, with Al-Raqqa mainly plotting at the 'interface' between Levantine and eastern samples. Most Ctesiphon samples separate into a group having the highest Cr/La ratio indicated by an ellipse. Some Samarra glasses have high 1000Zr/Ti and most plot in a negatively correlated field. Amongst Levantine glasses, those from Beirut can mainly be distinguished from Damascus glasses by their higher Cr/La and lower 1000Zr/ Ti ratios. Sasanian 4th-5th century plant ash glasses from Veh Ardašīr encompass the full range of Cr/La ratios found in our material but

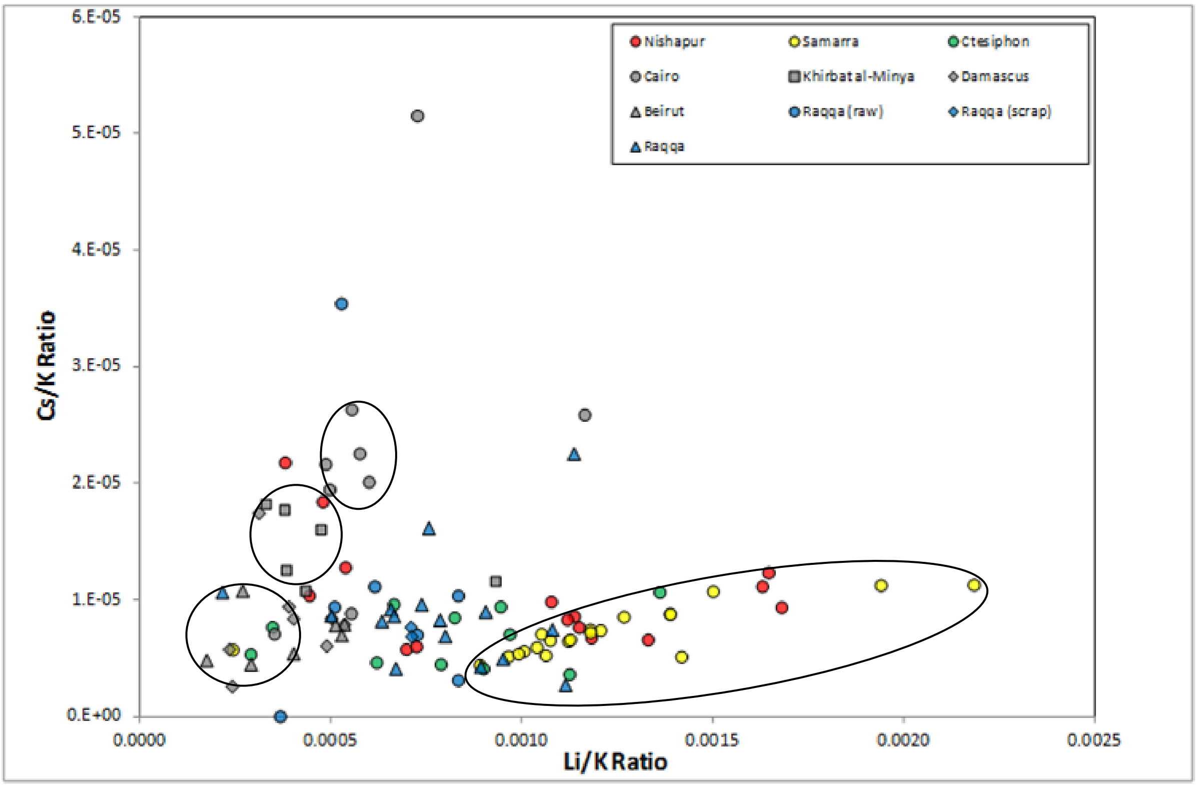


Fig 6

In Figure 6 some Levantine glasses have higher Cs/K ratios than Eastern glasses; conversely Eastern glasses tend to have higher Li/K ratios, particularly those from Nishapur and Samarra. Many Nishapur glasses are similar to Samarra glasses and four are more like Western material from the Levant. The Cairo samples have elevated Cs/K ratios and five form a cluster. Most Khirbat al-Minya glasses cluster together and can be distinguished from the mosque lamp glasses probably form Cairo and from glasses derived from Beirut and Damascus as indicated by ellipses). Although separable from other Levantine glasses Beirut and Damascus samples are indistinguishable in this plot (but are distinguishable in Fig 5). Surprisingly, the very low ratios found in a range of plant samples from Syria and the Lebanon [33] suggest that they cannot provide sufficient Cs or Li for the levels of K. This could therefore suggest that they may come in as a contaminant in the silica source.

For many glasses the Cr/La and Li/K values in Figures 5 and 6 respectively tend to increase moving from west (the Levant) to east (Iran and Iraq). These variations are ultimately determined by the geochemistry of the mountain ranges such as the Anti-Lebanon, Taurus, Zagros and Elburz from which the principle rivers such as the Barada, Euphrates and Tigris flow. The Nile in Egypt is a principle contributor to the geochemical characteristics of the southern part of the Levantine coast.

Conventional wisdom states that trace elements were introduced into the glass from either the silica sand source, as contaminant heavy minerals such zircon (Zr), rutile (Ti), illmenite (Ti), monazite (La), chromite (Cr), or from the plant ash source, as substitutes for K, Na (Li, Rb, Cs). However, this is likely to be an over-simplification since contamination of the silica sand source by alkali feldspars may bring in additional Li, Rb and Cs. Whilst significant La and Cr have been found in plant ashes [33], they may be associated with plant phytoliths; clay particles that have attached to poorly washed plants or sand may also provide a source of many elements including Zr, Ti, La and Cr.

Our results will now be discussed by sample origin moving from east to west, starting with Nishapur in north-east Iran and ending with Levantine sites. The results for Nishapur glasses plot mainly with other Eastern glasses, especially in Figures 4 and 6 and mainly with eastern glasses and northern Syrian glasses in Figure 5: a better discrimination for Nishapur glasses can be observed in Fig 6 where they plot almost exclusively within the ellipse containing only eastern glasses characterised by the highest Li/K ratios. Four of the samples tested plot with Levantine glasses in Figures 4, 5 and 6 (see section 4).

Eight of eleven Ctesiphon samples were taken from three 9th-10th century pale green and five colourless facet cut vessels. Nine samples fall into a well-defined eastern group with high Cr/La ratios in Figure 5. Seven of these are colourless or pale green facet cut vessels; the remaining 2 are a colourless bowl and an ovoid vessel. One colourless facet cut sample from Ctesiphon falls close to Al-Raqqa samples possibly indicating it was made in northern Syria; the second small pale green ovoid vessel sample plots amongst Samarra samples in Figure 5 so these vessels or the glass were probably imported to Ctesiphon.

Fourteen out of nineteen Samarra samples fall into a distinct negatively correlated group in Figure 5. These consist of four pale green mould-decorated vessels, five cameo decorated vessels, one pinch-decorated vessel, two scratch decorated vessels and two wall plaques (see Table 1). These results probably show that a range of characteristic early Islamic vessel types together with wall plaques were made in Samarra. Six Samarra samples with lower Cr/La ratios are separated from the main Samarra group in Figure 5. Intriguingly, unlike the correlated group, they all colourless, include cut vessels and were made with sand containing low iron levels (see Figure 4). These glasses plot close together and are close to (amongst others) Nishapur colourless samples in Figure 5. These Samarra samples are far more clearly associated with those from Nishapur in Figure 6, confirming their eastern origin and were therefore probably imported to Samarra from Nishapur.

Al-Raqqa is located between the Levant and the Eastern zone of Iraq and Iran. Many Al-Raqqa samples also plot between Levantine and eastern glasses in Figure 5 and more clearly in Figure 6. The results include raw furnace glasses from the primary glass-making site at Al-Raqqa; these have more constrained Cr/La and Li/K signatures than detected in scrap glasses derived from glass working and in vessel glasses from Al-Raqqa. A beaker, a phial and window glass samples found at Al-Raqqa plot with eastern samples in Figure 6, and in the Samarra correlated group in Figure 5, suggesting that they were imported along the river Euphrates from Samarra to Al-Raqqa some 430 miles away. Two nearly colourless Nishapur beaker fragments (with a yellowish tinge) decorated with applied knobs plot with Al-Raqqa samples and were presumably imported to Nishapur from Al-Raqqa.

Levantine and Egyptian glasses dating to between the late 8th and 15th centuries are united in Figures 5 and 6 by their characteristic low Cr/La and Li/K ratios respectively. Late 8th century glass samples from Khirbat al-Minya are especially well distinguished from most other Levantine glass. Results for the cosmopolitan centres of Beirut and Damascus have the lowest Cs/K ratios and Beirut glasses generally have lower Zr/Ti ratios than found in Damascus glasses. The 14th-15th century mosque lamp glasses attributed to local emirs in Cairo [22] contain amongst the highest Cs/K ratios. The results for two low lead opaque red enamels used to decorate the lamps plot with vessel body glasses suggesting that similar raw materials were used to make the vessel body glasses and the enamels and that they were therefore probably made in the same place.

4. Discussion

Given the large scale of glass production in the Byzantine and Islamic worlds, and the potential for mixing and recycling, our methods and results provide some surprisingly clear compositional distinctions. They are the first to show clear evidence for broad regional production zones, especially a clear distinction between glasses found in the Levant and in Iran/ Iraq. Had large scale mixing of glasses occurred between glasses made in the Levant, northern Syria and Iran/ Iraq it would have produced far fewer clear elemental groupings for individual site than those in Figures 5 and 6 and there would be more evidence of mixing lines. The correlated group of Samarra samples in Figure 5 could be evidence for mixing with highest and lowest 1000Zr/Ti values representing the end members and those in between the result of mixing different proportions of glasses with end member compositions. The Samarra data also fall into a positively correlated group in Figure 6. If mixing did occur at Samarra it appears to be for glass that was made and used there.

The samples of decorated colourless vessels found at Nishapur, northern Iran provide a useful example of how trace element compositions provide evidence for centres of production and exchange/ trade. Firstly, although colourless cut vessels have predominantly been found in Iraq and Iran, this does not prove that the glass itself was made there or even that glass vessels bearing this decoration were made there. We have shown that relative impurity levels of Cr, Fe, La, Zr and Ti, mainly found in sand, provide a distinction between glasses found in the Levant and Iraq/Iran. Nine Nishapur samples fall into the eastern grouping of Iraqi/ Iranian glasses in Figure 6; four plot in the Levantine area and 2 amongst Al-Raqqa samples. The eastern glasses are united, not only by composition but also by form, because they are all colourless and are decorated by cutting and engraving (5 samples) or are pinch decorated (4 samples; see Fig. 1(c)). The link between these colourless vessels and the eastern zone confirms what has long been suspected, but not proven scientifically before, that the glass used to make the colourless cut and pinch decorated vessels was made in that zone [13-14] and that both its colour and decorations constitute a regional technological specialisation. These vessels dating to the 9th and 10th centuries were preceded and clearly influenced by the production of similar colourless wheel cut plant ash vessels in the same area during the Sasanian period (3rd-7th centuries AD). However, even though similar raw materials would have been used to make them, the Sasanian and our 9th-10th century vessels can mainly be distinguished analytically from ours (see above). This may indicate that the raw materials used derived from slightly different locations.

Four Nishapur glasses fall into the Levantine group in Figures 4, 5 and 6. Significantly these are pale green or pale blue, rather than colourless, and are decorated with threads in pale green, cobalt blue or turquoise colours (See Fig. 1(c)). These results therefore suggest that a Levantine specialisation was the production of thread-decorated vessels.

The massive cosmopolitan settlement of Samarra by the river Tigris was a 9th century capital of the Abbasid caliphate, probably founded in 834-5. Our results provide evidence for another technological variation: they suggest that glass almost certainly made there was used for the manufacture of a relatively wide range of characteristic early Islamic decorative vessel types and wall plaques (see Fig. 1(e)). The colourless, including cut glass, vessels were apparently imported from Nishapur.

