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HAL Authorization

1 **High alumina plant ash (v-Na-Al) glass bangles from Siraf: clarifications on a Central Asian**
2 **glass group (9th-14th century)**

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4
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10 **Abstract**

11
12 During the excavations of 1966-1973 vast quantities of glass was found at Siraf in Iran on
13 the Persian Gulf, primarily dating to the 9th-11th centuries. Some of this glass assemblage held
14 in the Corning Museum of Glass was analysed using LA-ICP-MS, including nine glass bangle
15 fragments dating to ca. 14th century. One was found to be of a high alumina plant ash (v-Na-
16 Al) composition, as was a 14th-15th century glass kohl stick fragment. Further analysis of the
17 14th century Siraf glass bangle collection held at the British Museum has recently been
18 analysed using LA-ICP-MS, identifying several more v-Na-Al glass bangles. Recent studies have
19 concluded that plant ash soda glasses of Central Asian origin can most notably be
20 characterised by elevated levels of alumina (>4.5 wt%). This article reviews their glass
21 characteristics in the context of a recently improved understandings of glass dating between
22 the 9th-14th centuries from the historic Greater Khurasan region and particularly the v-Na-Al
23 glass collections of Central Asia. This investigation proposes there were at least three main
24 Central Asian glass production groups (CA1, CA2 and CA3) in circulation during this period.
25 These differ primarily on their alumina, titanium and zirconium concentrations. Additional
26 comparison with other relevant glass bangle collections, and v-Na-Al glass recently reviewed
27 from south and east Africa, reveals that multiple periodically definable subtypes of these
28 groups may have been in circulation. Further to this, while the CA3 category remained
29 relatively local, the CA2 type appears to have enjoyed the widest circulation along caravan
30 routes, yet the CA1 type the widest via maritime routes. These insights offer additional
31 information on the major characteristics of this elusive category of glass, its periods of
32 production and an improved understanding of distribution patterns.

33
34 **Keywords:** Historic glass analysis, Islamic glass, glass bangles, Middle East studies, Indian
35 Ocean trade

36 **INTRODUCTION**

37

38 The Islamic port-city of Siraf is most renowned for its major role in international maritime
39 trade during the Buyid dynasty in the 9th-11th centuries (Aubin 1959; Whitehouse 1970;
40 Whitcomb 2009). During six seasons of excavations at Siraf (1966-1973) by David Whitehouse,
41 thousands of glass fragments were recovered, and are now held at a number of museums
42 internationally. A hundred and one glass fragments held at the Corning Museum of Glass were
43 analysed in 2015-2016, using Laser Ablation Inductively-Coupled Plasma Mass Spectrometry
44 (LA-ICP-MS; Swan et al. 2017). The samples analysed were found to be primarily vessel
45 fragments from 9th-early 11th century Period 2 strata of the Siraf 'Main Group' compositional
46 type produced when the site was at the peak of its wealth and international status (Swan et
47 al. 2017). It is generally accepted, due to its presence in working debris and kiln wall
48 fragments, that this 'Main Group' was a glass produced local to Siraf. This 'Main Group' has
49 been divided into two subtypes, subtype A is slightly higher in zirconium and chromium than
50 subtype B (Swan et al. 2017, 105). Other glass varieties were also identified in this stratigraphic
51 context in smaller quantities, including vessel fragments with so called 'Low Zirconium'
52 composition and nine glass bangles and a kohl stick from a later occupation period. Although
53 these objects were largely surface finds, glass bangles only appear in the archaeological record
54 from Period 3 and most were found in 14th-15th century strata (Whitehouse 1968, 19).

55

56 Six glass bangle fragments were compositionally classified as 'Low Magnesium' and two as
57 'High Alumina'. Bangle 075 was plain with a circular cross section, dark aqua in colour and
58 mineral based (m-Na-Al) (**Figure 1a**). Its high uranium levels (26 ppm) suggest it to be m-Na-
59 Al 2 type from the west coast of India (see Swan et al. 2017, fig. 5; Dussubieux et al. 2010,
60 1650). Bangle 094 (**Figure 1b**) is twisted with a circular section and dark (black-looking) with a
61 plant ash (v-Na-Al) composition. The Siraf 090 kohl stick (v-Na-Al) was excavated from a
62 residential context, securely dating it to the 14th-15th century (Swan et al. 2017, 104). It has a
63 similar composition to bangle 094, a characteristic most often associated with Central Asia
64 (Swan et al. 2017, 110; Schibille et al. 2022; Siu et al. 2020).

65



Figure 1a. Bangle 075 from the Siraf collection that was at the Corning Museum. Image courtesy of Dr James Lankton (see also Swan et al. 2017, fig.5).



Figure 1b. Bangle 094 from the Siraf collection that was at the Corning Museum. Image courtesy of Dr James Lankton.

66

67 Ongoing research into Islamic glass bangles has included trace element analysis on the
 68 collection from Siraf held at the British Museum using LA-ICP-MS. This was undertaken as part
 69 of a larger study and includes the identification of additional v-Na-Al glass bangles. This paper
 70 presents the results of these fragments in context of other known v-Na-Al glasses identified
 71 primarily found in Central Asia (9th–14th centuries), east Africa (10th–16th centuries), southern
 72 Africa (13th–15th centuries) and southeast Asia (12th–13th centuries; Siu et al. 2020). These v-
 73 Na-Al glasses are generally assumed to originate in Central Asia, but as is discussed here there
 74 are likely other silica sources of a similar characteristic yet to be identified. This study intends
 75 to further clarify the categorisation, identifiable subtypes and illustrate likely dissemination
 76 patterns to aid in the identification of the v-Na-Al glass bangles from Siraf. It is hoped that this
 77 will add to the growing understanding of the chemical characteristics of this presumed region
 78 of production.

79

80 BACKGROUND

81

82 It should first be explained for those unfamiliar with Islamic glass compositions that glass
 83 believed to have been produced in northeast Iran is often termed Mesopotamian 1 (after
 84 Phelps 2016; et al. 2018). This differs greatly from glass from Samarra in Iraq, which is
 85 geographically within the region of Mesopotamia itself, but often termed collectively as
 86 Mesopotamia 2 (also after Phelps 2016; et al. 2018). To avoid geographical confusion, the
 87 authors believe that the collective term Mesopotamian (MS) glass should be reserved for the
 88 glass groups from Mesopotamia in the geographical sense of the word (see Drower, Gray and

89 Sherwin-White 2016) to include the areas between the Euphrates and Tigris rivers (e.g.
 90 Greater Syria, Iraq).

91

92 The term Western Khurasan (WK) will be used henceforth to refer to glass from northeast
 93 Iran, which was considered the western region of the historic Greater Khurasan Province
 94 (Sykes 1914). This area incorporated northeast Iran and much of Central Asia, including parts
 95 of Turkmenistan, Afghanistan, Uzbekistan and Tajikistan today (Figure 2). The Greater
 96 Khurasan region is archaeologically well known as a major industrial zone for other production
 97 crafts, such as metallurgy. Eastern Khurasan is thus used in this study as the regional term for
 98 glass categorised as of probable Central Asian (CA) origin.

99



100

101 Figure 2. The Greater Khurasan Province (shaded) and spatial distribution of sites (in red) where v-Na-Al glasses
 102 have been identified across the 'Silk Road' caravan routes discussed in this paper.

103

104 Regional categories of Islamic plant ash soda lime silica glass

105

106 Although soda-rich plant ash was the dominant fluxing agent used in Islamic glassmaking
 107 by the medieval period, natron glass from the Eastern Mediterranean continued to be
 108 produced into the 9th century (Schibille 2022). Mineral based glasses (including *reh* from South
 109 Asia) are easily distinguished from plant ash glasses due to their low magnesia and potash
 110 contents (<1.5 wt%). Glass production during the Islamic period appears to have become
 111 increasingly decentralised with more production locations and glass subtypes (see Freestone
 112 2002; Henderson 1999; Henderson, McLoughlin & McPhail 2004). The emergence of multiple

113 subtypes with similar geochemical compositions suggests that multiple small workshops were
 114 particularly active in the Greater Khurasan region between the 9th-14th centuries, but very few
 115 production sites have yet to have been identified (Chinni, et al. 2023; Fiorentino et al. 2019;
 116 Rehren & Osório 2010; Schibille 2022; et al. 2022; et al. 2024). Differences between the plant
 117 ash used in many of the subtypes rely mainly on variations between the magnesium,
 118 potassium, calcium, phosphorus and lithium concentrations, diagnostic of the plant ash
 119 component, ashing process or both (Schibille 2022). Variations in such ashing processes,
 120 furnace conditions and increased recycling activities certainly complicates matters.
 121 Nonetheless, regional connections between glasses can still be drawn and groups tentatively
 122 defined.

