



Kent Academic Repository

Nash-Pye, C.K., Meek, A., Schibille, N., Richards, L. and Charlton, M. (2026)
Glass bangles from the Yemeni workshop of Kawd am-Saila, Aden (c.14th–16th century): Defining a high-alumina plant-ash (v-Na-al) group. *Journal of Archaeological Science*, 194 . ISSN 0305-4403.

Downloaded from

<https://kar.kent.ac.uk/116212/> The University of Kent's Academic Repository KAR

The version of record is available from

<https://doi.org/10.1016/j.jas.2026.106677>

This document version

Publisher pdf

DOI for this version

Licence for this version

CC BY (Attribution)

Additional information

Versions of research works

Versions of Record

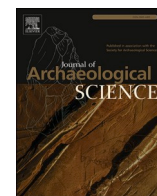
If this version is the version of record, it is the same as the published version available on the publisher's web site. Cite as the published version.

Author Accepted Manuscripts

If this document is identified as the Author Accepted Manuscript it is the version after peer review but before type setting, copy editing or publisher branding. Cite as Surname, Initial. (Year) 'Title of article'. To be published in **Title of Journal** , Volume and issue numbers [peer-reviewed accepted version]. Available at: DOI or URL (Accessed: date).

Enquiries

If you have questions about this document contact ResearchSupport@kent.ac.uk. Please include the URL of the record in KAR. If you believe that your, or a third party's rights have been compromised through this document please see our [Take Down policy](https://www.kent.ac.uk/guides/kar-the-kent-academic-repository#policies) (available from <https://www.kent.ac.uk/guides/kar-the-kent-academic-repository#policies>).



Glass bangles from the Yemeni workshop of Kawd am-Saila, Aden (c.14th–16th century): Defining a high-alumina plant-ash (v-Na-al) group

C.K. Nash-Pye^{a,b,*}, A. Meek^c, N. Schibille^d, L. Richards^e, M. Charlton^e

^a University of Kent Classical and Archaeological Studies, Division of Arts and Humanities, University of Kent, Canterbury, Kent, CT2 7NF, United Kingdom

^b The British Museum, London, WC1B 3DG, United Kingdom

^c Department of Scientific Research, The British Museum, London, WC1B 3DG, United Kingdom

^d IRAMAT-CEB, UMR 7065, CNRS, Orléans, 45071, France

^e Institute of Archaeology, UCL, London, WC1E 6BT, United Kingdom

ARTICLE INFO

Keywords:

Archaeometry
Historic glass analysis
Islamic glass bangles
Middle East studies
Indian Ocean trade
South Arabia
LA-ICP-MS

ABSTRACT

This paper presents compositional results and typological distinctions for glass bangle debris collected from the Yemeni workshop of Kawd am-Saila (c. 14th–16th centuries) in the province of Aden, and small contemporary collections from nearby al-Karf Road and neighbouring Somaliland held in the British Museum. These bangle fragments share the same typological designs and colour repertoires, consistent with export from Yemen to the Horn of Africa. Archaeochemical analyses were undertaken using SEM-EDX at the British Museum and LA-ICP-MS at CNRS Orléans and the UCL Institute of Archaeology. This study applies an established geochemical framework to identify a new, internally coherent category of glass termed 'KAS', characterised by distinct silica and plant-ash sources most likely associated with the region of Aden, consistent with archaeological indications of secondary production at the Kawd am-Saila workshop. The comparative collections were also found to be primarily of this previously undocumented 'KAS' composition and the few fragments with typological differences corresponded to other established regional glass groupings.

KAS is a soda-lime-silica plant-ash glass most notable for elevated alumina concentrations (c. >4 wt% Al₂O₃), placing it within the so-called 'v-Na-Al' compositional category, a characteristic often associated with Central Asian glass (c. 9th–17th centuries). This study defines the key compositional characteristics of KAS, establishing a new categorisation for a potential South Arabian glass production zone by highlighting notable differences from contemporary Central Asian glasses. Identification of this proposed new composition contributes to a better understanding of plant-ash glasses, offering a new regional reference point for Islamic glass studies. The findings also provide insights into production techniques, compositional variability and circulation patterns of glass bangles across the western Indian Ocean during the medieval to early modern period.