Al-Raqqa was also briefly an important city and the caliph resided there in the late 8th and early 9th centuries. The results for Al-Raqqa furnace glasses bolster the case for our interpretation, providing clear provenance information; they fall on quite a tight Cr/Fe correlation line in Figure 4 and Al-Raqqa scrap glasses also plot close to furnace glasses in this Figure. In both Figures 5 and 6 two Al-Raqqa vessel samples, a green bottle rim and colourless bowl rim, plot close to the furnace glasses, showing they were made in Al-Raqqa.

Turning to discussion of the Levantine samples, there is a notable trend in the Cs/K ratios moving from south (Egypt) to north (Beirut and Damascus). The mosque lamps, presumed to have been made in Cairo, have the highest ratio and Beirut and Damascus glasses having the lowest; Khirbat al-Minya glasses fall in between, both geographically and in terms of their Cs/K ratios. Two facet-cut vessels found at Ctesiphon and one from Samarra with low Li/K ratios were made with Levantine glass (Figure 6). The eastern tradition was to make such vessels with colourless glass; significantly these were green. This therefore suggests that raw green furnace glass made in the Levant was exported to Iraq where the vessel was made and decorated in the 'eastern' tradition by cutting. The two Ctesiphon samples plot close to Beirut and Damascus samples in Fig. 6 so the glasses were probably fused in this zone, possibly in one of these important urban centres.

In Figures 5 and 6 results for 14th-15th century Egyptian mosque lamps fall within the clearly defined Levantine production zone yet five are also separated from Khirbat al-Minya, Damascus and Beirut glasses by having high Cs/K values [34].This suggests that the mineral combinations ultimately deposited by the Nile deriving from the East African Highlands (the Blue Nile in Ethiopia and the White Nile in Tanzania, Kenya and Uganda) taken up by plants and deposited in sands are distinct from those used to make glasses from the other 'Levantine' sites [35-36]. Nevertheless it is possible that the glass used to make the mosque lamps was fused outside Egypt (perhaps in the southern Levant). Concentrations of Zr, Ti, Cr and La (Fig. 5) for much earlier (Late Bronze Age) glass mainly associated with probable inland sand sources [37], can be distinguished from most of our Levantine glass data. Evidently the mosque lamp glass was not made in northern Syria, Iraq or Iran. The compositionally well-defined Khirbat al-Minya glasses were probably not made in, for example, Beirut or Damascus, which are further north, but perhaps in an urban centre closer to the site such as Amman or Jerusalem. Trace element analysis of more well dated samples from the Levant should help to substantiate these findings

By using chemical and isotopic analyses (with some exceptions [10]) mainly of raw furnace glasses, it has been suggested that there were two principal production zones for Roman and Byzantine *natron glass* during the first millennium AD, one in Egypt and the other on the Levantine coast [5, 6, 9, 10]. The centralised production model envisages that raw glass was exported from primary production sites to secondary production sites where glasses were remelted and blown into vessels. Chemical sub-types of natron glass can sometimes be associated with coastal furnace sites but in spite of a suggested link between some vessel types/ decorations and chemical compositions [37], so far there is limited compositional evidence [6, 39].

5. Conclusions

The trace element analyses of Islamic plant ash glasses from across a broad geographical area in this study provide the first clear evidence for regional production zones in the Levant, northern Syria and in Iraq/ Iran. They also provide evidence for production sub-zones associated with the large cosmopolitan urban hubs with thriving economies supporting the manufacture of a range of materials such as ceramics and glass and supplying local, regional and supra-regional markets. As for natron glass, a centralised production model within the Levant has recently been suggested for plant ash glass [40]. While it is clear from the data presented here that the Levant was an important production zone, we the production sub-zones associated with urban centres we have detected in the Levant indicate that decentralised production occurred and over a period of c. 800 years. This model of broad production zones and internal sub-zones also applies to areas much further east in Iran and Iraq, as exemplified by separate production associated with Samarra and Ctesiphon, which are only 84 miles apart (see Figure 2). We are also able to discriminate using trace elements between most (earlier) Sasanian plant ash glasses and our later Iraqi and Iranian samples made in the same geographical area. Much of the manufactured glass and vessels appears to have remained in or near the cosmopolitan hubs locations where it was made.

However, in contrast to this, we are able to indicate when glass has travelled between centres linked by the Silk Road across the 2000 mile area. We have shown that glass made in the Levant was exported to Samarra, Ctesiphon and Nishapur, that glass made in Al-Raqqa was exported to Samarra and Nishapur, that glass made in Ctesiphon was exported to Al-Raqqa and that glass made in Nishapur and Samarra was exported to Ctesiphon.

We have detected evidence for technological specialisation. Results from Nishapur and Ctesiphon demonstrate that the centres specialised in producing colourless and pale green wheel cut facetted glass vessels respectively (see Fig. 1(a)). These contrasting results provide evidence for the existence of two separate production centres within the broad eastern zone that specialised in different colours of cut and engraved glass vessels.

The study's supra-regional sampling strategy has highlighted regional differences, including evidence for the specialised production of different glass colours and vessel decorations and has helped to define the Silk Road, linking the 'centre' of the Middle Eastern Islamic world to its 'periphery'. The results have also provided evidence for the existence of technological identities associated with production zones as part of the decentralised production of plant ash glass. Our results can also improve predictions about trade and exchange without scientific analysis. This new evidence for production zones provides an interesting way forward for the study of ancient glass in relation to production, supply, trade and exchange.

Acknowledgements

We are grateful to Professors Jane Evans and Mark Pearce for reading through this paper and commenting on it. We are also grateful to the University of Nottingham Centre for Advanced Studies for funding this research and to The Museum of Islamic Art in Berlin (especially the Director, Prof. Dr. Stefan Weber), The Museum of Islamic Art in Doha. The Director General of Antiquities for Syria, Dr Sophie Bertier, the Director General of Antiquities in Beirut and Dr. Hans Curvers for giving us permission to take micro-samples of glass for scientific analysis. Simon Chenery published with permission of the Director of the British Geological Survey.

Figure captions

Figure 1 Photographs of glass from which samples were removed: (a) Facet cut bowl fragments from Ctesiphon in Iraq (samples CTES 15 and 16); (b) Undecorated flask from Khirbat al-Minya in Israel (sample KAM 11); (c) Pinch decorated beaker rim and trail decorated bowl rim fragment from Nishapur, Iran (Samples NISH 9 and 17); (d) Pinched decorated bowl rim and scratch decorated fragment from Samarra, Iraq (Samples SAM 11 and 15); (e) A cameo decorated bowl rim fragment and a wall plate from Samarra, Iraq (samples SAM 17 and 35); (f) One of hundreds of glass furnace floor fragments from Al-Raqqa, Syria. This one has raw purple glass attached to it (sample RAQ 38). Photographs: J. Henderson.

Fig 2 Location map showing where the glass samples were derived from (the locations of Baghdad and Tehran are also given)

Fig 3 Weight % MgO versus CaO for glasses in this study compared with analyses of glasses from Nishapur, Iran [16], Raya, Egypt [19], the Serç Limani shipwreck [25], enamelled vessel glasses [29-30] and raw glass from Banias [5]. The parallel lines enclose glass mainly from northern Syria and enamelled glasses. Glasses mainly from Iran and Iraq plot below the line and those from the Levant above it.

Fig 4 Fe versus Cr concentrations (mg/kg) in the samples analysed

Figure 5 Cr/La versus 1000Zr/Ti ratios in the samples analysed

Fig 6 Li/K versus Cs/K ratios in the samples analysed

List of appendices

Appendix A Comparison between our LA-ICP-MS analyses of the Corning B standard, the expected composition [24] and Wagner et al.'s analytical assessment [27].

Appendix B Electron probe microanalyses (wt % oxide) of the samples analysed. Sam= Samarra; Kam= Khirbat al-Minya; Nish= Nishapur; Ctes= Ctesiphon; Bei= Beirut; Dam= Damascus.
0= below level of detection

Appendices C.1-C.8 LA-ICP-MS analyses of glass samples

References

(1) S. Carboni, D. Whitehouse, Glass of the sultans, Metropolitan Museum of Art, New York, 2001

(2) AnJiayao, Dated Islamic glass in China, Bulletin of the Asia Institutes 5 (1991) 123-138.

(3) E.V. Sayre and R.W. Smith**,** Compositional categories of ancient glass, *Science* 133 (1961) 1824–6.

(4) J. Henderson, Ancient Glass, an interdisciplinary exploration, Cambridge University Press, New York and Cambridge, 2013

(5) I.C. Freestone, Y. Gorin-Rosen, M.J. Hughes, Primary glass from Israel and the production of glass in late antiquity and the early Islamic period, in: Nenna M.-D. (Ed.), La Route du verre: Ateliers

primaires et secondaires du second millénaire av. J.-C. au Moyen Age, Maison de l'Orient Méditerraneéan-Jean Pouilloux, Lyon, 2000, pp. 65–84.

(6) C.M. Jackson, Making colourless glass in the Roman world, Archaeometry 47 (2005) 763–80.

(7) R. Arletti, C. Giacobbe, S. Quartieri, G. Sabatino, G. Tigano, M. Triscari, G. Vezzalini, Archaeometrical investigation of Sicilian early Byzantine glass: chemical and spectroscopic data, Archaeometry 52, 1 (2010) 99–114.

(8) N. Schibille, Late Byzantine Mineral Soda High Alumina Glasses from Asia Minor: A New Primary Glass Production Group, Plos One (2011).

(9) I.C. Freestone, K.A. Leslie, M. Thirlwell, Y. Gorin-Rosen, Strontium isotopes in the investigation of early glass production: Byzantine and early Islamic glass from the Near East, Archaeometry 45 (2003) 19–32.

(10) P. Degryse P ed., Glass Making in the Greco-Roman World: Results of the ARCHGLASS project, Leuven University Press, Leuven, 2015.

(11) V. Devulder, P. Degryse, F. Vanhaecke F, Development of a Novel Method for Unravelling the Origin of Natron Flux Used in Roman Glass Production Based on B Isotopic Analysis via Multicollector Inductively Coupled Plasma Mass Spectrometry, Anal. Chem. 85 (2013) 12077–12084.

(12) R. Irwin R, A note on textual sources for the history of glass, in: R. Ward (Ed.), Gilded and enameled glass from the Middle East, The British Museum, London, 1998, pp. 24–26.

(13) S. Carboni, Glass from Islamic lands, the al-Sabah collection, Thames and Hudson, London, 2001.

(14) J. Kröger J, Nishapur: Glass of the early Islamic period*,* Metropolitan Museum of Art, New York, 1995.

(15) G.T. Scanlon, R. Pinder-Wilson, Fustat glass of the early Islamic period. Finds excavated by the American Research Center in Egypt 1964–1980, Altajir World of Islam Trust, London, 2001.

(16) R.H. Brill R H, Chemical analyses of some glass fragments from Nishapur in the Corning Museum of Glass in: J Kröger, Nishapur: Glass of the Early Islamic Period, Appendix 3, The Metropolitan Museum of Art, New York, 1995, pp. 211–33.

(17) R.H. Brill, Some Thoughts on the Chemistry and Technology of Islamic Glass, in: S. Carboni, D. Whitehouse, Glass of the Sultans, The Metropolitan Museum of Art in association with The Corning Museum of Glass, Benaki Museum, and Yale University Press, New York, 2001, pp. 25–45.

(18) J. Henderson, S. McLoughlin, D. McPhail, Radical changes in Islamic glass technology: evidence for conservatism and experimentation with new glass recipes from early and middle Islamic Raqqa, Syria, Archaeometry 46 (2004) 439–68.

(19) N. Kato, I. Nakai,Y. Shindo, Transitions in Islamic plant ash glass vessels: On-site chemical analyses conducted at the Raya/al Tur area on the Sinai Peninsula, Egypt. J. Archaeol. Sci. 37 (2010) 1381–95.

(20) J. Henderson, J. Evans, Y. Barkoudah, The roots of provenance: glass, plants and isotopes in the Islamic Middle East, Antiquity 83 (2009) 414–29.

(21) J. Henderson J, Archaeological and scientific evidence for the production of early Islamic glass in al-Raq*qa,* Syria*,* Levant 31 (1999) 225–40.