123

124 Major regional groupings of plant ash glass have been defined based primarily on similar
 125 silica compositions, but also drawing on elements related to the plant ash component
 126 (Schibille 2022). Four regional production zones can thus be tentatively identified: Eastern
 127 Mediterranean, Mesopotamian, Western Khurasan and Eastern Khurasan (**Figure 3**). Glass
 128 from Tyre in Lebanon (10th-11th century; Freestone 2002), Banias in Israel (11th-13th century;
 129 Freestone et al. 2000) al-Raqqqa 1 in Syria (8th-11th century; Henderson et al. 2004), Damascus
 130 in Syria (11th-12th century) and Cairo in Egypt (14th-15th century; Henderson et al. 2016) have
 131 been conflated to represent the ‘Eastern Mediterranean’ region in yellow. Samarra 1 and 2
 132 type glass from Iraq (9th century; Schibille 2018) is likewise conflated to represent
 133 Mesopotamia in green. G1a, G1b and G2 glass (Schibille et al. 2022) from various sites in
 134 northeast Iran (8th-10th century Qom, 9th-10th century Nishapur, 9th-11th century Rayy, 11th-
 135 12th century Gorgan and ‘Islamic period’ Hamadan) have been combined to represent Western
 136 Khurasan glass in purple. Merv 1 and Merv high alumina type from the 9th century
 137 Turkmenistan represent the Eastern Khurasan in blue (Schibille 2022; Meek, Simpson and
 138 Schibille *in peer review*).¹

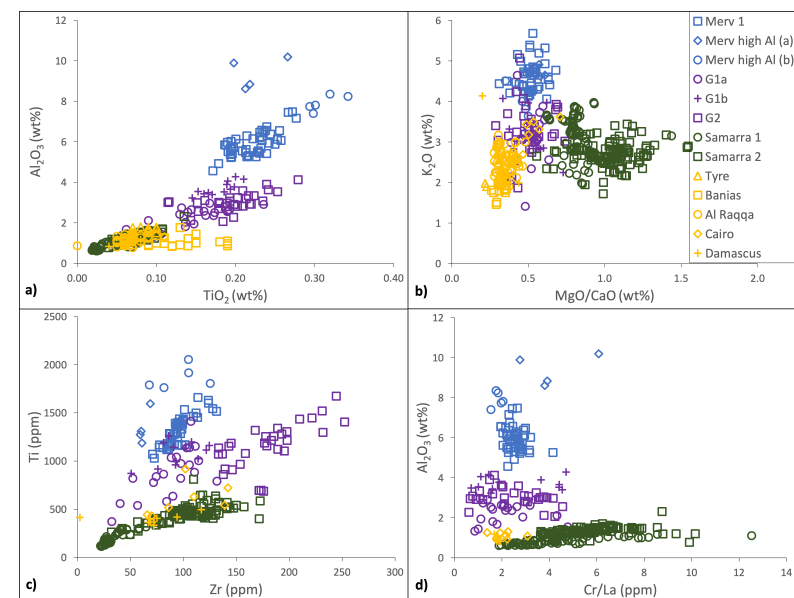
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¹ Merv 1 glass under discussion is referred to as Merv G1 in Meek, Simpson and Schibille (*in peer review*) but the term Merv 1 is retained from Schibille (2022) in this paper to avoid any confusion with G1a-b types identified from various northeast Iranian sites (Schibille et al. 2022).

142



143

Figure 3. Elements separate the major regional glass groupings Eastern Mediterranean in yellow, Mesopotamia in green, Western Khurasan in purple and Eastern Khurasan in blue. Data: Eastern Mediterranean in yellow, represented by Tyre in Lebanon (Freestone 2002), Banias in Israel (Freestone et al. 2000) al-Raqqqa 1 in Syria (Henderson et al. 2004), Damascus in Syria and Cairo in Egypt (Henderson et al. 2016), Samarra 1 and 2 (Schibille 2018), G1a-b and G2 (Schibille et al. 2022), Merv 1 and Merv high Al a-b (Schibille 2022; Meek, Simpson and Schibille *in peer review*).

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Mesopotamian plant ash glass groups

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Identification of a large quantity of 9th century glass at Samarra in Iraq revealed the likely origin of an exceptionally clean glass composition (Schibille et al. 2018; Wypyski 2015). This glass was first identified in proportionately high quantities (ca.70%) at Nishapur in northeast Iran, so initially named ‘Nishapur Colourless’ (Brill, 1995, 308) or ‘Nishapur A’ (Wypyski 2015). It was then also identified at Fustat in Egypt and Qasr al-Hayr in Syria, representing a wide distribution (Schibille 2022, 138). Samarra 1 and Samarra 2 are often conflated to represent the ‘Mesopotamian’ regional signature. Mesopotamian glass can easily be distinguished from

160 other regional production groups as it has fairly high magnesia and low lime contents and
 161 chromium to lanthanum (Cr/La) ratio (Schibille 2022, 159).

162

163 **Western Khurasan plant ash groups**

164

165 Further compositional categories of glass called G1a-b and G2 were recently identified in
 166 context of various Iranian sites, including 9th-10th century Nishapur (Schibille et al.2022),
 167 previously categorised by Brill (1995) as ‘Nishapur B’ or ‘Nishapur coloured.’ It later became
 168 known as Mesopotamian 1 type (Phelps 2016; et al. 2018). No compelling evidence of glass
 169 production was identified at the site, but these major subtypes are also found at many other
 170 sites in the Western Khurasan region, indicating a probably northeast Iranian origin. Western
 171 Khurasan glass has more elevated potash contents than plant ash glass from the Eastern
 172 Mediterranean and Mesopotamian regions, as well as higher alumina concentrations levels
 173 (ca. >2.12 wt%). They are identified by a silica source that is high in thorium but with differing
 174 zirconium and titanium concentrations, resulting in different zirconium to thorium (Zr/Th)
 175 ratios (Schibille et al. 2022). G1b generally corresponds well with the G1a but has a higher
 176 alumina content (ca. 4 wt%). Large quantities of G2 were identified from the northern Iranian
 177 site of Gorgan (Schibille et al. 2022). Five pieces of glass working waste and the remains of
 178 two glass furnaces (ca.11th–12th century) were also discovered, suggesting it was the primary
 179 production site (see Kiani 1984; Salehvand et al. 2020; Schibille 2022, 159; **Table 1**).²

180

181 *Table 1. Approximate average lime (CaO) and alumina (Al₂O₃) contents of the major known regional glass groups*
 182 *in circulation in the Middle East between the 9th-14th centuries. Data from: Freestone 2002; Freestone et al. 2000;*
 183 *Henderson et al. 2004; Meek, Simpson and Schibille in peer review; Schibille 2018, Schibille et al. 2022; Schibille*
 184 *2022; Dussubieux et al 2008.*

Regional glass Group	Eastern Mediterranean (plant ash) Raqqa 1, Banias, Tyre	Mesopotamian (plant ash) Samarra 1 and 2	Western Khurasan (plant ash) G1a-b, G2	Central Asian (plant ash) Merv 1 and 2	South Asian (mineral) m-Na-Al 2
Approximate average of Al ₂ O ₃	ca. 1 wt%	ca. 1 wt%	ca. 3 wt%	ca. 7 wt%	ca. 7 wt%
Approximate average of CaO	ca. 9 wt%	ca. 6 wt%	ca. 6 wt%	ca. 8 wt%	ca. 5 wt%

² Although not the subject of this investigation, it is worth noting that this is a similar alumina level given for most m-Na-Al glasses from South Asia, but this mineral based glass contains much lower levels of lime.

185

186 **Eastern Khurasan plant ash groups**

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188 As demonstrated and further discussed in Schibille (2022, 163; Fig. 53), Western Khurasan
 189 glass from northeast Iran appears to share some compositional characteristics, such as similar
 190 calcium, zirconium and chromium levels (amongst others), with those from neighbouring
 191 ‘Eastern Khurasan’ region in Central Asia. However, the main compositional differences
 192 between the Western Khurasan and Eastern Khurasan groups seem to pertain to their alumina
 193 and titanium levels, demonstrating that they represent distinct regional categories. The
 194 alumina concentrations of glasses believed to have been produced in Western Khurasan cut
 195 off at about 4.5 wt% alumina. Alumina appears to increase eastwardly from the Eastern
 196 Mediterranean, with the highest concentrations found in glass assemblages from Central Asia
 197 (Schibille et al. 2022; Siu et al. 2020).

198

199 The compositional characteristics of the 9th century glass found at Merv in Turkmenistan is
 200 mixed, including some imported Mesopotamian and many Western Khurasan glass types with
 201 lower alumina (usually <4 wt%). These were probably imported from Iraq and north eastern
 202 Iran respectively, as well as around sixty Eastern Khurasan fragments, some with very high
 203 Al₂O₃ (>7 wt%), a group that is more likely to have been locally produced (Schibille 2022, 159
 204 Fig. 53a). Both the Western and Eastern Khurasan glasses from Merv also have higher potash
 205 (ca. >4 wt% K₂O) and phosphorus (ca. ~0.44 wt% P₂O₅) concentrations, and a higher lithium
 206 to soda (Li/Na₂O) ratio, when compared with Eastern Mediterranean and Mesopotamian glass
 207 (Schibille 2022, 159; Fig. 53c; Brill 2001). However, glass identified as Eastern Khurasan from
 208 Merv have higher titanium (ca. ~0.24 wt%) and alumina (>4.4 wt%) than the Western
 209 Khurasan glasses.