(22) A. Meek, J. Henderson, J. Evans, Isotope analysis of English forest glass from the Weald and Staffordshire, J. Anal. Atomic Spec., 27 (2012) 786–795.

(23) R.H. Brill, Chemical analyses of early glasses, volume 2, Tables of analyses, The Corning Museum of glass, Corning, New York 1999.

(24) B. Wagner, A. Nowak, E. Bulska, K. Hametner, D. Günther, Critical assessment of the elemental composition of Corning archaeological reference glasses by LA-ICP-MS, Anal. Bioanal. Chem. 402 (2012),1667–1677.

(25) J. Henderson, Glass trade and chemical analysis: A possible model for Islamic glass production, in D. Foy, M.-D. Nenna (Eds.), Échanges et commerce du verre dans le monde antique, Actes du colloque de l'Association Francaise pour l'Archéologie du Verre, Aix-en-Provence et Marseille, 7–9 June 2001, Éditions Monique Mergoil, Montagnac, 2003, pp. 109–23.

(26) J. Henderson, J.A. Allan, Enamels on Ayyubid and Mamluk glass fragments, Archaeomaterials 4 (1990) 167–83.

(27) J. Henderson, Investigations into marvered glass II, in J. Allan (Ed.) Islamic Art in the Ashmolean Museum, Oxford Studies in Islamic Art, vol. 10, part 1, Oxford, Oxford University Press, 1995, pp. 31–50.

(28) P. Mirti, M. Pace, M. M. Negro Ponzi, M. Aceto, ICP-MS analysis of glass fragments of Parthian and Sasanian epoch from Seleucia and VehArdašīr (central Iraq), Archaeometry *50 (2008) 429–50.*

(32) R.H. Brill, Chemical analyses of some Sasanian glasses from Iraq, in D. Whitehouse, Sasanian and Post-Sasanian glass in the Corning Museum of Glass, The Corning Museum of Glass, Corning, New York, 2005, pp. 85-88.

(33) Y. Barkoudah, J. Henderson, The use of halophytic plants in the manufacture of ancient glass: ethnographic evidence and the scientific analysis of plant ashes, J. Glass Studies 48 (2006) 297-321.

(34) J. Henderson, S. Chenery, J. Kröger, E. Faber, Glass provenance and the Levantine Silk Road: the use of trace element analysis, in: Gan Fuxi, Li Quinghui*,* Julian Henderson (Eds.) Recent progress in scientific research of ancient glasses and glazes, World Scientific Publishing Co., Singapore, in press.

(35) Y. Be'eri-Shlevin, D. Avigad, A. Gerdes, O. Zlatkin, Detrital zircon U-Pb-Hf systematics of Israeli coastal sands: new perspectives on the provenance of Nile sediments, J. Geol. Soc., 171 (1) (2014) 107–116.

(36) M. Krom, R. Cliff, L. Eijsink, B. Herut, R. Chester, The characterisation of Saharan dusts and Nile particulate matter in surface sediments from the Levantine basin using Sr isotopes, Marine Geol., 155 (3-4) (1999) 319–330.

(37) A.J. Shortland**,** N. Rogers**,** K. Eremin**,** Trace element discriminants between Egyptian and Mesopotamian Late Bronze Age glasses, J. Archaeol. Sci*.* 34 (2007) 781–9.

(38) C. Jackson and H. Foster, Provenance studies and Roman glass, in J. Bayley, I. Freestone and C. Jackson (Eds.), Glass of the Roman World, Oxbow Books, Oxford and Philadelphia, 2015, 44-56.

(39) M.J. Baxter, H.E.M. Cool, C.M. Jackson, Further studies in the compositional variability of colourless Romano-British vessel glass, Archaeometry 47 (2005) 47-68.

(40) M. Phelps, I. Freestone, Y. Gorin-Rosen, B. Gratuze, J. Langton, Technological change and provenance of glass in Early Islamic Palestine, 20th Congress of the International Association for the History of Glass, Friborg-Romont, Switzerland, Programme and Abstracts, 2015, p. 157.

Appendix A: Table of LA-ICP-MS results for Corning 'B' glass

N=3 Corning B Glass
Assumed Si Concentration: 287706 mg/kg

Element	**This Study (mg/kg)**	**Expected Brill**	**%Error**		**Expected Wagner et al. [24]**	**%Error**
Li	11	5	135			
B	96	62	54		109	-12
Na	126100	126116	0			
Mg	5816	6211	-6			
Al	23880	23075	3			
P	2475	3579	-31			
K	8856	8301	7			
Ca	61823	61178	1			
Ti	582	533	9			
V	179	168	7			
Cr	59	34	73		66	-10
Mn	1940	1936	0			
Fe	2227	2378	-6			
Co	328	362	-9			
Ni	737	786	-6			
Cu	21137	21250	-1			
Zn	1576	1526	3			
Rb	12	9	26			
Sr	152	161	-5			
Zr	171	185	-7			
Sn	206	315	-35		190	9
Sb	3035	3462	-12			
Ba	702	1075	-35		690	2
Pb	4593	5663	-19			
As	19					
Y	0.43					
Nb	0.15					
Mo	1.5					
Cs	0.09					
La	0.21					
Ce	0.17					
Pr	0.02					
Nd	0.09					
Sm	0.02					
Eu	0.05					
Gd	0.04					
Tb	0.01					
Dy	0.04					
Ho	0.02					
Er	0.05					

Tm	0.01					
Yb	0.06					
Lu	0.02					
Hf	4.0					
Th	0.78					
U	0.24					

Appendix B

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	FeO	CoO	CuO	Sb_2O_5	PbO
SAM1	13.52	5.15	0.67	68.36	0.1	0.25	0.73	3.51	6.26	0	0.2	0.14	0	0.12	0.15	0
SAM11	13.92	3.64	0.93	70.35	0.28	0.38	0.4	3.45	4.61	0	0.68	0.46	0	0.1	0.18	0
SAM12	16.05	6.13	1.08	65.08	0.12	0.32	0.68	3.15	4.97	0.03	1.08	0.28	0	0.1	0.16	0
SAM13	13.72	5.77	1.26	66.95	0.11	0.21	0.7	2.61	6.69	0	0.8	0.43	0	0.1	0.16	0
SAM14	12.5	5.07	0.7	70.77	0.09	0.22	0.72	2.78	6.21	0	0.29	0.17	0	0.07	0.16	0
SAM15	15.6	5.89	1.37	66.09	0.08	0.23	0.64	2.42	4.54	0.04	1.15	0.82	0.03	0.16	0.13	0
SAM16	14.47	6.06	1.43	65.12	0.08	0.27	0.55	2.71	5.33	0.05	2.47	0.52	0	0	0.15	0
SAM17	12.25	5.13	0.8	71.17	0.08	0.2	0.52	3.51	4.06	0.03	0.36	0.19	0	0	0.21	0
SAM18	12.5	5.14	0.82	71.81	0.09	0.27	0.52	3.46	4.03	0.03	0.35	0.2	0	0.06	0.19	0
SAM19	12.1	5.09	0.8	70.94	0.11	0.25	0.51	3.41	4.03	0.03	0.35	0.2	0	0.04	0.19	0
SAM20	14.27	5.58	1.01	68.84	0.03	0.27	0.68	1.99	6.18	0.03	0.27	0.25	0	0.05	0.11	0
SAM21	14.14	5.56	1.02	68.74	0.06	0.34	0.68	1.97	6.15	0	0.26	0.25	0	0.09	0.12	0
SAM22	12.85	5.73	0.74	68.79	0.09	0.22	0.75	2.98	6.28	0	0.42	0.17	0	0	0.17	0
SAM23	16.29	6.12	1.41	66.57	0.11	0.26	0.66	2.92	4.32	0.04	0.61	0.36	0	0.1	0.16	0
SAM24	16.13	6.11	1.42	66.54	0.06	0.26	0.66	2.9	4.33	0.06	0.61	0.34	0	0.09	0.15	0
SAM25	16.13	6.12	1.4	66.38	0.11	0.27	0.67	2.9	4.35	0.03	0.63	0.34	0	0.1	0.15	0
SAM27	12.16	5.2	0.73	70.51	0.06	0.2	0.76	2.86	5.85	0	0.39	0.18	0	0	0.17	0
SAM28	12.5	5.56	0.79	68.41	0.08	0.24	0.66	2.91	6.5	0	0.22	0.19	0	0	0.14	0
SAM33	12.74	5.68	0.68	68.16	0.09	0.18	0.77	3.05	6.22	0	0.32	0.13	0	0	0.15	0
SAM34	15.15	6.15	1.44	63.17	0.09	0.34	0.44	3.18	5.33	0.05	3.23	0.44	0	0	0.17	0
SAM35	14.99	6.17	1.26	64.72	0.11	0.32	0.53	2.9	5.36	0.06	2.21	0.43	0	0	0.17	0
KAM3	13.51	3.03	3.09	59.7	0.23	0.22	0.48	2.08	7.77	0.2	0.4	4.2	0	2.3	0.11	0.22
KAM6	10.68	3.37	1.39	67.11	0.29	0.2	0.78	2.52	9.24	0.14	1	0.55	0	0.13	0.15	0
KAM7	11.44	3.95	1.18	64.79	0.3	0.23	0.85	2.6	10.68	0.11	0.65	0.49	0	0.15	0.12	0
KAM8	9.59	3.13	1.53	66.66	0.19	0.31	0.81	2.65	9.42	0.12	2.59	0.52	0	0.2	0.12	0
KAM11	10.08	4.01	1.34	67.86	0.3	0.19	0.74	2.52	10.62	0.12	0.08	0.42	0	0.87	0.17	0.1
KAM12	11.64	2.96	1.43	67.64	0.27	0.18	0.76	2.46	9.33	0.1	1.23	0.61	0	0.62	0.13	0.29
NISH1	12.33	5.54	0.89	70.58	0.08	0.23	0.68	2.53	6.09	0	0.33	0.18	0	0.23	0.13	0
NISH2	12.47	5.34	1.13	69.85	0.04	0.24	0.47	2.35	7.15	0	0.41	0.2	0	0.22	0.13	0
NISH3	12.4	5.33	1.28	69.68	0.06	0.26	0.45	2.41	7.26	0	0.39	0.25	0	0.21	0.13	0
NISH4	12.54	5.56	1.0E+00	69.67	0.08	0.32	0.52	2.98	6.81	0	0.33	0.22	0	0.22	0.15	0
NISH5	11.58	5.14	1.06	71.09	0.05	0.25	0.62	2.66	6.53	0	0.32	0.25	0	0.17	0.13	0
NISH6	15.08	6.19	1.35	68.59	0.11	0.3	0.58	2.75	4.5	0.05	0.22	0.31	0	0.17	0.14	0
NISH7	12.78	5.61	0.81	69.7	0.08	0.29	0.66	2.94	6.63	0	0.23	0.17	0	0.15	0.16	0
NISH8	14.97	5.76	1.21	69.67	0.1	0.21	0.66	2.58	3.31	0.04	1.02	0.29	0	0.15	0.11	0
NISH9	13.44	6.29	0.98	69.03	0.1	0.3	0.49	3.31	4.73	0.03	0.65	0.28	0	0.2	0.17	0
NISH10	18.86	3.93	1.52	64.63	0.26	0.22	1.22	3.69	4.62	0.09	0.44	0.46	0	0	0.24	0
NISH12	18.94	3.93	1.53	65.06	0.25	0.21	1.17	3.69	4.65	0.1	0.44	0.46	0	0	0.21	0
NISH16	17.45	4.24	2.7	62.59	0.27	0.3	0.76	3.82	6.01	0.07	0.98	0.82	0	0.23	0.18	0
NISH17	11.31	4.34	2.54	67.49	0.27	0.28	0.58	3.64	8.15	0.06	0.03	0.42	0	0.1	0.19	0
NISH18	14.91	2.01	2.03	67.42	0.48	0.22	0.85	3.8	6.5	0.06	0.73	0.51	0	0	0.21	0