210

211 **METHODS AND MATERIALS**

212

213 The analytical data for seven bangles from Siraf are discussed here in more detail, alongside
 214 three glass bangles from Merv in Turkmenistan (British Museum collections). These bangles
 215 were analysed as part of a larger collection using LA-ICP-MS at IRAMAT-CEB in Orléans
 216 (France), following the standard analytical protocol (Gratuze 2016; Schibille et al. 2024). Small

217 fragments mounted in resin blocks were analysed for 27s following a pre-ablation of 15s. Fifty-
 218 eight isotopes from Li to U were measured and ²⁸Si was used as an internal standard. Regular
 219 background measurements were subtracted and the readout of five different reference
 220 materials (NIST610, Corning B, C, D and APL1) were used to calculate the response coefficient
 221 for each element and by extension fully quantitative data (Schibille et al. 2024).

222

223 Much of the comparative data used in this paper was also produced using LA-ICP-MS, which
 224 facilitates comparisons (**Table 2**). This data includes v-Na-Al glass bangles from Siraf (14th
 225 century), samples recently analysed from Merv in Turkmenistan (9th century; see Schibille
 226 2022), Ghazni (late 9th–14th century) in Afghanistan (Fiorentino et al. 2019) and Kuva and
 227 Akhsiket (10th–11th century; Rehren & Osório 2010) and Kafir Kala (7th–14th century) in
 228 Uzbekistan (Chinni, et al. 2023). We also compare other relevant glass bangle collections,
 229 including three Islamic glass bangles from the British Museum found at Merv in Turkmenistan
 230 that have not previously been analysed (using the same analytical conditions), (**Table 3**) and
 231 the six Islamic glass bangles from the Ghazni collection that were identified by Fiorentino et
 232 al. (2019), half of which are of a v-Na-Al composition. These are also typologically similar to
 233 those from Siraf (**Table 4**) in both styles and colour. The v-Na-Al Islamic glass bangles identified
 234 from Tell Abu Sarbut and Khirbat Faris in Jordan (Boulogne and Henderson, 2009, see page 63
 235 photo 205, 314 and 423) are likewise compared. In addition, a periphery comparison is also
 236 made with contemporary v-Na-Al glass samples (primarily beads) from the south and east
 237 African sites, recently reviewed and also tentatively identified as of Central Asian origin by Siu
 238 et al. (2022).

239

240

241 **Table 2.** Glass assemblages from the Eastern Khurasan region used in this study to define likely regional
 242 groupings.

Region	Site	Period	Samples reviewed	Object Type	Analysis Method	Author
Eastern Khurasan sites	Merv, Turkmenistan	9th century	62	Mostly vessel (3 bangles)	LA-ICP-MS	Meek, Simpson & Schibille <i>in peer review</i>
	Ghazni, Afghanistan	late 9th-14th century	24	Mostly bangle	LA-ICP-MS	Fiorentino et al. 2019
	Kuva & Akhsiket, Uzbekistan	10th-11th century	24	Mostly vessel	EPMA	Rehren & Osório 2010
	Kafir Kala, Uzbekistan	7th-14th century and 'Islamic period'	26	Vessel	EPMA and LA-ICP-MS	Chinni, et al. 2023
	Pendjikent, Tajikistan	8th-9th century	05	Vessel	ICP-OES	Brill 1999
South and East Africa	Duldur-Aqur, Xinjiang, China	6th-7th century	12	Vessel		
	Malindi, Kenya	15th-16th century	17	Vessel	EPMA-WDS and LA-ICP-MS	Siu, et al. 2020
	Mambrui, Kenya	15th-16th century	20	beads		
	Mapungubwe Oblate series, South Africa	13th-14th century	63	beads	LA-ICP-MS	Robertshaw et al. 2010
	Zimbabwe series, Zimbabwe	14th-15th century	93	beads		
	Mahilaka, Madagascar	13th-14th century	11	beads	LA-ICP-MS	Robertshaw et al. 2006
Ingombe Ilede, Zambia	15th-17th century	14	beads	LA-ICP-MS	Robertshaw & Wood 2017	
Songo Mnara, Tanzania	14th-16th century	41	beads	LA-ICP-MS	Wood et al. 2023	






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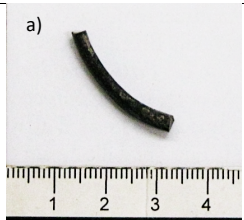



246 **Table 3:** Glass bangles with new data reviewed in this study, with a-g. (h. a kohl stick) from the unpublished
 247 collection from Siraf, Iran at the British Museum; i-k. from the unpublished collection from Merv, Turkmenistan
 248 at the British Museum. Images courtesy of the Trustees of the British Museum.

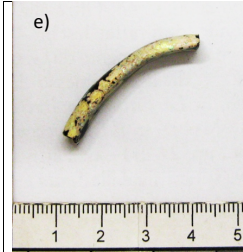

Glass bangle Image	Object No.	Site / source	Date	Description
	2007,6001.13883	Siraf, Iran	c.14 th -15 th century	Light green transparent (looks dark) loose twist glass bangle, with circular section
	2007,6001.13941	Siraf, Iran	c.14 th -15 th century	Dark loose twist glass bangle with circular section
	2007,6001.13952	Siraf, Iran	c.14 th -15 th century	Dark, loose twist glass bangle, with circular section
	2007,6001.13960	Siraf, Iran	c.14 th -15 th century	Dark, loose twist glass bangle, with circular section
	2007,6001.13975	Siraf, Iran	c.14 th -15 th century	Dark loose twist glass bangle with circular section
	2007,6001.13860	Siraf, Iran collection)	c.14 th -15 th century	Dark loose twist glass bangle, with circular section

	2007,6001.13971	Siraf, Iran	c.14 th -15 th century	White-grey corroded dark loose twist glass bangle, with circular section
	2007,6001.14056	Siraf, Iran	c.14 th -15 th century	Natural translucent pale green glass kohl stick, plain with circular section
	2009,6016.296	Merv, Turkmenistan	9 th century	Grey-weathered dark plain bangle with circular section
	2015,6001.13	Merv, Turkmenistan	12 th century	Black plain bangle with peaked section
	2015,6001.14	Merv, Turkmenistan	12 th century	black plain bangle with flat section

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250

251 **Table 4.** Glass bangles with published data reviewed for comparison, a-f from Ghazni, Afghanistan (Fiorentino
 252 2019, 154, 157 Table1); g-i. from Tell Abu Sarbut and Khirbat Faris, Jordan (Boulogne & Henderson 2009, 63).
 253 Images courtesy of Dr Sara Fiorentino

Glass bangle Image	Object No.	Site / source	Date	Description
	GH02	Ghazni, Afghanistan (Fiorentino et al. 2019, 154, 157 Table1)	c.9th-14th century	Black plain bangle
	GH04	Ghazni, Afghanistan (Fiorentino et al. 2019, 154, 157 Table1)	c.9th-14th century	Two black streaked bangle fragments
	GH22	Ghazni, Afghanistan (Fiorentino et al. 2019, 154, 157 Table1)	c.9 th -14 th century	Black streaked bangle
	GH07	Ghazni, Afghanistan (Fiorentino et al. 2019, 154, 157 Table1)	9th-10th century	Black plain bangle

	GH11	Ghazni, Afghanistan (Fiorentino et al. 2019, 154, 157 Table1)	c.9th-14th century	Black plain bangle
	GH16	Ghazni, Afghanistan (Fiorentino et al. 2019, 154, 157 Table1)	c.9th-14th century	Black plain bangle

254

255 RESULTS AND DISCUSSION

256

257 The composition of archaeological glass reflects the geochemical nature of its raw
 258 materials. This assumption requires further investigation by taking into account a whole suite
 259 of elements related to the silica source such as Al, Cr, Ti, Zr, La, Ba Nd and Th. Plant ash
 260 subtypes can likewise be separated by variation in MgO, K₂O, P₂O₅, and Na₂O concentrations
 261 and MgO/CaO, K₂O/P₂O₅, Li/K₂O and Cs/K₂O ratios. Due to their high alumina concentrations,
 262 at first glance the v-Na-Al glass bangles from Siraf appear to be compositionally similar to glass
 263 from Eastern Khurasan. However, on closer inspection of known v-Na-Al glass, it is also
 264 possible to further distinguish several silica subtypes within this regional grouping. Apart from
 265 the large collection recently analysed from Merv, only a small quantity of these glass types
 266 have been analysed and are currently available for comparison (including the primary v-Na-Al
 267 glass bangle samples from Siraf), making these glass bangle results preliminary when taken
 268 alone. However, when reviewed collectively, the conclusions become much more compelling.
 269

270 We propose that three major glass subtypes of Eastern Khurasan glass from Central Asia,
 271 termed CA1, CA2 and CA3, were in circulation during the 9th-14th centuries. These can

272 primarily be differentiated from one another by variations in alumina, titanium and zirconium
 273 concentrations. The small group of v-Na-Al glass bangles from the Siraf collection held at the
 274 British Museum is characterised by an average of 7.41 wt% Al₂O₃, 0.27 wt% TiO₂ and 124 ppm
 275 Zr (Table. 5), which place it within the ranges of the CA2 type (see Table 6). CA2 samples have
 276 higher Al, Ti, Fe, Ga, Rb, Nb, La, Cr, Nd and Th concentrations, similar Zr levels but lower Sr to
 277 the CA1 type. Group CA1 has average values of ca. 6 wt% Al₂O₃, 0.22 wt% TiO₂ and 96 ppm
 278 Zr, which differs from group CA2 with ca. 9 wt% Al₂O₃, 0.27 wt% TiO₂ and 82 ppm Zr (Table 6).

280 Table 5. Average compositions and standard deviations of the v-Na-Al Siraf glass bangles at the British Museum

Site	Bangles	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	Cl	K ₂ O	CaO	TiO ₂	MnO	Fe ₂ O ₃	Li	Cr	Rb	Sr	Zr	La	Ce
Siraf CA2	Average (n=7)	16.1	2.55	7.82	57.6	0.37	0.75	5.35	7.00	0.28	0.12	1.88	44.9	38.9	51.8	312	107	18.0	34.4
	StDev	0.86	0.74	0.72	0.50	0.05	0.09	1.45	1.81	0.05	0.12	0.28	25.3	6.89	17.7	118	13.2	1.80	3.45

281

282 Defining the CA1, CA2 and CA3 groups from the Eastern Khurasan

283

284 The vast majority of samples belonging to the CA1 and CA2 types found so far have been
 285 identified among the glass assemblage from 9th century Merv (Schibille 2022; Meek, Simpson
 286 and Schibille *in peer review*). CA2 has been found in comparatively small quantities at Merv
 287 and distinctively differs from CA1, which was found in far larger quantities. Nine glass samples
 288 from Merv have outstandingly high alumina concentrations (Al₂O₃ > 7 wt%). As discussed in
 289 Meek, Simpson & Schibille (*in peer review*) CA2 is comprised of Merv 'high alumina (a) and
 290 (b)' subsets, the prior displaying closer characteristics to CA1 glass but with higher alumina
 291 but lower zirconium, while subgroup (b) contains exceptionally high Cr, Nb, Ta and Th and is
 292 of a silica source depleted in the heavy REEs. Meek, Simpson & Schibille (*in peer review*)
 293 hypothesise that these characteristics are indicative of a significant contribution of feldspar in
 294 the raw materials of the type (b) group. Group CA3 is identified as having an average of ca. 5
 295 wt% Al₂O₃, 0.12 wt% TiO₂ and 48 ppm Zr. This group was defined on the basis of glass found
 296 at Kafir Kala in Uzbekistan (Table 6; Chinni, et al. 2023).

297

298

299 Table 6. Average compositions and standard deviations of the proposed Central Asian groups (CA1, CA2, CA3).

300 CA1 and CA2 have been defined based on samples from Merv (Schibille 2022)³, while 16 samples from Kafir
 301 Kala, Uzbekistan (Chinni, et al. 2023) are used to represent the CA3 category. Oxides and Cl are given as wt%,
 302 elements as ppm.

Site		Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	Cl	K ₂ O	CaO	TiO ₂	MnO	Fe ₂ O ₃	Li	Cr	Rb	Sr	Zr	La	Ce
Merv CA1	Average (n=48)	14.8	4.10	5.90	59.8	0.44	0.49	4.63	7.91	0.22	0.04	1.24	24.1	27.2	43.3	404	96.2	10.6	19.5
	StDev	0.82	0.58	0.61	1.93	0.04	0.11	0.35	1.02	0.03	0.02	0.20	2.42	3.63	4.66	61	13.0	1.09	2.04
Merv CA2	Average (n=9)	16.2	4.37	8.56	54.3	0.37	0.51	4.39	8.72	0.27	0.05	1.73	27.6	51.3	52.8	509	81.5	18.3	33.8
	StDev	1.24	0.71	0.95	1.42	0.03	0.05	0.46	1.66	0.05	0.01	0.59	7.46	24.8	5.28	121	24.3	2.53	4.60
Kafir Kala CA3	Average (n=16)	17.4	4.08	4.63	59.6	0.56	0.59	3.86	7.46	0.12	0.05	0.80	17.1	13.8	41.5	524	48.2	9.19	18.4
	StDev	1.55	0.43	0.24	1.56	0.03	0.22	0.39	1.25	0.02	0.02	0.12	14.7	1.90	5.35	110	6.3	0.97	1.65

	MgO/CaO	MgO/K ₂ O	K ₂ O/P ₂ O ₅	Cr/La
Merv CA1	0.52	0.88	10.7	2.57
Merv CA2	0.50	1.00	12.0	2.81
Kafir Kala CA3	0.55	1.06	6.91	1.51

307

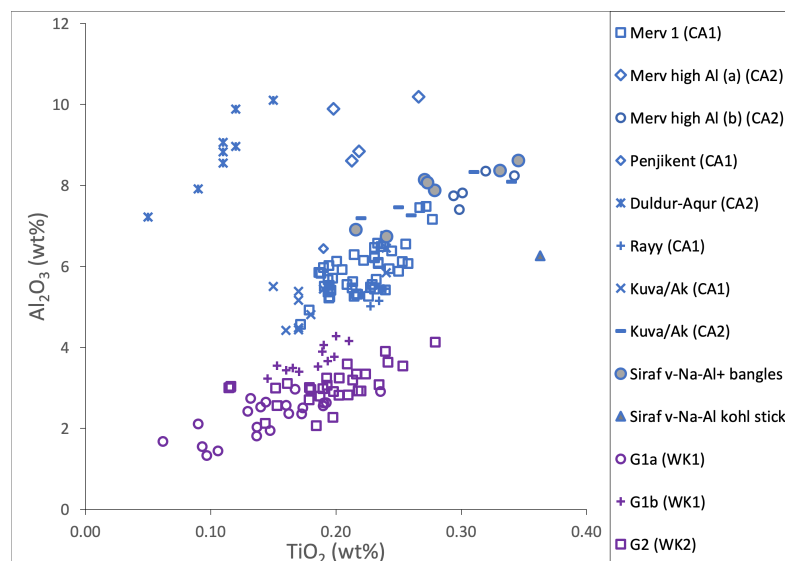
308 High alumina glass, whether it be a plant ash (v-Na-Al) or mineral (m-Na-Al) based, has
 309 often been classified as glass with alumina >4.2 wt% (Dussubieux et al. 2010; Schibille 2022).
 310 The v-Na-Al data from Merv enables isolation of two distinct v-Na-Al subvarieties from the
 311 region, CA1 and CA2. The majority of the glass from Merv corresponds to CA1 characterised
 312 by alumina contents ranging from roughly 4.5-7.5 wt% (average ca. 6 wt% Al₂O₃). This is
 313 entirely coherent with other samples from the region, such as nearby Akhsiket and Kuva in
 314 the Ferghana Valley of Uzbekistan (five from each, including two furnace fragments) dating to
 315 the 10th to 11th century (Rehren et al., 2010). Other such samples include one 8th-9th century
 316 sample from Pendjikent (Pendjikent 6252) in Tajikistan (Brill 1999) and five from the 9th-11th
 317 century site of Rayy in Iran (Rayy BC 03, 04, 10, 08 and 19) (Schibille et al. 2022) (**Figure 4**).

318

319 There are far fewer of the CA2 compositional group, characterised by extra high alumina
 320 (v-Na-Al⁺; 7.5-11 wt% Al₂O₃) in Merv, compared to the other collections. Five fragments from
 321 the nearby 10th-11th century sites of Akhsiket (two samples) and Kuva (three samples) appear
 322 to be of the CA2 type (Rehren et al., 2010). Several v-Na-Al vessel glass samples from Duldur-
 323 Aqur (Duldur-Aqur 6122-23, 6125-29), Kucha in the Xinjiang province of China that were
 324 analysed using ICP-OES (Brill 1999), dating to the 6th-7th century (or possibly pre-4th century,

³ Extra high alumina CA2 fragments from Merv represent two glass subgroups, termed there Merv high Al a) and b) (see Meek, Simpson and Schibille *in peer review*).