NISH10	18.86	3.93	1.52	64.63	0.26	0.22	1.22	3.69	4.62	0.09	0.44	0.46	0	0	0.24	0
NISH12	18.94	3.93	1.53	65.06	0.25	0.21	1.17	3.69	4.65	0.1	0.44	0.46	0	0	0.21	0
NISH16	17.45	4.24	2.7	62.59	0.27	0.3	0.76	3.82	6.01	0.07	0.98	0.82	0	0.23	0.18	0
NISH17	11.31	4.34	2.54	67.49	0.27	0.28	0.58	3.64	8.15	0.06	0.03	0.42	0	0.1	0.19	0
NISH18	14.91	2.01	2.03	67.42	0.48	0.22	0.85	3.8	6.5	0.06	0.73	0.51	0	0	0.21	0
NISH19	18.74	3.28	3.34	61.77	0.23	0.15	1.24	3.39	5.41	0.15	0.71	1	0	0.06	0.19	0
CTE1	14.72	4.52	2.59	60.78	0.23	0.3	0.58	2.77	7.84	0.12	1.03	1.65	0.15	0.18	0.15	0.06
CTE2	14.7	6.08	1.7	64.21	0.15	0.23	0.58	3.29	6.2	0.07	0.38	0.5	0	0.03	0.16	0
CTE12	14.31	3.29	1.92	65.13	0.25	0.29	0.75	3.09	8.26	0.08	0.04	0.73	0	0.03	0.19	0
CTE13	13.13	3.87	1.97	67.15	0.19	0.26	0.82	2.3	7.74	0.05	0.03	0.69	0	0.024	0.11	0
CTE14	11.08	3.79	2.05	68.53	0.22	0.2	0.81	1.7	7.93	0.07	0.04	0.7	0	0.08	0.12	0
CTE15	16.67	4.8	1.6	58.9	0.24	0.34	0.64	3.21	10.86	0.08	0.44	0.56	0	0	0.19	0
CTE16	15.58	4.41	1.58	63.56	0.31	0.28	0.81	3.58	7.98	0.04	0.23	0.59	0	0.04	0.21	0
CTE17	17.43	5.9	1.34	60.96	0.18	0.28	0.81	2.96	8.1	0	0.17	0.41	0	0	0.16	0
CTE18	17.25	5.37	0.99	63.82	0.17	0.23	0.91	3.14	6.37	0	0.25	0.25	0	0.04	0.17	0
CTE19	14.27	5.16	1.84	63.26	0.16	0.28	0.51	3.24	7.96	0.05+K	0.48	0.68	0	0.04	0.18	0
CTE20	13.91	6.91	0.45	68.44	0.08	0.21	0.66	3.57	3.94	0	0.27	0.08	0	0.04	0.23	0
Cairo 9	13.15	3.57	1.25	67.95	0.39	0.18	0.75	2.59	8.84	0.06	8.84	0.06	0.0	0.00	0.11	0.00
Cairo 10	13.08	3.55	1.26	67.99	0.38	0.17	0.73	2.60	8.77	0.09	8.77	0.09	0.0	0.08	0.06	0.00
Cairo 13	12.56	3.36	1.31	66.97	0.34	0.27	0.63	2.69	7.22	0.11	7.22	0.11	0.0	0.01	0.09	0.11
Cairo 14	12.74	4.31	1.12	66.99	0.33	0.22	0.64	3.50	8.07	0.07	8.07	0.07	0.0	0.03	0.10	0.00
Cairo 16	12.78	4.64	0.94	66.55	0.34	0.23	0.64	3.18	9.23	0.06	9.23	0.06	0.0	0.00	0.11	0.00
Cairo 17	12.61	4.57	0.93	66.49	0.34	0.27	0.61	3.43	9.38	0.06	9.38	0.06	0.0	0.01	0.08	0.00
Cairo 18	14.60	5.90	1.02	62.87	0.37	0.23	0.74	3.62	8.34	0.08	8.34	0.08	0.0	0.01	0.12	0.00
Cairo19	14.48	4.19	1.09	65.43	0.34	0.29	0.61	3.31	7.33	0.07	7.33	0.07	0.0	0.05	0.09	0.13
Beirut 48	14.4	2.7	0.5	65.02	0.2	0.28	1.02	1.8	8.99	0.11	0.98	0.31	0	0	0.1	0
Beirut49	13.05	3.14	0.57	64.97	0.18	0.2	0.82	2.26	8.45	0.15	1.51	0.47	0	0	0.16	0
Beirut 51	11.96	3.65	1.04	65.54	0.34	0.16	0.77	3	7.62	0.13	0.96	0.48	0	0.03	0.21	0
Beirut 53	11.63	3	1.18	67.13	0.15	0.19	0.85	1.97	8.56	0.18	0.62	0.61	0	0	0.18	0
Beirut 54	12.79	1.99	1.04	64.37	0.52	0.08	1.1	4.04	7.96	0.06	1.22	0.55	0	0	0.32	0
Beirut 55	12.53	1.97	1	63.84	0.5	0.09	1.1	4.1	7.94	0.05	1.23	0.54	0	0.03	0.32	0
Beirut 109	11.36	2.32	1.78	65	0.25	0.12	0.77	2.83	10.53	0.1	1.02	0.52	0	0	0.21	0
Damas 1	12.18	3.12	1.17	65.94	0.2	0.17	0.73	2.67	10.25	0.08	0.79	0.4	0	0.08	0.17	0
Damas 14	14.34	3.14	0.96	64.46	0.23	0.13	0.96	2.36	9.92	0.06	0.9	0.29	0	0.05	0.21	0
Damas 35	12.44	2.38	1.1	67.14	0.1	0.21	0.8	2.94	8	0.08	0.6	0.33	0	0.01	0.23	0
Damas 37	14.66	2.03	0.94	63.92	0.2	0.19	0.93	4.14	10.14	0.06	0.85	0.32	0	0.1	0.13	0
Damas 43	12.4	2.97	0.89	6.74	0.17	0.17	0.91	1.99	6.77	0.07	0.89	0.36	0	0	0.16	0
Damas 44	12.43	2.65	0.82	66.13	0.2	0.21	0.88	2	7.87	0.06	0.77	0.28	0	0	0.15	0
Damas 45	12.67	2.76	0.82	66.59	0.16	0.2	0.93	2.02	7.88	0.06	0.76	0.29	0	0	0.12	0
Damas 46	12.27	2.69	0.84	65.31	0.14	0.2	0.92	1.99	7.72	0.04	0.74	0.29	0	0	0.12	0

Damas 46	12.27	2.69	0.84	65.31	0.14	0.2	0.92	1.99	7.72	0.04	0.74	0.29	0	0	0.12	0

Appendix C.1 (Nishapur)																	
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	7	11	23	24	27	28	31	39	42	47	51	52	55	56	59	60
Site	Sample	Li	B	Na	Mg	Al	Si	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni
Nishapur	NISH 1	19.6	57.9	92517	39195	4147	329592	241	17216	42401	152	5.77	9.22	2671	1318	1.15	7.55
Nishapur	NISH 2	26.7	66.1	92591	38739	5336	326157	191	16193	50871	168	4.80	11.2	3433	1543	1.49	8.30
Nishapur	NISH 3	26.3	66.1	91944	38489	5616	326227	339	16113	50985	187	5.24	11.7	3423	1699	1.60	9.07
Nishapur	NISH 4	22.5	67.5	95299	40383	4789	325362	255	20144	47990	254	6.31	14.8	2726	1926	2.72	10.5
Nishapur	NISH 5	19.7	74.7	87173	36157	4989	332046	417	18257	45593	233	7.21	14.4	2608	2252	1.47	9.54
Nishapur	NISH 6	31.7	85.4	114480	44132	6709	320360	299	18867	32039	402	7.79	27.5	1715	2634	1.70	11.3
Nishapur	NISH 7	23.2	67.0	98474	41141	3902	325736	253	20204	46521	192	5.28	11.6	1863	1364	4.94	7.46
Nishapur	NISH 8	23.9	91.0	117191	39680	5363	325899	365	17982	22817	377	14.1	24.0	8392	2307	6.09	12.6
Nishapur	NISH 9	27.5	78.7	101064	44744	4849	322698	359	23266	33700	364	7.98	19.9	5453	2200	4.71	12.3
Nishapur	NISH 10	21.2	94.1	142784	27580	8349	302411	960	30333	33552	773	16.3	12.5	3929	4500	1.82	4.66
Nishapur	NISH 12	22.1	98.4	147043	27725	8032	303836	894	30483	34083	777	16.2	12.1	3748	4321	1.86	4.70
Nishapur	NISH 16	15.1	121	131829	31714	15045	292805	1288	31429	44214	761	16.7	32.9	8333	7961	16.6	25.6
Nishapur	NISH 17	11.4	102	84226	33448	12924	315382	1453	29985	55224	504	11.3	12.3	209	4278	4.53	5.91
Nishapur	NISH 18	16.8	90.4	107597	14416	10102	315031	2075	31262	43068	493	11.4	10.5	5806	5058	1.74	6.19
Nishapur	NISH 19	12.7	96.4	142258	23571	18049	288972	955	28590	39486	1132	27.8	16.0	6206	9569	2.20	6.19
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Site	Sample	63	66	75	85	88	89	90	93	95	120	121	133	138	139	140	141
Nishapur	NISH 1	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	Mo	Sn	Sb	Cs	Ba	La	Ce	Pr
Nishapur	NISH 2	5.07	9.9	1.06	15.5	415	2.47	21.2	1.07	1.00	1.54	0.110	0.200	189	2.30	4.39	0.518
Nishapur	NISH 3	5.21	11.4	1.07	15.7	423	2.49	21.9	1.09	1.07	1.52	0.110	0.180	194	2.41	4.57	0.530
Nishapur	NISH 4	7.57	13.6	1.20	15.6	406	2.92	37.8	1.05	1.46	1.49	0.0613	0.167	122	3.02	5.82	0.685
Nishapur	NISH 5	9.73	12.2	1.24	13.7	332	2.38	24.6	0.905	0.987	1.38	0.104	0.179	94.3	2.55	5.11	0.569
Nishapur	NISH 6	9.90	14.4	1.02	15.1	383	3.71	68.5	1.43	0.929	1.42	0.101	0.177	89.2	4.89	9.59	1.08
Nishapur	NISH 7	10.5	13.2	0.779	14.5	407	2.38	28.6	0.707	0.807	1.12	0.0324	0.154	78.4	2.79	5.60	0.620
Nishapur	NISH 8	15.8	15.0	1.11	11.9	296	3.23	81.9	1.34	7.26	1.04	0.142	0.118	151	4.80	9.55	1.05
Nishapur	NISH 9	12.0	17.6	1.45	14.6	456	3.48	72.6	1.33	1.47	1.19	0.0560	0.157	139	5.28	10.4	1.15
Nishapur	NISH 10	45.5	48.9	21.0	11.5	398	6.41	88.6	2.83	1.26	1.06	0.183	0.175	425	8.14	15.8	1.69
Nishapur	NISH 12	43.4	46.6	19.5	11.3	391	6.41	88.4	2.78	1.16	1.10	0.170	0.182	404	7.79	15.4	1.66
Nishapur	NISH 16	1947	119	18.7	23.9	460	6.58	77.4	2.60	1.82	69.4	8.72	0.579	270	7.18	14.2	1.61
Nishapur	NISH 17	19.0	29.8	1.80	28.3	318	4.32	43.2	1.55	1.37	1.31	0.245	0.653	135	5.30	11.1	1.19
Nishapur	NISH 18	19.3	32.8	3.14	22.9	341	4.06	39.4	1.53	1.53	1.02	0.174	0.399	108	4.41	9.65	1.09
Nishapur	NISH 19	65.2	62.8	41.1	19.3	452	8.30	84.3	3.90	1.42	1.89	0.498	0.296	846	11.4	20.9	2.31
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	
Site	Isotope	146	147	153	157	159	163	165	166	169	172	175	178	208	232	238	
Nishapur	Sample	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Pb	Th	U	
Nishapur	NISH 1	2.07	0.408	0.0755	0.390	0.0523	0.390	0.0747	0.212	0.0337	0.213	0.0298	0.552	1.58	0.692	0.357	
Nishapur	NISH 2	2.08	0.424	0.0907	0.403	0.0663	0.404	0.0893	0.277	0.0342	0.232	0.0385	0.564	1.64	0.796	0.482	
Nishapur	NISH 3	2.27	0.525	0.0846	0.431	0.0752	0.439	0.0877	0.291	0.0431	0.244	0.0387	0.592	1.72	0.819	0.504	
Nishapur	NISH 4	2.72	0.580	0.134	0.540	0.0757	0.499	0.102	0.283	0.0402	0.300	0.0426	0.977	1.86	0.839	0.441	
Nishapur	NISH 5	2.29	0.451	0.0940	0.406	0.0675	0.426	0.0825	0.234	0.0365	0.258	0.0419	0.686	2.19	0.755	0.438	
Nishapur	NISH 6	4.12	0.837	0.162	0.689	0.113	0.680	0.127	0.384	0.0606	0.408	0.0561	1.66	3.39	1.20	0.415	
Nishapur	NISH 7	2.34	0.483	0.0947	0.403	0.0663	0.451	0.085	0.259	0.0387	0.233	0.0434	0.809	1.72	0.693	0.364	
Nishapur	NISH 8	4.02	0.836	0.152	0.650	0.0879	0.597	0.117	0.341	0.0560	0.366	0.0548	1.97	2.86	1.21	0.574	
Nishapur	NISH 9	4.43	0.860	0.167	0.771	0.0995	0.638	0.126	0.345	0.0572	0.352	0.0595	1.70	2.66	1.13	0.431	
Nishapur	NISH 10	7.05	1.36	0.300	1.28	0.173	1.13	0.228	0.616	0.0938	0.572	0.0905	2.11	161	1.60	0.643	
Nishapur	NISH 12	6.83	1.41	0.296	1.12	0.186	1.12	0.220	0.588	0.0934	0.588	0.0945	2.12	152	1.62	0.640	
Nishapur	NISH 16	6.39	1.34	0.252	1.06	0.176	1.13	0.236	0.681	0.103	0.699	0.104	1.99	445	2.19	0.698	
Nishapur	NISH 17	4.63	0.909	0.200	0.741	0.125	0.687	0.152	0.421	0.0692	0.430	0.0715	1.02	4.01	1.38	0.500	
Nishapur	NISH 18	4.03	0.835	0.179	0.663	0.105	0.676	0.140	0.396	0.0683	0.409	0.0661	1.00	3.88	1.33	0.475	
Nishapur	NISH 19	9.06	1.74	0.402	1.62	0.238	1.38	0.282	0.780	0.116	0.784	0.120	2.07	293	2.79	0.933	