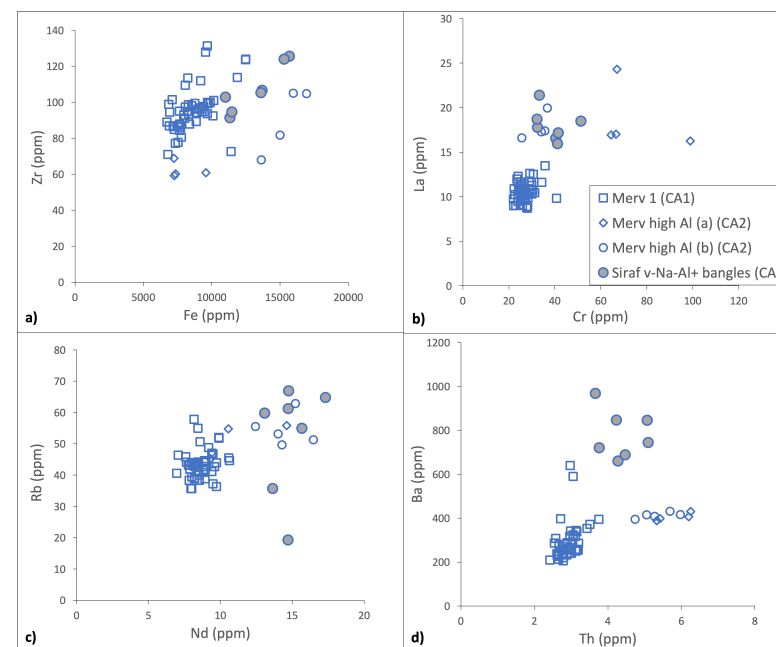
325 as recently suggested by Henderson, An and Ma (2018)), also align well with CA2 based on its
 326 alumina values. However, this group differs by significantly lower titanium levels (0.05-0.15
 327 wt%), which indicates different silica sources and thus most likely a different origin, although
 328 it is closer in composition to the Merv high Al (a) than (b) subgroup (**Figure 4**).
 329



330
 331 **Figure 4.** Al_2O_3 versus TiO_2 values of proposed Western and Eastern Khurasan collections. Data: Duldur-Aqur,
 332 China and Pendjikent, Tajikistan (Brill 1999), G1a-b, G2 northeast Iranian sites (Schibille et al. 2022), Merv,
 333 Turkmenistan (Schibille 2022; Meek, Simpson & Schibille in peer review), Akhsiket & Kuva (Ferghana Valley), in
 334 Uzbekistan (Rehren et al., 2010) and Rayy, Iran, samples reassigned as CA1 from G1b (Schibille et al. 2022).
 335

336 All seven of the 14th century v-Na-Al glass bangles identified amongst the British Museum
 337 collection from Siraf appear to be of a CA2 composition and correlate more specifically with
 338 the five Merv high Al (b) type fragments, characterised by elements indicative of much higher
 339 quantities of feldspar (Meek, Simpson & Schibille in peer review). The alumina concentrations
 340 average 7.7 wt% and, although two of the bangles (2007,6001.13860 and 2007,6001.13971)
 341 have slightly lower alumina (~6.6 wt%), the rest of their geochemical signature indicates they
 342 perfectly fit the CA2 profile. There are more notable differences for the kohl stick

343 (2007,6001.14056), which has lower alumina, higher titanium and more notable differences
 344 in the Cu, Sr, Zr, Ba, La, Ce, Pr, Nd, Sm, Gd, Hf, Th and U values. This may be an outlier caused
 345 by extensive glass recycling or it could perhaps suggest a different workshop for the bangles
 346 to the kohl stick. With only one sample, such suggestions remain entirely speculative.
 347 However, due to the range of anomalies, this sample has not been included in the
 348 compositional averages and will not be included in the v-Na-Al comparatives charted
 349 henceforth. Despite the wide periodic range between the 9th century Merv CA2 vessel glass
 350 and v-Na-Al* glass bangles from 14th century Siraf, these samples appear compositionally
 351 coherent (**Figure 5a-c**). The only notable difference is variation in the plant ash components
 352 (Li/K₂O, Cs/K₂O and MgO) and the elevated barium in the bangles (**Figure 5d**). These findings
 353 suggest CA2 was widely distributed but only in small quantities, potentially for specialist
 354 purposes.
 355



356

357 **Figure 5a-c.** Graphs showing compositional homogeneity between the 9th century 'Merv high Al' glass samples and
 358 seven 14th century v-Na-Al+ glass bangle fragments from Siraf; **d.** except for a notable elevations of barium (Merv
 359 data: Meek, Simpson & Schibille in peer review).

360

361 Thanks to the recently published glass data from the ca. 7th–14th century Kafir Kala (KK)
 362 citadel (Samarkand; Chinni, et al. 2023), evidence for another possible Central Asian category
 363 has emerged, termed here CA3. Although three glass types (Groups A-C) were initially
 364 identified by Chinni, et al. (2023), Group A was defined as having a much higher Zr/Ti ratio,
 365 but when looking at the data this was found not to be the case.⁴ Nonetheless, multiple
 366 subtypes can be identified from at least three regions. A small number were found to be glass
 367 of the Eastern Mediterranean and Western Khurasan regions, but most are characteristic of
 368 Eastern Khurasan. Specifically, over half (sixteen) of the 29 vessel fragments from Kafir Kala
 369 (see Chinni, et al. 2023) are of the CA3 composition. They are mostly vessel walls with some
 370 rims, bottoms and handles and all are described as aqua, light green or light blue in colour.

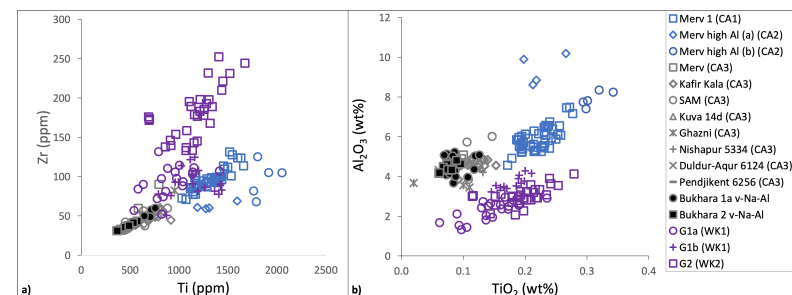
371

372 This CA3 subgroup appears to have similar compositional characteristics to CA1 and CA2
 373 but with slightly lower alumina (ca 4–5 wt% Al₂O₃) and very different titanium (ca. 0.10-0.15
 374 wt% TiO₂) and zirconium (ca. 40-60 Zr ppm) concentrations, demonstrating they are made
 375 from different silica sources (**Figure 6a.-b.**). CA3 also does not seem to have been as widely
 376 distributed, being restricted to areas of Uzbekistan, suggesting it may have been a localised
 377 glass produced near here. Whilst collating the Central Asian data for this study, it was noted
 378 that a few outliers in each of the data sets appeared homogenous with this Kafir Kala CA3
 379 group (group B, Chinni et al., 2023) when plotted together. This includes two samples from
 380 Merv (589 and 742) with around 5 wt% Al₂O₃, one from Nishapur (NIS5334), one from Kuva
 381 (14d) four from Ghazni (GH18, GH21, GH25 and GH27), two from Duldur-Aqur (6256 and
 382 6124) and one from Pendjikent (6256). Six samples of vessel fragments and glass chunks
 383 dating to the 'Islamic period' from the neighbouring site of Cholaktepa (SAM) were also
 384 analysed (see Chinni, et al. 2023). Although these also appear possibly CA3 in character, most
 385 have notable antimony contents that may be an analytical artefact, , making an interpretation

⁴ From reassessing the original data it appears as though a plotting error has occurred for the Cholaktepa (SAM) group, artificially creating 'Group A'. When replotted we found this group to have comparable levels of Zr/Ti to those of Kafir Kala defined as 'Group B'. All defined as 'Group C' do have more elevated Cr/Al, with the addition of KK-d14, which is extremely elevated but not highlighted (34.08 ppm).

386 less reliable (Chinni, et al. 2023). The lately published Central Asian collection from nearby
 387 Bukhara Oasis, Uzbekistan (Schibille et al 2024) reveals two v-Na-Al glass groups (Bukhara 1a
 388 and 2) compatible with this likely regionally produced CA3 category from the surrounding
 389 Uzbeki region. They align on most major, minor and trace elements (except higher REE) (Figure
 390 6c-d.).

391



392 **Figure 6.** Silica-related characteristics of the CA3 samples from various collections in grey. a) Zr ppm versus Ti
 393 ppm values and b) Al₂O₃ and TiO₂ (wt%). Data: Duldur-Aqur, Kucha (Xinjiang province), in China, Pendjikent, in
 394 Tajikistan (Brill 1999); Merv (Schibille 2022; Meek, Simpson & Schibille in peer review); Ghazni (Fiorentino et al.
 395 2019); Akhsiket & Kuva (Ferghana Valley; (Rehren et al., 2010) and Kafir Kala (Chinni, et al. 2023); G1a-b and G2
 396 Western Khurasan types (Schibille et al 2022) Bukhara 1a and 2 types (Schibille et al 2024)

397

398 Central Asian glass subtype distribution across land routes

399

400 The CA1 subtype represents the highest proportion of Eastern Khurasan glass so far
 401 analysed. It is concentrated at Merv but is also found in very small quantities amongst almost
 402 all of the collections reviewed, representing a fairly wide but low level of distribution (**Figure**
 403 **7.a**). The current lack of production evidence at Merv means we cannot currently state that
 404 this was the producer of CA1 glass, but the high quantities identified at the site suggest it was
 405 the main market for this glass. If not produced in Merv itself, the CA1 production site is likely
 406 to have been located close to the city.

407

408 This overview also indicates that the v-Na-Al Siraf glass bangles are of the CA2 (v-Na-Al+)
 409 group. Although found in much smaller quantities, the CA2 glass appears to be more widely
 410 distributed along the caravan routes connecting these regions (**Figure 7.b**). Merv in
 411

412 Turkmenistan was a major Islamic city during the 9th-13th centuries, strategically positioned
 413 along the 'Silk Roads' networks of mobility and commerce. Merv was certainly the conduit of
 414 these v-Na-Al glass groups with even the most distant sites (of Siraf on the Iranian coast of the
 415 Persian Gulf and Duldur-Aqur in the province of Xinjiang in northwest China) being indirectly
 416 connected via the major trade routes through the city. In contrast, the CA3 group is found
 417 both in relatively small quantities and clustered more locally (Figure 7.c).

418

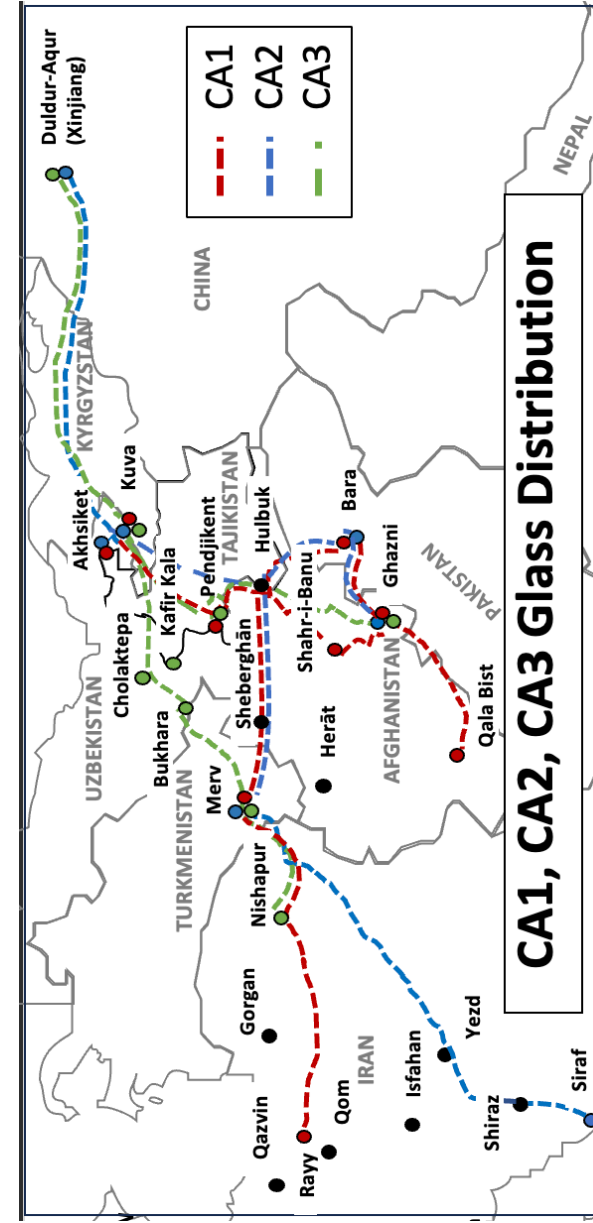


Figure 7. Map representing Central Asian glass subtype distribution across land routes to show dissemination (not a faithful rendering of specific routes of the period but loosely based on Mansson (2019) and The Silk Road and Arab Sea Routes (11th and 12th centuries) (2023) trade maps). Coloured dots represent sites where each sub type has been identified in this study to date. Those marked black are either mentioned in the paper or part of the suspected glass trade route but have yet to be excavated and/or analysed to verify. The Jordanian sites have been omitted due to doubt over their origin. Qala Bist and Bara v-Na-Al marked here but not discussed due to the earlier periods only use of ICP-OES and one sample in the prior. However they are marked amongst their closest group to acknowledge their earlier existence and possible trade connections. It is also acknowledged the Duldur-Aqur samples closest to the CA2 group were of a different silica and earlier period.

22

21

419 **The v-Na-Al Siraf glass bangles in context of other relevant glass bangle collections**

420

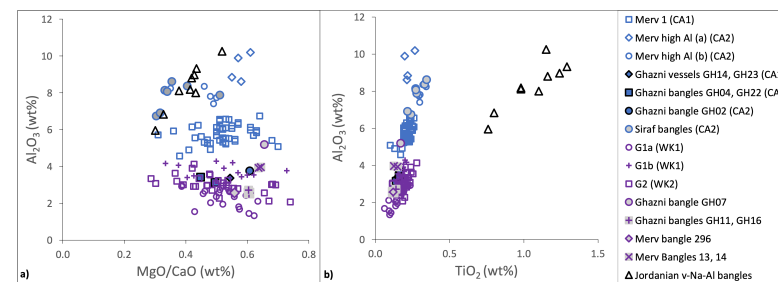
421 As discussed above, the Siraf glass bangles belong to the CA2 v-Na-Al⁺ glass type. Of the six
 422 glass bangles from Ghazni previously analysed (Fiorentino et al. 2019), half are v-Na-Al glass,
 423 so likely of Eastern Khurasan (Central Asian) origin. Fiorentino et al. (2019, 167; Fig. 8b)
 424 classifies three (GH02, GH04 and GH22) as high alumina, stating they have Al₂O₃, K₂O and
 425 Na₂O contents most comparable to v-Na-Al bangles from Jordan and v-Na-Al glass from the
 426 Ferghana Valley. Vessel fragments GH14 (a light green rim) and GH23 (a green base) also have
 427 similar alumina and titanium concentrations. Fiorentino et al. (2019, 167) had already noted
 428 that high alumina bangles GH04 and GH22 have a higher Ba than the bulk of the Ghazni
 429 assemblage (>800 ppm Ba), including the high alumina bangle GH02 (345 ppm Ba) implying
 430 use of a different type of sand and plant ash source (see Brems & Degryse, 2014).⁵ These
 431 fragments (GH04 and GH22) were found to be CA1 glass, whereas the v-Na-Al GH02 seems to
 432 be CA2 glass like the v-Na-Al glass bangles from Siraf. Of the nine comparable v-Na-Al glass
 433 bangle samples mentioned from Tell Abu Sarbut and Khirbat, Jordan (Boulogne & Henderson
 434 2009), samples AB30 and AB32 have alumina levels akin to the high alumina CA1 group. The
 435 other seven have extra high alumina levels, aligning more with the CA2 subtypes (**Figure 8a**).
 436 However, the very strong differentiation in titanium levels (~1.05 wt%) from other CA2 glass
 437 (~0.12 wt%), suggests an alternative origin of the silica source altogether (**Figure 8b**).

438
 439 Despite clear similarities in both colour and typology, the other half of the Ghazni glass
 440 bangle samples (GH07, GH11 and GH16) are of a Western Khurasan (formally Mesopotamia
 441 1) composition. More specifically, GH07 aligns well with G1a glass and GH11 and GH16 more
 442 closely with the G1b type. As Fiorentino et al. (2019, 167) states, these resemble the 'bulk
 443 composition of the assemblage from Ghazni closely', although as we have shown here four of
 444 those vessel fragments are of the newly proposed CA3 glass type (GH18, GH21, GH25, GH27).
 445 Intriguingly, the analysis of three glass bangle fragments at the British Museum from Merv,
 446 revealed Western Khurasan compositions thought to be from northeast Iran, most similar to
 447 the G1-G2 groups (after Schibille et al. 2022). The 9th century sample (2009,6016.296) aligns

⁵ Although the authors also make the same claim for the Sr content when replotting the data we found all of the v-Na-Al bangles (GH02, GH04 and GH22) to be within comparable levels to the rest of the Ghazni assemblage (227-588 ppm Sr) and actually on the lower end of this scale (<400 ppm)

448 very closely with the GH07 bangle from Ghazni but the two 12th century samples
 449 (2015,6001.13 and 2015,6001.14) appear more characteristic of the G1b subtypes (**Figure 8c-**
 450 **d**).