Appendix C.2 (Samarra)

	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	7	11	23	24	27	28	31	39	42	47	51	52	55	56	59	60
Site	Sample	Li	B	Na	Mg	Al	Si	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni
Samarra	SAM 1	25.9	77.8	106068	39998	3664	319496	763	24390	45601	175	3.88	7.40	1554	1487	1.58	8.71
Samarra	SAM 11	18.7	54.0	89312	37470	3352	327816	132	18562	43351	154	4.13	8.65	2405	1610	2.55	6.41
Samarra	SAM 12	29.8	94.6	121372	45857	5256	304795	382	20985	35142	433	12.0	21.7	9211	3028	3.56	9.86
Samarra	SAM 13	26.8	79.2	104501	43680	6177	312835	344	17861	47049	404	12.3	27.6	6823	4689	9.09	16.4
Samarra	SAM 14	5.64	75.0	103247	26828	4383	330457	658	23146	32476	323	9.83	26.8	5745	4980	2.69	15.9
Samarra	SAM 15	22.6	75.1	116315	40924	6979	308978	328	16311	31395	385	24.8	30.8	9082	6256	273	16.3
Samarra	SAM 16	27.0	84.5	112518	42477	6698	304140	368	19454	36686	440	27.4	39.1	20138	3749	17.8	19.5
Samarra	SAM 17	22.6	79.8	98520	34268	3264	333799	371	25441	24194	369	4.79	15.6	2687	1318	1.24	7.52
Samarra	SAM 18	26.8	93.2	110548	30680	2057	335435	354	27763	16859	313	6.35	19.2	3028	2080	1.39	8.36
Samarra	SAM 19	23.5	83.2	100769	35036	3368	331298	356	23738	24792	384	5.46	16.1	2918	1431	1.26	7.66
Samarra	SAM 20	29.9	73.5	113283	43059	4881	321061	225	13685	43657	314	6.62	22.9	2137	2573	1.17	9.14
Samarra	SAM 21	26.4	62.5	107539	41564	4891	321412	207	13583	43143	310	6.94	23.6	2303	2768	1.29	10.0
Samarra	SAM 22	25.1	70.3	101361	41765	3418	321365	291	20815	43464	152	7.54	9.52	3364	1135	3.60	7.84
Samarra	SAM 23	21.2	75.2	120534	45222	7390	310006	499	19769	31090	484	9.76	31.9	5292	3957	8.45	13.4
Samarra	SAM 24	21.2	75.4	120804	44706	7435	310661	317	20141	30162	458	9.62	31.4	5164	3833	7.99	12.5
Samarra	SAM 25	20.4	71.8	120004	44901	7457	310240	210	19676	30472	476	9.59	31.0	5233	3873	8.10	11.7
Samarra	SAM 28	23.0	65.8	94211	39758	3782	319332	269	19527	44340	186	5.00	11.3	1659	1202	1.15	7.71
Samarra	SAM 27	22.1	68.3	95716	37028	3325	329616	318	19677	40061	156	4.65	8.78	3159	1137	3.17	6.97
Samarra	SAM 33	23.5	66.4	98459	41134	3339	317649	263	20862	44561	142	5.63	7.69	2521	995	2.60	6.66
Samarra	SAM 34	25.1	81.5	115289	43223	7154	294978	348	21280	36755	536	24.7	35.3	26253	3345	31.7	27.7
Samarra	SAM 35	25.0	78.5	112123	43210	6482	302247	325	19717	38089	533	19.3	31.9	18207	3523	17.3	19.4

	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	63	66	75	85	88	89	90	93	95	120	121	133	138	139	140	141
Site	Sample	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	Mo	Sn	Sb	Cs	Ba	La	Ce	Pr
Samarra	SAM 1	10.5	19.5	0.814	14.3	396	2.48	31.1	0.747	1.30	1.84	0.0599	0.127	89.3	2.70	5.68	0.610
Samarra	SAM 11	6.59	7.31	0.862	11.7	425	2.30	23.8	0.635	0.823	1.49	0.0405	0.104	107	2.47	5.02	0.571
Samarra	SAM 12	11.5	14.2	2.19	11.8	473	3.98	121	1.51	1.76	1.66	0.0570	0.107	175	5.44	10.4	1.19
Samarra	SAM 13	82.1	35.6	3.11	13.8	428	3.46	55.5	1.43	3.59	5.15	0.508	0.192	147	3.71	7.52	0.888
Samarra	SAM 14	30.6	18.8	2.06	12.7	271	2.04	10.4	0.879	1.51	39.8	0.547	0.132	67.4	1.84	3.58	0.418
Samarra	SAM 15	1129	193	4.41	11.4	482	3.94	65.1	1.47	3.41	3.44	0.371	0.143	265	5.10	10.0	1.14
Samarra	SAM 16	68.8	27.5	3.75	13.6	461	3.84	77.6	1.65	6.03	5.35	0.423	0.171	362	4.94	9.95	1.11
Samarra	SAM 17	5.68	14.4	1.13	11.8	312	3.05	121	1.30	1.49	1.39	0.0840	0.112	45.6	4.09	10.1	1.01
Samarra	SAM 18	8.01	13.8	1.20	16.2	254	1.88	74.7	1.10	1.71	0.843	0.0701	0.143	40.8	2.76	11.0	0.802
Samarra	SAM 19	6.84	14.8	1.21	11.9	330	3.18	126	1.37	1.50	1.51	0.0799	0.127	48.7	4.45	10.9	1.06
Samarra	SAM 20	3.80	10.3	1.16	11.6	315	2.59	42.1	1.01	1.84	1.34	0.0442	0.154	82.1	2.69	5.28	0.625
Samarra	SAM 21	5.29	9.6	1.29	12.0	332	2.73	44.6	1.14	1.93	1.40	0.0656	0.153	84.6	2.80	5.50	0.664
Samarra	SAM 22	8.71	14.6	0.931	14.0	387	2.25	25.1	0.571	1.28	1.41	0.0093	0.154	112	2.58	5.20	0.578
Samarra	SAM 23	18.4	22.9	1.70	11.6	439	4.25	115	1.75	1.62	1.72	0.104	0.129	169	5.71	11.0	1.28
Samarra	SAM 24	17.5	20.9	1.80	11.8	426	3.99	107	1.74	1.75	1.29	0.0950	0.142	164	5.44	11.1	1.29
Samarra	SAM 25	15.9	15.0	1.90	11.6	438	4.32	115	1.79	1.61	1.57	0.0779	0.117	167	5.68	11.0	1.25
Samarra	SAM 28	5.88	13.4	0.760	13.4	395	2.32	28.6	0.726	0.749	1.84	0.0630	0.145	76.9	2.67	5.22	0.574
Samarra	SAM 27	6.51	15.4	1.03	11.5	378	2.09	23.0	0.618	0.991	1.50	0.0571	0.127	128	2.41	4.88	0.570
Samarra	SAM 33	7.73	14.7	0.779	13.1	384	2.20	25.0	0.591	0.981	1.58	0.0762	0.137	96.6	2.58	5.04	0.548
Samarra	SAM 34	83.2	35.5	5.40	12.5	669	4.84	126	1.93	4.93	1.70	0.157	0.153	718	6.47	11.3	1.36
Samarra	SAM 35	56.4	30.9	3.48	12.4	556	4.78	137	1.92	4.03	1.95	0.207	0.168	513	6.24	11.4	1.38

	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	146	147	153	157	159	163	165	166	169	172	175	178	208	232	238
Site	Sample	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Pb	Th	U
Samarra	SAM 1	2.46	0.486	0.119	0.474	0.0817	0.473	0.112	0.298	0.0765	0.317	0.0787	0.849	1.72	0.780	0.466
Samarra	SAM 11	2.14	0.497	0.0855	0.364	0.0547	0.371	0.0730	0.216	0.0315	0.209	0.0291	0.602	0.77	0.606	0.306
Samarra	SAM 12	4.72	0.907	0.168	0.680	0.105	0.784	0.153	0.459	0.0737	0.431	0.0782	2.80	2.60	1.47	0.503
Samarra	SAM 13	3.43	0.651	0.131	0.632	0.0820	0.612	0.123	0.355	0.0513	0.337	0.0513	1.32	227	1.10	0.532
Samarra	SAM 14	1.72	0.422	0.105	0.376	0.0537	0.359	0.0663	0.181	0.0257	0.180	0.0264	0.228	75.8	0.435	0.151
Samarra	SAM 15	4.36	0.887	0.193	0.715	0.124	0.694	0.133	0.390	0.0614	0.396	0.0726	1.58	16.4	1.15	0.434
Samarra	SAM 16	4.43	0.871	0.190	0.691	0.104	0.677	0.136	0.410	0.0669	0.404	0.0731	1.82	63.7	1.20	0.596
Samarra	SAM 17	3.78	0.706	0.153	0.572	0.0796	0.533	0.0954	0.318	0.0446	0.316	0.0550	2.70	2.88	1.16	0.487
Samarra	SAM 18	2.67	0.461	0.0856	0.341	0.0548	0.375	0.0669	0.218	0.0325	0.203	0.0336	1.70	3.51	0.804	0.555
Samarra	SAM 19	3.77	0.782	0.143	0.562	0.0806	0.579	0.112	0.334	0.0470	0.374	0.0612	2.76	3.03	1.20	0.496
Samarra	SAM 20	2.55	0.511	0.116	0.433	0.0712	0.462	0.0927	0.293	0.0437	0.300	0.0418	1.07	1.82	0.854	0.427
Samarra	SAM 21	2.62	0.527	0.102	0.486	0.0687	0.470	0.0902	0.298	0.0455	0.309	0.0457	1.09	1.70	0.859	0.432
Samarra	SAM 22	2.33	0.496	0.0925	0.436	0.0610	0.426	0.0782	0.221	0.0333	0.223	0.0346	0.655	1.70	0.607	0.355
Samarra	SAM 23	5.18	1.06	0.194	0.759	0.130	0.729	0.164	0.461	0.0717	0.488	0.0772	2.63	3.00	1.53	0.497
Samarra	SAM 24	4.87	0.939	0.189	0.727	0.116	0.721	0.146	0.422	0.0600	0.459	0.0677	2.44	2.94	1.43	0.481
Samarra	SAM 25	5.06	0.923	0.190	0.869	0.108	0.742	0.162	0.467	0.0706	0.462	0.0683	2.58	2.51	1.54	0.481
Samarra	SAM 28	2.32	0.463	0.118	0.419	0.0618	0.365	0.0824	0.224	0.0329	0.243	0.0315	0.693	1.59	0.635	0.345
Samarra	SAM 27	2.27	0.426	0.0936	0.363	0.0548	0.347	0.0781	0.220	0.0324	0.222	0.0339	0.593	1.40	0.592	0.345
Samarra	SAM 33	2.34	0.475	0.0940	0.392	0.0558	0.390	0.0901	0.229	0.0307	0.215	0.0343	0.636	1.54	0.602	0.336
Samarra	SAM 34	5.43	1.11	0.200	0.878	0.122	0.865	0.168	0.487	0.0694	0.519	0.0783	2.71	27.7	1.47	0.579
Samarra	SAM 35	5.38	1.04	0.205	0.914	0.132	0.837	0.170	0.481	0.0741	0.517	0.0840	3.00	30.4	1.53	0.534