451



452

453 **Figure 8.** Charts of Al₂O₃ and MgO/CaO and Al₂O₃ and TiO₂ concentrations in the bangles under discussion against
 454 Eastern and Western Khurasan glass. Data: *British Museum bangles from Merv and v-Na-Al from Siraf, Persian*
 455 *Gulf (Unpublished data); Bangles from Ghazni (Fiorentino et al. 2019); v-Na-Al bangles from Tell Abu Sarbut and*
 456 *Khirbat Faris in Jordan (Boulogne and Henderson, 2009); Merv 1 and high Al, (Schibille 2022; Meek, Simpson &*
 457 *Schibille in peer review); G1a-b and G2 glass from various northeast Iranian sites (Schibille et al. 2022).*

458

459 It must be stressed that a high alumina characteristic is not unique to silica of the Central
 460 Asian region and seems to be more common than previously assumed. For example, high
 461 alumina glass has been found at various sites in Asia Minor (e.g. Dussubieux et al. 2010;
 462 Schibille 2011; Swan et al. 2018). The m-Na-Al 5 group from Asia Minor (Dussubieux et al.
 463 2010) is easily differentiated from other m-Na-Al glass because it is boron-rich (>300 ppm B).
 464 Other glass of this characteristic has been since identified from Asia Minor (Schibille 2011).
 465 Likewise, high alumina high boron glass with elevated magnesia and potash values (>2.5 wt%),
 466 which is usually characteristic of plant ash glass, has been identified from a 10th-12th century
 467 Byzantine glass bangle collection from Asia Minor (Swan et al. 2018). Asia Minor thus presents
 468 a possible alternative regional candidate for some of the v-Na-Al glass bangles like the ones
 469 from Jordan (Boulogne and Henderson, 2009). Unfortunately, such speculations can neither
 470 be verified nor disputed with the current dataset produced from electron microprobe analysis
 471 (EPMA) that does not contain boron contents and so this remains a subject for future
 472 investigation.

473

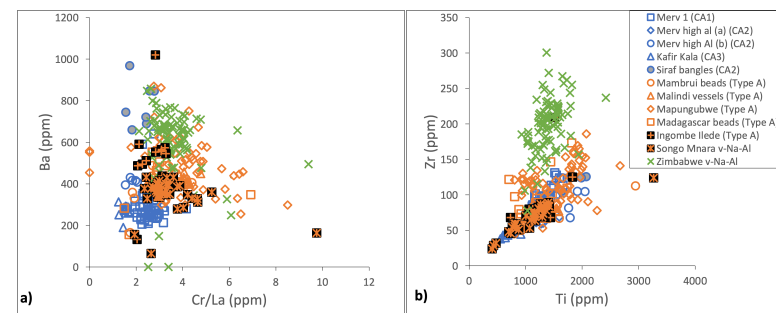
474 Glass bangles produced in Yemen were also found to be exceptionally high in alumina
 475 (unpublished data), representing another type of v-Na-Al glass and further providing evidence
 476 that high alumina may be more common than initially thought. However, it is worth noting to
 477 avoid any future confusion that the v-Na-Al Yemeni bangles do not otherwise present with the
 478 same geochemical signatures as the bangles from Jordan, nor any of the other v-Na-Al glass
 479 under discussion from Central Asia or Asia Minor.

481 Comparing v-Na-Al glass bangles from Siraf with v-Na-Al glass beads from east Africa

482
 483 In a recent study, Siu et al. (2020) identified seventeen v-Na-Al glass vessel fragments
 484 excavated from Malindi and twenty v-Na-Al glass beads from Mambui in Kenya, using EPMA
 485 and LA-ICP-MS. They reviewed these against other known v-Na-Al collections and argued that
 486 from the silica (Zr, Ti, La and Cr) and alkali components (Cs and Li) at least four main v-Na-Al
 487 compositional groups could be identified (Siu et al. 2020). 'Type A' v-Na-Al is characterised by
 488 elevated alumina, titanium and barium, relatively high ratios of Cr/La and relatively low lime
 489 and zirconium concentrations with low ratios of Zr/Ti (Siu et al. 2020, 2). Some sub-variation
 490 within the type is identified mainly between the plant ash components (Na₂O, MgO, Li and
 491 CaO), and a slight differentiation in Zr. Siu et al. (2020) argue this is indicative of a periodic
 492 change of local workshops between the earlier 13th–14th century glass beads collections from
 493 Mapungubwe Oblate (Robertshaw et al. 2010) and Madagascar (Robertshaw et al. 2006) and
 494 later Kenyan collections (15th–16th century) from Malindi and Mambui.

495
 496 In contrast, the Zimbabwe series of the 14th–15th century (Robertshaw et al. 2010),
 497 designated as 'Type B,' has higher concentrations of Zr and Ba and a relatively high ratio of
 498 Cr/La, indicative of a different silica source (Figure 9). The 'Type C' v-Na-Al glass vessels from
 499 10th–17th centuries Mtwapa, Kenya (see Dussubieux and Kusimba 2012), display a different
 500 mineralogical composition with lower Ba, Ti, Zr and Cr/La and distinct plant species with
 501 higher Na₂O. Likewise, the 'Type D' 12th–13th century Pengalan Bujang vessel glass is similar
 502 to Type C, with lower Ba (~179 ppm) and Ti (~1136 ppm) than Type A and B and lower Zr (~94

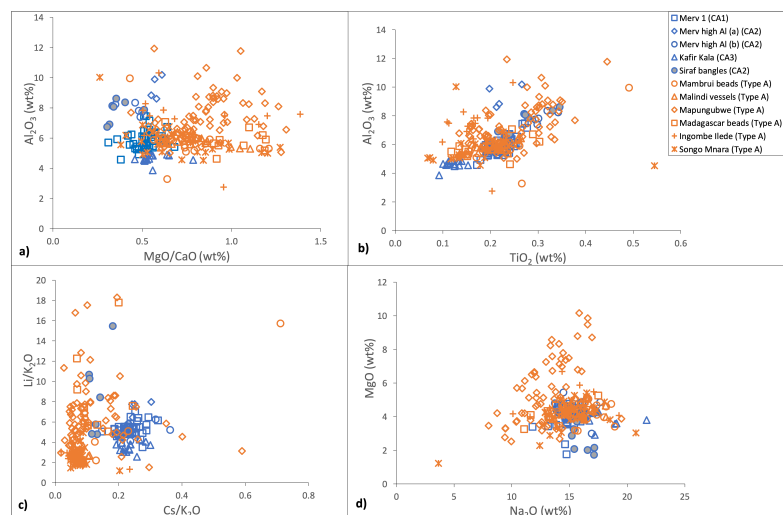
503 ppm) than Type B. However, it differs from Type C with lower CaO (~4 %wt), MgO (~4.5 wt%),
 504 Ti (~1136 ppm), Sr (~283 ppm) and Cr/La ratios (~1.57 ppm) (Siu et al. 2020).⁶
 505



506
 507 **Figure 9.** Plotting the CA1-3 groups (blue), including the v-Na-Al Siraf glass bangles (grey), against the 'Type A'
 508 (orange) and 'Type B' group (green) defined by Siu et al. (2020), plus v-Na-Al beads from Ingombe Ilede and
 509 Songo Mnara (orange and black). Data: Merv (Schibille 2022; Meek, Simpson & Schibille *in peer review*); Kafir
 510 Kala (Chinni, et al. 2023); v-Na-Al Siraf bangles (Unpublished); Malindi and Mambui, Kenya (Siu et al. 2020);
 511 Zimbabwe and Mapungubwe Oblate (Robertshaw et al. 2010); Madagascar (Robertshaw et al. 2006); Ingombe
 512 Ilede, Zambia (Robertshaw & Wood 2017); Songo Mnara, Tanzania (Wood et al. 2023).

513
 514 As suggested by Siu et al. (2020), the 'Type A' grouping appears to correspond particularly
 515 well with 9th-14th century Central Asian groups (Figure 10.a-b). Differences can be drawn with
 516 the plant ash components (MgO/CaO, Li/K₂O and Cs/K₂O ratios) (Figure 10.c-d). This group
 517 comprises the Malindi glass vessels and Mambui glass beads from Kenya, the Mapungubwe
 518 Oblate series beads from South Africa (below Great Zimbabwe) and the beads from Mahilaka
 519 in Madagascar. These were found to differ from the 'Type B' Zimbabwe series, 'Type C' Mtwapa,
 520 Kenya vessels and 'Type D' Southeast Asian vessels from Pengalan Bujang, Malaysia (Siu et al.
 521 2020; see Dussubieux & Allen 2014). In addition, their study has found that 15th-17th century
 522 v-Na-Al glass beads from Ingombe Ilede, Zambia (Robertshaw & Wood 2017) and 14th-16th
 523 century v-Na-Al beads from Songo Mnara, Tanzania (Wood et al. 2023) also align extremely
 524 well with the 'Type A' (CA1) category.