Appendix C.3 (Ctesiphon)

	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	7	11	23	24	27	28	31	39	42	47	51	52	55	56	59	60
Site	Sample	Li	B	Na	Mg	Al	Si	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni
Ctesiphon	CTES 1	20.8	104	110918	34877	13421	283362	753	22002	53980	930	20.1	75.5	8594	16768	1134	32.9
Ctesiphon	CTES 2	24.7	96.1	112665	47405	8928	300097	504	25503	42917	650	12.3	41.6	3150	4707	16.0	16.9
Ctesiphon	CTES 12	8.34	87.4	112680	24876	8755	303743	906	24025	50474	658	15.4	60.9	234	6635	3.16	25.4
Ctesiphon	CTES 13	12.0	94.1	104511	30167	10417	311292	720	18022	54858	587	14.6	50.6	237	6368	3.15	26.0
Ctesiphon	CTES 14	18.4	116	89877	29966	10677	320524	970	13495	54078	584	13.9	60.2	246	6592	3.19	26.9
Ctesiphon	CTES 15	15.3	99.5	129275	38129	8633	275393	838	24736	76282	590	15.3	59.1	3781	5463	3.50	20.9
Ctesiphon	CTES 16	8.40	97.0	113831	31294	8163	296334	966	28875	56713	628	13.9	42.9	1782	5589	3.10	25.1
Ctesiphon	CTES 17	19.0	92.2	127827	41403	6268	284508	561	24162	56859	426	10.1	37.4	1307	3727	2.71	15.3
Ctesiphon	CTES 18	28.8	128	126240	37743	4477	297549	578	25593	44293	222	6.27	17.1	2119	2095	1.28	8.94
Ctesiphon	CTES 19	21.6	70.8	104512	36495	9210	296240	499	26174	54837	528	13.7	51.3	4426	5779	3.27	26.5
Ctesiphon	CTES 20	26.2	65.3	101769	48615	2207	319379	413	29147	27392	112	4.75	26.6	1813	644	1.44	6.19

	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	63	66	75	85	88	89	90	93	95	120	121	133	138	139	140	141
Site	Sample	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	Mo	Sn	Sb	Cs	Ba	La	Ce	Pr
Ctesiphon	CTES 1	1628	6070	11.1	12.0	541	5.55	117	2.68	4.23	117	2.09	0.207	244	7.41	14.4	1.65
Ctesiphon	CTES 2	51.7	55.5	3.90	12.8	484	4.82	128	2.12	1.54	5.53	4.31	0.179	118	6.54	12.9	1.46
Ctesiphon	CTES 12	10.2	22.4	1.35	9.89	255	3.42	65.8	1.95	0.448	1.29	0.0804	0.184	93.7	3.45	7.19	0.788
Ctesiphon	CTES 13	8.72	20.9	1.32	9.05	332	3.94	40.1	1.82	0.359	1.34	0.140	0.173	88.6	4.00	7.77	0.943
Ctesiphon	CTES 14	9.05	28.7	1.08	8.42	378	3.86	40.6	1.88	0.437	1.39	0.0979	0.144	100	4.00	7.92	0.921
Ctesiphon	CTES 15	13.3	21.8	1.31	9.72	601	3.82	68.5	1.86	3.01	1.29	0.0826	0.114	129	4.10	7.56	0.898
Ctesiphon	CTES 16	13.9	24.4	0.976	9.07	330	3.94	55.7	2.01	1.49	1.35	0.113	0.154	89.7	4.08	7.67	0.898
Ctesiphon	CTES 17	9.37	15.1	0.836	9.55	431	3.16	40.1	1.30	1.03	1.14	0.0923	0.108	105	3.44	6.38	0.782
Ctesiphon	CTES 18	6.21	11.4	0.885	12.3	385	2.33	25.5	0.849	2.00	1.23	0.0803	0.0924	88.6	2.56	4.89	0.569
Ctesiphon	CTES 19	19.1	21.5	1.50	13.3	407	3.62	36.5	1.67	1.09	1.28	0.167	0.222	114	3.66	7.32	0.836
Ctesiphon	CTES 20	7.88	17.6	0.601	13.9	419	1.60	19.9	0.402	0.957	1.15	0.0652	0.119	54.1	1.73	4.03	0.409

	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	
	Isotope	146	147	153	157	159	163	165	166	169	172	175	178	208	232	238	
Site	Sample	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Pb	Th	U	
Ctesiphon	CTES 1	6.43	1.38	0.266	1.07	0.156	0.989	0.204	0.609	0.0851	0.629	0.0977	2.71	428	1.82	0.821	
Ctesiphon	CTES 2	5.97	1.20	0.234	0.920	0.144	0.907	0.179	0.547	0.0742	0.569	0.0889	3.02	180	1.72	0.616	
Ctesiphon	CTES 12	3.02	0.630	0.142	0.553	0.0850	0.555	0.107	0.347	0.0495	0.369	0.0548	1.45	1.74	1.11	0.549	
Ctesiphon	CTES 13	3.77	0.768	0.159	0.659	0.118	0.681	0.150	0.409	0.0659	0.418	0.0604	1.05	2.12	1.24	0.541	
Ctesiphon	CTES 14	3.71	0.746	0.154	0.685	0.0976	0.676	0.150	0.417	0.0576	0.401	0.0597	1.05	2.25	1.21	0.678	
Ctesiphon	CTES 15	3.61	0.692	0.170	0.640	0.109	0.675	0.128	0.387	0.0529	0.401	0.0595	1.61	2.29	1.20	0.561	
Ctesiphon	CTES 16	3.60	0.723	0.146	0.703	0.111	0.686	0.130	0.411	0.0668	0.443	0.0569	1.43	1.69	1.30	0.525	
Ctesiphon	CTES 17	3.01	0.525	0.134	0.606	0.0814	0.563	0.105	0.327	0.0475	0.332	0.0419	0.993	1.64	0.963	0.450	
Ctesiphon	CTES 18	2.24	0.422	0.0875	0.401	0.0573	0.408	0.082	0.230	0.0316	0.262	0.0338	0.668	1.32	0.676	0.425	
Ctesiphon	CTES 19	3.18	0.690	0.162	0.599	0.0886	0.614	0.123	0.371	0.0536	0.367	0.0523	0.890	4.03	1.05	0.475	
Ctesiphon	CTES 20	1.58	0.331	0.0610	0.282	0.0480	0.264	0.0587	0.154	0.0274	0.154	0.0248	0.530	1.28	0.611	0.295	

Appendix C.4 (Beirut)																	
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	7	11	23	24	27	28	31	39	42	47	51	52	55	56	59	60
Site	Sample	Li	B	Na	Mg	Al	Si	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni
Beirut	BEI 48	6.73	79.5	107164	18849	2641	303977	877	16721	64406	676	15.8	9.20	7052	2064	3.10	7.50
Beirut	BEI 49	11.5	104	94787	22197	3361	303930	745	21521	61063	856	19.7	11.0	11117	3743	11.1	14.1
Beirut	BEI 51	7.73	116	88059	26324	6205	306360	1426	28750	54812	869	12.2	12.0	7307	3824	14.3	8.20
Beirut	BEI 53	9.86	81.2	85943	21332	6899	313793	766	18657	60866	1119	40.2	16.0	4531	4688	6.00	9.50
Beirut	BEI 54	11.1	106	90328	13925	5852	300891	2028	38089	56646	344	10.8	7.00	9061	4267	14.0	15.5
Beirut	BEI 55	9.17	73.0	81189	20060	6580	298414	684	17908	58724	1062	38.0	15.3	4374	4445	5.70	9.60
Beirut	BEI 109	4.72	58.7	81159	16467	10513	303836	1136	27001	77494	672	13.1	13.3	7453	4140	3.80	8.70
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	63	66	75	85	88	89	90	93	95	120	121	133	138	139	140	141
Site	Sample	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	Mo	Sn	Sb	Cs	Ba	La	Ce	Pr
Beirut	BEI 48	10.0	20.4	1.00	7.90	531	2.83	117	2.23	3.26	13.0	0.070	0.0900	181	2.94	5.14	0.600
Beirut	BEI 49	22.5	27.1	2.44	10.3	546	3.20	109	2.21	6.53	179	1.14	0.170	127	4.03	7.65	0.810
Beirut	BEI 51	318	104	2.14	12.4	458	4.11	138	2.50	0.930	13.0	0.110	0.310	581	4.42	8.65	0.930
Beirut	BEI 53	15.3	31.4	4.17	9.50	527	4.49	123	4.52	1.90	18.0	0.210	0.130	125	5.94	12.5	1.40
Beirut	BEI 54	116	61.3	73.4	11.6	531	2.34	17.0	1.30	1.20	20.0	517	0.170	146	3.02	5.31	0.640
Beirut	BEI 55	14.1	31.9	4.16	9.00	514	4.39	116	4.43	1.80	15.0	0.300	0.140	121	5.50	11.9	1.30
Beirut	BEI 109	17.8	24.7	2.58	12.8	660	7.11	39.0	2.08	2.01	13.0	0.180	0.130	317	6.13	11.2	1.40
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	
	Isotope	146	147	153	157	159	163	165	166	169	172	175	178	208	232	238	
Site	Sample	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Pb	Th	U	
Beirut	BEI 48	2.28	0.450	0.100	0.400	0.0700	0.450	0.100	0.290	0.0400	0.310	0.0500	2.69	2.00	0.640	0.360	
Beirut	BEI 49	3.17	0.620	0.140	0.570	0.0800	0.570	0.110	0.330	0.0500	0.410	0.0600	2.56	430	0.830	0.610	
Beirut	BEI 51	3.97	0.770	0.170	0.720	0.110	0.690	0.150	0.410	0.0700	0.440	0.0800	3.28	92.0	1.27	1.49	
Beirut	BEI 53	5.83	1.13	0.220	0.890	0.130	0.880	0.190	0.500	0.0800	0.520	0.0800	2.80	56.0	1.61	0.430	
Beirut	BEI 54	2.58	0.500	0.120	0.420	0.0600	0.380	0.0700	0.210	0.0300	0.210	0.0300	0.40	271	0.740	0.960	
Beirut	BEI 55	5.44	0.980	0.200	0.890	0.130	0.780	0.170	0.490	0.0700	0.480	0.0700	2.73	50.0	1.50	0.420	
Beirut	BEI 109	5.92	1.21	0.310	1.14	0.170	1.06	0.220	0.580	0.0900	0.570	0.0800	0.990	79.0	0.880	0.480	