⁶ Although Siu et al. 2020 state its Cr/La ratios to be higher, their data in Table.4 shows the Type D to be lower



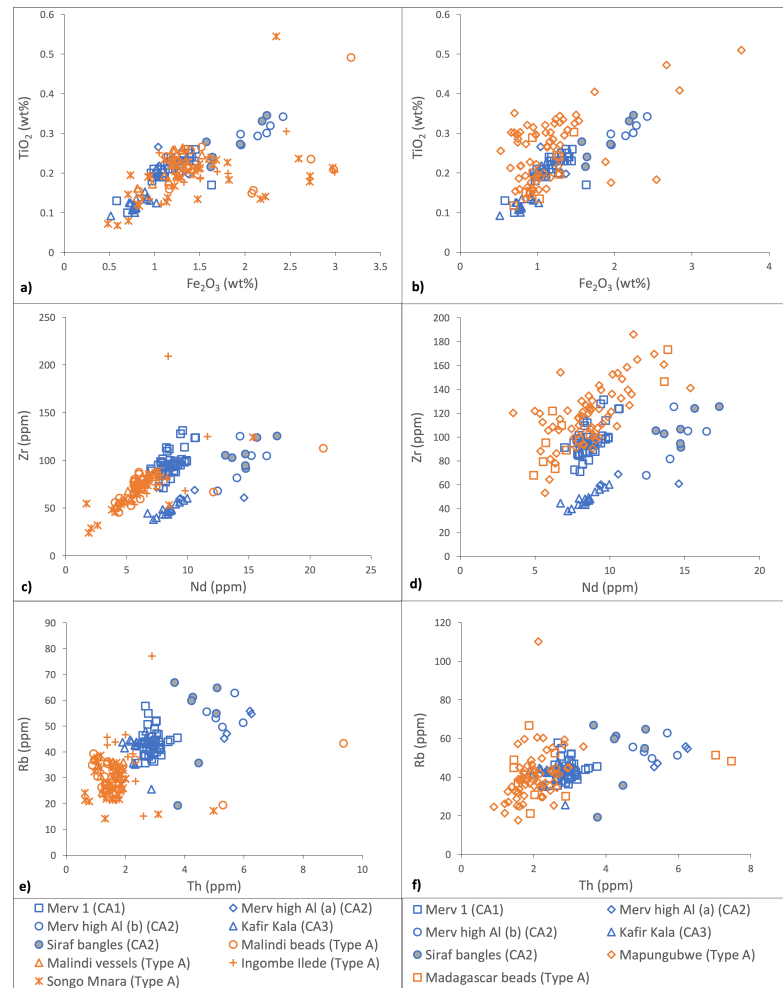
527
 528 **Figure 10.** Plotting the CA1-3 groups (blue), including the v-Na-Al Siraf glass bangles (grey) against the 'Type A'
 529 group (orange), including v-Na-Al beads from Ingombe Ilede, Zambia and Songo Mnara, Tanzania. Data: Merv
 530 (Schibille 2022; Meek, Simpson & Schibille *in peer review*); Kafir Kala (Chinni, et al. 2023); v-Na-Al bangles Siraf
 531 (Unpublished); Malindi and Mamburi, Kenya (Siu et al. 2020); Mapungubwe Oblate (Robertshaw et al. 2010);
 532 Madagascar (Robertshaw et al. 2006); Ingombe Ilede, Zambia (Robertshaw & Wood 2017); *Songo Mnara,*
 533 *Tanzania* (Wood et al. 2023).

534
 535 A review of other elements imparted by the silica component confirm that 'Type A' should
 536 be conflated more generally within the CA1 glass category, found in greatest quantities at
 537 Merv, suggesting it is indeed of Central Asian origin (**Figure 11**). However, it must be noted
 538 that the Mapungubwe Oblate series is far less homogenous than the other CA1 (Type A)
 539 collections with some samples having more elevated Cr/La ratios and others higher Ba
 540 concentrations. Elevated Ba is also displayed by some of the beads in the Madagascar
 541 collection. This lack of homogeneity is demonstrated by other compositional elements, evident
 542 when separated from the much more coherent Malindi, Mamburi, Ingombe Ilede and Songo
 543 Mnara collections that are contemporary to the 16th century (**Figure 12**).



544
 545 **Figure 11.** Map showing sites reviewed in this article with CA1 (Type A) subtype of v-Na-Al glass from the Eastern
 546 Khurasan region of Central Asia adapted from Siu et al. 2020.

547



548

549 **Figure 12.** TiO₂, Fe₂O₃, Zr, Rb and Th of CA1-3 with: (a,c,e.) v-Na-Al Malindi, Mambroi, Ingombe Ilede and Songo
 550 Mnara glass; (b,d,f.) v-Na-Al Madagascar and Mapungubwe. Data: Merv (Schibille 2022; Meek, Simpson &
 551 Schibille *in peer review*); Kafir Kala(Chinni, et al. 2023); v-Na-Al bangles Siraf (Unpublished); Malindi and
 552 Mambroi, Kenya (Siu et al. 2020); Mapungubwe Oblate (Robertshaw et al. 2010); Madagascar (Robertshaw et al.
 553 2006); Ingombe Ilede, Zambia (Robertshaw & Wood 2017); Songo Mnara, Tanzania (Wood et al. 2023).

554

555 As argued by Siu et al. (2020) these compositional differences between the collections may
 556 further suggest periodic shifts in workshops and recipes, or possibly changes in recycling
 557 practices. It is worth further noting that the earlier Mapungubwe Oblate beads not only differ
 558 slightly to the compositions of the later Mambroi beads (such as elevated barium), but
 559 according to Marilee Wood (personal correspondence) they are morphologically distinct.
 560 Elevated barium is also a characteristic observed amongst the 14th century v-Na-Al Siraf glass
 561 bangles (~685 ppm Ba), when compared to the 9th century Merv CA2 vessel fragments (~398
 562 ppm Ba), as well as similar periodic variation between the plant ash components (MgO
 563 concentrations and MgO/CaO and Li/K₂O ratios).

564

565 CONCLUSIONS

566

567 The principal objective of this investigation has been to attempt to better identify the
 568 presumed Central Asian provenance for v-Na-Al glass bangles from Siraf in Iran by comparing
 569 the data against other known v-Na-Al collections. It has long been speculated that v-Na-Al
 570 glass is a characteristic of Central Asian glass production, which was known during the
 571 Sasanian and Islamic periods as the eastern region of the Khurasan Province (Sykes 1914). We
 572 have now tentatively distinguished three compositional groups from Central Asia (CA1, CA2,
 573 CA3) all with relatively high alumina (ca. >4 wt%) but with varying levels of this component
 574 and also zirconium and titanium concentrations. Apart from these major differences these
 575 subtypes can be differentiated by a variety of other minor trace elements, suggesting different
 576 silica source within the same wider regional area.

577

578 The v-Na-Al glass bangles from Siraf in Iran dating to the 14th century share close
 579 compositional similarities with one of the v-Na-Al glass bangles from Ghazni in Afghanistan
 580 (ca. 14th century) and the few glass vessel fragments from 9th century Merv in Turkmenistan
 581 (particularly Merv high Al (b)) identified as the CA2 type. Variations are seen primarily
 582 amongst elements imparted by the plant ash component, probably indicative of the different
 583 periods of production. Elevated barium is also observed amongst the glass bangles, something
 584 that needs further investigation. This is a characteristic also found in the earlier (13th-14th
 585 century) 'Type A' glass from v-Na-Al Madagascar and Mapungubwe Oblate (Robertshaw et al.

586 2006; et al.2010) glass bead collections from south and east Africa of the same period that
587 were recently reviewed by Siu et al. (2020). Otherwise, this review suggests the 'Type A'
588 collections should be more generally conflated with the Central Asian glass group CA1. So too
589 should the v-Na-Al glass beads from Ingombe Ilede, Zambia (Robertshaw & Wood 2017) and
590 Songo Mnara, Tanzania (Wood et al. 2023), which this study also found to be a direct match
591 to the later contemporary collections from 15th-16th century Malindi and Mambui, Kenya (Siu
592 et al. 2020). Thus, the maritime trade network for CA1 glass may be far larger than CA2 glass,
593 despite the latter's seemingly wider dissemination over land routes.

594

595 Intriguingly, what this study also shows is that these v-Na-Al collections of South and East
596 African sites are mostly made up of CA1 type beads that are also found in its highest quantities
597 at the city of Merv, Turkmenistan in Central Asia. These collections compositionally differ from
598 the contemporary v-Na-Al Siraf (and one Ghazni) CA2 glass bangles (likewise found at Merv as
599 vessel fragments but in small quantities). Both the subtypes (CA1 and CA2) appear to be from
600 somewhere in Central Asia and contemporary, as do the wide dissemination of glass bangles
601 and beads. Despite two of the v-Na-Al glass bangles from Ghazni (GH04 and GH22) being
602 identified as CA1 glass, no CA1 glass bangles have been identified at Siraf. Likewise, no CA2
603 glass beads have been identified at any of the East or Southern African sites, nor any glass
604 bangles at all according to Peter Robertshaw (personal correspondence). This suggests
605 entirely different *chaîne opératoire* of specialist workshops producing specific objects and
606 using particular glass. It also indicates different trade networks to reach different consumer
607 markets for these small, highly portable and decorative glass objects of 9th-14th century female
608 adornment. Something that is also potentially suggested in the observed minor compositional
609 differences between the v-Na-al glass bangle fragments and the v-Na-Al kohl stick sample
610 fragment (2007,6001.14056).

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