Appendix C.5 (Damascus)																		
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	7	11	23	24	27	28	31	39	42	47	51	52	55	56	59	60
Site	Sample	Li	B	Na	Mg	Al	Si	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni
Damascus	DAM 1	6.56	87.1	106020	23072	5930	301078	1271	27130	73715	419	9.5	9.70	6653	2975	2.10	12.5
Damascus	DAM 37	7.34	93.7	90777	23229	6927	308885	1471	31271	73257	495	16.2	13.5	5904	4114	2.30	15.7
Damascus	DAM 14	7.16	91.1	106317	29197	5660	298320	1134	22926	73275	400	10.1	10.4	6749	3055	3.70	11.7
Damascus	DAM 35	9.12	92.1	92174	19331	5612	306173	1420	23360	56865	334	14.2	8.90	5575	2769	2.50	10.8
Damascus	DAM 43	8.89	83.0	95611	20722	4970	311970	773	18173	47506	404	17.7	8.90	6687	2690	3.80	11.3
Damascus	DAM 44	10.2	86.9	95197	19657	4729	309118	697	19028	57378	364	13.8	9.40	5750	2318	2.70	11.9
Damascus	DAM 45	9.53	85.0	92944	19214	4865	311269	733	19000	56375	367	14.3	9.60	5710	2270	2.50	11.7
Damascus	DAM 46	6.72	222	57820	12003	4289	305285	564	16695	34928	415	12.4	11.0	3833	2940	1.80	8.30
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	63	66	75	85	88	89	90	93	95	120	121	133	138	139	140	141
Site	Sample	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	Mo	Sn	Sb	Cs	Ba	La	Ce	Pr
Damascus	DAM 1	13.3	22.4	0.980	13.7	476	4.13	94.0	1.78	1.93	25.0	0.0700	0.0700	250	5.78	12.3	1.32
Damascus	DAM 37	14.0	38.4	1.80	12.9	553	4.00	117	2.21	1.99	23.0	0.0600	0.180	315	7.27	14.2	1.50
Damascus	DAM 14	18.3	30.0	1.31	11.7	578	3.29	68.0	1.72	1.79	27.0	0.0000	0.400	256	5.73	12.7	1.34
Damascus	DAM 35	50.8	17.4	0.700	9.20	523	2.66	72.0	1.56	3.11	13.0	0.360	0.220	149	4.86	10.0	1.18
Damascus	DAM 43	24.8	32.0	1.57	8.40	432	3.20	75.0	1.65	2.85	17.0	0.430	0.110	133	4.99	9.92	1.12
Damascus	DAM 44	20.8	27.0	1.38	8.40	532	3.09	67.0	1.56	3.03	12.0	0.380	0.150	147	4.99	10.2	1.16
Damascus	DAM 45	20.2	25.8	1.52	8.40	534	3.15	69.0	1.55	2.98	13.0	0.350	0.160	143	4.98	9.76	1.15
Damascus	DAM 46	19.8	33.3	2.89	8.20	331	2.28	2.28	53.0	1.67	1.94	0.180	0.130	317	6.13	11.2	1.40
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	
	Isotope	146	147	153	157	159	163	165	166	169	172	175	178	208	232	238	
Site	Sample	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Pb	Th	U	
Damascus	DAM 1	5.79	0.830	0.260	0.840	0.130	0.880	0.150	0.370	0.0500	0.560	0.0900	2.00	3.00	1.42	0.490	
Damascus	DAM 37	5.54	0.600	0.200	0.830	0.130	0.700	0.150	0.360	0.0400	0.440	0.0900	2.57	4.00	1.64	0.740	
Damascus	DAM 14	4.51	0.980	0.200	0.650	0.0900	0.540	0.130	0.390	0.0600	0.340	0.0600	1.60	5.00	1.27	0.470	
Damascus	DAM 35	4.90	1.14	0.160	0.610	0.110	0.470	0.120	0.310	0.0500	0.350	0.0800	1.53	45.0	1.03	0.460	
Damascus	DAM 43	4.77	0.970	0.170	0.720	0.100	0.570	0.110	0.320	0.0500	0.350	0.0600	1.83	25.0	1.09	0.410	
Damascus	DAM 44	4.92	1.00	0.180	0.720	0.100	0.630	0.120	0.330	0.0400	0.300	0.0500	1.64	47.0	1.04	0.400	
Damascus	DAM 45	5.12	0.990	0.170	0.770	0.0900	0.610	0.120	0.320	0.0500	0.330	0.0400	1.56	44.0	1.04	0.390	
Damascus	DAM 46	5.92	1.21	0.310	1.14	0.170	1.06	0.220	0.580	0.0900	0.570	0.0800	0.990	79.0	0.880	0.480	

Appendic C.6 (Cairo)																	
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	7	11	23	24	27	28	31	39	42	47	51	52	55	56	59	60
Site	Sample	Li	B	Na	Mg	Al	Si	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni
Cairo	Cairo 9	8.94	81.5	93133	26911	9641	317626	1319	15528	64972	721	22.1	15.0	4105	5861	3.00	14.6
Cairo	Cairo 10	7.41	84.7	99895	27944	6718	317813	1011	14906	62874	540	15.8	10.1	4258	3414	2.20	12.5
Cairo	Cairo 13	7.87	89.4	93076	25894	6701	313045	1160	16180	54102	629	20.9	14.0	6096	53861	2.60	12.3
Cairo	Cairo 14	11.2	91.6	98415	33948	12902	313138	1114	20135	61544	443	17.7	11.2	6071	3478	3.60	12.5
Cairo	Cairo 16	11.0	79.9	92311	32039	5931	311082	1082	18397	65848	430	24.3	12.1	5676	41373	4.30	16.1
Cairo	Cairo 17	10.7	74.2	94874	36017	5317	310801	997	19245	66369	366	17.0	9.80	5572	3012	3.70	12.6
Cairo	Cairo 18	7.46	119	111345	45726	5908	293880	1215	21176	60035	517	14.9	10.4	9865	3400	2.90	14.6
Cairo	Cairo 19	17.5	114	113688	37734	25557	305846	1385	24058	80168	916	23.7	18.1	8289	6589	97.8	19.7
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	63	66	75	85	88	89	90	93	95	120	121	133	138	139	140	141
Site	Sample	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	Mo	Sn	Sb	Cs	Ba	La	Ce	Pr
Cairo	Cairo 9	46.0	44.1	42.9	20.1	639	4.72	142	2.67	1.63	8.00	1.47	0.350	235	7.80	16.6	1.75
Cairo	Cairo 10	12.0	43.3	1.76	17.6	593	4.18	139	2.21	1.68	6.00	0.570	0.290	224	7.32	14.4	1.50
Cairo	Cairo 13	52.1	29.8	13.1	15.9	427	3.98	110	2.35	2.40	1264	4.48	0.350	206	6.21	12.5	1.34
Cairo	Cairo 14	45.1	25.0	9.40	14.2	584	5.24	66.0	1.91	2.92	87.0	11.9	0.530	192	5.16	10.5	1.16
Cairo	Cairo 16	102	65.1	38.9	13.9	733	4.97	70.0	2.08	3.67	1335	8.39	0.370	211	5.46	10.8	1.20
Cairo	Cairo 17	27.4	27.0	2.04	11.9	814	4.53	70.0	2.02	2.82	2.00	0.270	0.170	185	5.54	10.8	1.19
Cairo	Cairo 18	23.4	34.5	40.0	14.7	479	3.58	86.0	1.97	2.74	3.00	0.820	0.150	334	5.81	11.3	1.28
Cairo	Cairo 19	737	242	28.6	25.0	493	5.03	102	3.02	3.13	111	30.4	1.240	384	5.88	12.7	1.27
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	
	Isotope	146	147	153	157	159	163	165	166	169	172	175	178	208	232	238	
Site	Sample	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Pb	Th	U	
Cairo	Cairo 9	6.76	1.21	0.280	0.950	0.120	0.800	0.160	0.400	0.0700	0.490	0.0700	3.09	142	2.07	0.530	
Cairo	Cairo 10	5.56	1.07	0.230	0.850	0.130	0.720	0.140	0.380	0.0700	0.420	0.0800	3.32	57.0	1.95	0.520	
Cairo	Cairo 13	5.15	0.940	0.180	0.750	0.110	0.700	0.130	0.420	0.0700	0.370	0.0800	2.53	4791	1.69	0.590	
Cairo	Cairo 14	4.56	0.890	0.200	0.830	0.120	0.770	0.160	0.490	0.0800	0.450	0.0800	1.55	1421	1.19	0.480	
Cairo	Cairo 16	4.67	0.870	0.170	0.790	0.120	0.740	0.150	0.450	0.0700	0.430	0.0600	1.61	9496	1.24	0.540	
Cairo	Cairo 17	4.47	0.850	0.180	0.730	0.100	0.710	0.150	0.450	0.0600	0.410	0.0700	1.63	3.00	1.24	0.450	
Cairo	Cairo 18	4.77	1.02	0.200	0.760	0.100	0.670	0.130	0.370	0.0500	0.370	0.0500	2.02	137	1.38	0.440	
Cairo	Cairo 19	5.15	1.00	0.250	0.900	0.130	0.840	0.180	0.540	0.0600	0.530	0.0700	2.21	15007	1.27	0.760	

Appendix C.7 (Khirbat al-Minya)

	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	7	11	23	24	27	28	31	39	42	47	51	52	55	56	59	60
Site	Sample	Li	B	Na	Mg	Al	Si	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni
Kam	Kam 3	15.9	116	101667	22311	16374	279062	786	17049	54763	1391	27.5	184	3877	44911	11.6	84.1
Kam	Kam 6	10.1	93.2	80537	26166	7260	315055	1001	21205	64860	1027	14.9	18.4	9314	5927	8.10	11.7
Kam	Kam 7	9.27	99.4	89455	32154	6131	304304	1260	21347	79274	892	13.1	16.5	5688	5141	12.0	7.70
Kam	Kam 8	7.25	81.4	73199	25337	8762	312250	1024	21946	71818	1073	18.5	17.3	25826	5433	51.3	8.60
Kam	Kam 11	7.92	92.9	73383	30834	6352	312250	1274	20875	73054	1080	14.1	13.7	602	4890	10.9	15.4
Kam	Kam 12	7.95	89.1	85684	23188	7848	315990	1073	20711	67711	909	14.2	18.5	11787	6309	150	109
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	63	66	75	85	88	89	90	93	95	120	121	133	138	139	140	141
Site	Sample	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	Mo	Sn	Sb	Cs	Ba	La	Ce	Pr
Kam	Kam 3	18980	210	33.1	13.7	388	6.74	76.4	3.22	1.75	730	10.7	0.198	178	7.18	14.1	1.65
Kam	Kam 6	97.2	80.4	3.57	11.2	468	4.59	151	3.09	1.51	40.0	0.910	0.340	189	4.84	9.32	1.01
Kam	Kam 7	124	57.1	5.88	9.30	613	4.10	145	2.65	1.62	16.0	0.430	0.230	387	4.43	8.53	1.01
Kam	Kam 8	473	164	4.94	13.7	639	4.58	147	3.09	1.26	3.00	0.160	0.400	1339	5.56	9.71	1.06
Kam	Kam 11	7267	71.1	35.6	11.3	555	4.21	168	2.98	1.76	216	47.9	0.370	94.0	4.30	9.22	1.01
Kam	Kam 12	5021	108	22.1	11.6	470	4.95	146	2.79	6.59	736	24.4	0.260	480	5.22	9.88	1.12
	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	
	Isotope	146	147	153	157	159	163	165	166	169	172	175	178	208	232	238	
Site	Sample	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Pb	Th	U	
Kam	Kam 3	6.62	1.38	0.348	1.26	0.177	1.13	0.239	0.638	0.100	0.656	0.0986	1.82	3003	1.60	0.799	
Kam	Kam 6	4.02	0.850	0.170	0.700	0.100	0.700	0.140	0.430	0.0700	0.500	0.0700	3.31	119	1.32	0.890	
Kam	Kam 7	3.91	0.750	0.160	0.690	0.110	0.680	0.150	0.400	0.0700	0.430	0.0700	3.35	93.0	1.29	1.45	
Kam	Kam 8	4.17	0.810	0.190	0.700	0.120	0.730	0.160	0.480	0.0800	0.510	0.0800	3.23	64.0	1.73	2.60	
Kam	Kam 11	4.00	0.780	0.150	0.630	0.100	0.660	0.140	0.440	0.0700	0.470	0.0800	3.67	930	1.39	0.750	
Kam	Kam 12	4.41	0.820	0.210	0.860	0.120	0.760	0.160	0.470	0.0800	0.490	0.0700	3.28	3851	1.39	1.57	

Appendic C.8 Al-Raqqa

	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	7	11	23	24	27	28	31	39	42	47	51	52	55	56	59	60
Site	Sample	Li	B	Na	Mg	Al	Si	P	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni
Raqqa	RAQ 34	14.1	104	101019	27927	7008	319028	936	22922	66872	619	20.7	30.9	5179	3962	7.66	19.5
Raqqa	RAQ 35	10.8	58.5	89002	15883	11081	326741	2683	14231	29489	1772	49.4	55.5	37451	12271	21.8	60.3
Raqqa	RAQ 36	10.3	94.2	96126	22840	5484	333472	780	20245	53493	526	21.3	19.0	8672	2870	13.3	17.0
Raqqa	RAQ 38	18.2	81.0	74223	19414	93402	296310	761	34427	70912	5739	135	105.1	14354	37101	19.2	76.8
Raqqa	RAQ 41	26.7	68.9	97605	41064	5568	301172	344	28107	52725	177	8.14	10.0	3494	1460	3.06	13.0
Raqqa	RAQ 42	16.7	113	116000	25019	11327	306360	1164	23585	65538	771	20.8	30.7	6044	7293	399	90.2
Raqqa	RAQ 43	16.1	106	110001	25480	12690	302434	1108	22587	66650	943	27.0	38.9	6412	8189	320	87.3
Raqqa	RAQ 44	16.4	95.9	100845	22291	6334	317953	799	19622	55259	507	22.7	15.1	16385	2516	14.3	17.7
Raqqa	RAQ 45	12.1	68.8	91876	17004	11573	326647	841	14539	31101	1730	50.1	45.8	32213	10272	24.0	64.3
Raqqa	RAQ 46	15.6	101	106393	23775	7165	311689	894	21556	66110	599	19.2	21.4	6354	3325	11.9	18.5
Raqqa	RAQ 47	33.7	90.3	103981	46225	7617	311830	425	30288	40182	544	17.5	30.3	8667	2539	4.31	14.2
Raqqa	RAQ 48	15.7	125	111169	22122	6756	312016	1014	23397	59900	568	19.4	18.5	8721	3190	13.3	19.1
Raqqa	RAQ 49	7.16	195	61650	13048	7429	296918	548	19479	42686	586	12.7	23.6	922	4645	120	24.6
Raqqa	RAQ 50	17.7	76.9	124798	16429	11587	315476	1048	19795	37202	1013	29.9	36.2	12775	5708	18.5	29.5
Raqqa	RAQ 54	14.7	113	109593	24821	6623	306173	2782	23231	68709	519	15.6	19.6	7233	3012	11.8	14.9
Raqqa	RAQ 58	24.7	81.1	121062	42015	7007	310848	1743	22834	31011	442	14.1	30.3	10272	2675	3.10	15.0
Raqqa	RAQ 59	17.2	108	129712	34328	13212	320150	3105	26109	60526	785	18.4	69.7	6693	5470	5.00	23.2
Raqqa	RAQ 60	11.6	106	98015	25245	6191	316457	2221	23122	59201	562	13.7	19.8	4654	3410	5.20	13.7
Raqqa	RAQ 61	21.2	66.0	154701	15018	14011	311315	2055	18638	22694	1149	24.8	60.2	292	6831	4.00	21.7
Raqqa	RAQ 66	19.1	102	111092	31981	11956	293553	2623	21124	51615	727	16.1	56.5	4383	10940	21.6	29.5
Raqqa	RAQ 67	19.0	97.6	110742	32094	12328	291683	2558	24169	53042	839	18.6	67.2	6673	11208	793	29.8

	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	63	66	75	85	88	89	90	93	95	120	121	133	138	139	140	141
Site	Sample	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	Mo	Sn	Sb	Cs	Ba	La	Ce	Pr
Raqqa	RAQ 34	18.0	74.9	2.23	8.93	556	6.23	105	1.93	2.98	5.62	0.158	0.255	195	7.85	14.8	1.71
Raqqa	RAQ 35	57.2	47.0	7.68	9.40	314	7.02	101	5.68	17.6	8.00	0.390	0.230	606	10.3	20.6	2.36
Raqqa	RAQ 36	12.0	48.7	3.58	10.3	486	4.20	101	1.83	5.20	3.79	0.147	0.190	363	6.08	12.5	1.37
Raqqa	RAQ 38	36.4	84.8	7.65	30.2	547	29.9	221	20.1	10.0	5.42	0.670	1.220	513	32.2	61.6	6.68
Raqqa	RAQ 41	13.1	16.8	2.16	15.9	549	3.14	27.3	1.02	3.62	7.32	0.155	0.139	131	3.02	6.36	0.693
Raqqa	RAQ 42	903	299	13.0	9.62	586	7.31	106	2.76	6.78	13.4	2.68	0.181	231	8.70	17.2	1.91
Raqqa	RAQ 43	2563	221	9.62	9.58	566	7.77	105	3.01	6.96	15.6	1.84	0.155	232	8.91	17.5	1.97
Raqqa	RAQ 44	60.3	40.5	7.16	8.19	486	5.95	112	1.87	10.7	7.76	0.251	0.0608	252	7.54	15.3	1.68
Raqqa	RAQ 45	52.2	46.9	6.57	8.52	350	8.57	125	6.23	18.4	7.13	0.370	0.150	698	12.1	23.2	2.61
Raqqa	RAQ 46	24.0	44.7	4.28	8.32	592	5.35	122	2.16	4.15	5.13	0.136	0.151	204	7.34	14.3	1.54
Raqqa	RAQ 47	17.0	16.0	2.53	15.3	552	5.40	163	2.19	3.27	4.97	0.162	0.0823	379	7.11	13.7	1.54
Raqqa	RAQ 48	26.9	38.8	4.08	8.88	539	5.79	103	2.04	5.88	3.90	0.165	0.0959	262	8.03	16.5	1.81
Raqqa	RAQ 49	335	113	2.55	10.2	434	5.89	121	2.11	2.23	6.35	0.765	0.0000	70.8	5.31	14.4	1.36
Raqqa	RAQ 50	30.7	26.4	7.42	10.1	374	7.81	112	3.54	7.82	6.15	0.230	0.0844	326	10.0	20.3	2.23
Raqqa	RAQ 54	30.0	47.0	2.88	9.40	646	5.66	88.0	1.84	3.97	8.00	0.130	0.190	213	7.43	15.2	1.71
Raqqa	RAQ 58	11.6	16.4	2.84	12.8	385	3.78	99.0	1.65	5.72	6.00	0.120	0.170	136	5.14	11.0	1.17
Raqqa	RAQ 59	16.6	28.0	3.72	13.7	683	5.11	83.0	2.23	2.74	9.00	0.410	0.240	228	7.09	14.3	1.57
Raqqa	RAQ 60	17.9	31.2	2.18	9.80	497	5.65	107	1.92	3.00	9.00	0.0500	0.200	154	6.71	14.3	1.65
Raqqa	RAQ 61	24.9	22.0	2.47	16.8	237	9.17	167	3.64	2.38	7.00	0.170	0.420	139	10.2	20.5	2.22
Raqqa	RAQ 66	16111	145	31.8	11.3	547	5.25	99.0	2.15	2.03	132	14.8	0.190	191	6.54	12.9	1.46
Raqqa	RAQ 67	1442	3106	15.2	11.7	540	5.39	105	2.34	4.11	720	6.05	0.200	215	7.06	13.8	1.57

	Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	Isotope	146	147	153	157	159	163	165	166	169	172	175	178	208	232	238
Site	Sample	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Pb	Th	U
Raqqa	RAQ 34	6.66	1.23	0.267	1.15	0.179	0.986	0.231	0.567	0.0868	0.623	0.0980	2.63	10.6	2.04	0.637
Raqqa	RAQ 35	9.62	1.93	0.460	1.54	0.220	1.31	0.250	0.700	0.0900	0.640	0.110	2.41	14.0	2.21	1.16
Raqqa	RAQ 36	5.06	1.05	0.184	0.908	0.103	0.616	0.139	0.371	0.0595	0.398	0.0601	2.16	3.83	1.49	0.631
Raqqa	RAQ 38	27.3	5.27	1.237	4.99	0.746	4.80	0.934	2.83	0.399	2.79	0.389	4.73	6.98	9.27	2.91
Raqqa	RAQ 41	2.88	0.632	0.133	0.606	0.0845	0.603	0.109	0.350	0.0501	0.342	0.0478	0.784	2.05	0.89	0.558
Raqqa	RAQ 42	7.71	1.70	0.351	1.55	0.186	1.18	0.254	0.722	0.111	0.685	0.112	2.75	169	2.49	0.784
Raqqa	RAQ 43	7.96	1.52	0.352	1.43	0.203	1.41	0.257	0.798	0.112	0.790	0.119	2.65	157	2.46	0.790
Raqqa	RAQ 44	6.72	1.31	0.289	1.23	0.220	0.972	0.207	0.540	0.0844	0.623	0.0980	2.74	97.7	1.97	0.716
Raqqa	RAQ 45	10.9	2.28	0.525	2.13	0.265	1.60	0.302	0.838	0.125	0.872	0.124	3.17	14.8	2.66	1.21
Raqqa	RAQ 46	6.58	1.33	0.245	0.990	0.125	0.890	0.184	0.523	0.0843	0.509	0.0770	2.78	9.73	1.94	0.645
Raqqa	RAQ 47	6.09	1.18	0.223	1.01	0.151	0.927	0.205	0.580	0.0933	0.628	0.0935	3.92	2.89	1.97	0.623
Raqqa	RAQ 48	6.99	1.43	0.269	1.30	0.174	1.10	0.177	0.518	0.0845	0.511	0.0856	2.39	14.0	1.92	0.685
Raqqa	RAQ 49	5.60	1.06	0.232	1.07	0.140	0.976	0.207	0.557	0.0854	0.657	0.0802	2.96	55.0	2.29	1.35
Raqqa	RAQ 50	8.92	1.94	0.383	1.66	0.220	1.46	0.268	0.804	0.118	0.797	0.122	2.75	17.5	2.66	0.723
Raqqa	RAQ 54	6.62	1.36	0.290	1.07	0.160	0.960	0.190	0.540	0.0800	0.560	0.0900	2.16	10.0	1.91	0.660
Raqqa	RAQ 58	4.81	0.910	0.190	0.750	0.110	0.710	0.140	0.390	0.0600	0.450	0.0700	2.31	3.00	1.41	0.570
Raqqa	RAQ 59	6.45	1.22	0.260	0.990	0.150	0.890	0.180	0.550	0.0800	0.530	0.0800	1.93	18.0	1.63	0.760
Raqqa	RAQ 60	5.84	1.17	0.250	1.16	0.150	0.990	0.190	0.640	0.0900	0.510	0.0800	2.71	10.0	2.09	0.710
Raqqa	RAQ 61	8.89	1.72	0.350	1.54	0.230	1.46	0.300	0.880	0.130	0.850	0.130	4.14	5.00	3.10	0.720
Raqqa	RAQ 66	6.09	1.15	0.290	0.990	0.150	0.910	0.180	0.560	0.0800	0.530	0.0800	2.35	663	1.51	0.760
Raqqa	RAQ 67	6.10	1.24	0.260	0.960	0.140	0.920	0.210	0.520	0.0800	0.590	0.0800	2.46	1726	1.65	0.790