1. Introduction

Scientific analysis has refined regional compositional frameworks for Islamic glass production across the Middle East and wider Indian Ocean. However, South Arabia remains absent from these schemes despite long-standing archaeological evidence for glass manufacture and export. This absence has limited the accurate provenancing of Islamic glass and obscured regional production and circulation patterns within the western Indian Ocean world. Recent compositional studies using LA-ICP-MS have demonstrated that Islamic glass production across the Middle East and wider Indian Ocean can be divided into a series of broadly coherent

regional geochemical production zones through comparison of major, minor and trace element compositions, even when raw or furnace glass from primary production sites have yet to be identified archaeologically. This paper builds directly on Nash-Pye et al. (2025), which synthesised these past studies to establish the comparative framework for high-alumina plant-ash bangles visualised through variations of bivariate charts and provides further explanation of these compositional divisions into recognisable production regions. These include compositional groups from Western Anatolia (Schibille, 2011), the Eastern Mediterranean (Freestone, 2002; Henderson et al., 2004), Mesopotamia (Schibille et al., 2018), Western Khurasan (Schibille et al.,

* Corresponding author. University of Kent Classical and Archaeological Studies, Division of Arts and Humanities, University of Kent, Canterbury, Kent, CT2 7NF, United Kingdom.

E-mail address: charlotte.k.nash@gmail.com (C.K. Nash-Pye).

<https://doi.org/10.1016/j.jas.2026.106677>

Received 24 April 2026; Received in revised form 10 August 2026; Accepted 19 August 2026

Available online 30 August 2026

0305-4403/© 2026 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

2022), Eastern Khurasan (Meek et al., 2025) and South Asia (Dussubieux et al., 2010).

These frameworks provide a critical comparative baseline for provenance studies, yet to date no compositional signature has been defined for South Arabian production. In fact, glass recovered from confirmed Yemeni workshops, including glass bangles, has curiously remained analytically uncharacterised. This omission is particularly significant given that Yemen is documented as a centre of glass production under the Rasulid dynasty (13th–mid 15th centuries) in the *Geniza papers* and *Chu-Fan-Chi* by Chau Ju-Kua (Zhao Rugua) from at least the 12th–13th centuries (Goitein, 1974: 18–35; trans. Hirth and Rockhill, 1911: 120, 227). Without compositional characterisation, Yemeni glass has remained difficult to distinguish from other plant-ash traditions, contributing to potential misattribution and over-generalisation within broader regional classifications. Employing trace element analysis on glass bangle debris from the Kawd am-Saila workshop in Aden (c.14th–16th century), thus, presents a rare opportunity to reveal whether the raw glass was likely exploiting local resources, being imported from another production region or using recycled glass. As a securely identified workshop assemblage, the fragments also enable stylistic, technological and geochemical characteristics to be examined together.

The typological uniformity of distinct Kawd am-Saila glass bangles, especially those employing unusual frit-coating production techniques of limited colours, has resulted in a widely held assumption that distinct ‘Yemeni-type’ bangles were of the same production tradition (Lane and Serjeant, 1948; Harding, 1964; Monod, 1978; Whitcomb and Johnson, 1979; Whitcomb, 1988; King and Tonghini, 1996; Shindo, 2001). It was, therefore, hypothesised that the typologically coherent al-Karf Road and Somaliland¹ fragments would also be of the same general glass composition and, if the Kawd am-Saila collection was not produced using recycled or imported glass of a known composition, they would reveal a previously undocumented composition, likely reflecting locally available raw materials in the Aden region. This could establish a link between typological and geochemical characteristics, demonstrate wider export of these objects (Fig. 1), and possibly define a distinct geochemical profile for Yemeni glass bangle production and, by extension, a wider South Arabian production zone for future glass analysis.

2. Background

It has long been suspected that the many Islamic glass bangle designs in circulation between c.13th–20th centuries represent wider dissemination patterns, and that the few collections that have been analysed reveal a wide range of both typological designs and geochemical compositions. However, the key to their origins lies in establishing whether stylistic designs can confidently be linked with geochemical compositions of a glass production site or region. Establishing links between Islamic glass bangle typology and geochemistry has been the focus of recent research by the lead author. Glass bangles are commonly found in the Middle East during the Mamluk period (mid 13th–early 16th century) (Spaer, 1992; Rougeulle, 2015). Known glass bangle workshops include those at Kolhapur, India (14th–17th century) (Sankalia and Dikshit, 1952), Fustat, Egypt (14th–15th century) (Shindo, 1987), Hebron, Palestine (c.14th–19th century) (Spaer, 1992) and Sardis, Turkey (c.13th–14th century) (Von Saldern, 1980). In Yemen, bangle furnaces at Kawd am-Saila in Aden (c.14th–16th century) (Monod, 1978) and al-Shihr in Hadhramaut (c.16th century) (Boulogne and Hardy-Guilbert, 2010) have been identified.

Glass bangles from Yemen are visually distinctive from those of other verified production regions, often described as being frit-coated giving them an opaque matt, pasty look of limited colours, roughly applied over

a streaked, bubbled and shiny dark green or black-looking glass of poor quality (Doe, 1963; Lane and Serjeant, 1948; Harding, 1964; Pirenne, 1976: 421–422). The most common designs from Aden are plain dark green or black-looking with opaque burgundy-red and yellow prunt or stripe designs (Doe, 1963; Lane and Serjeant, 1948; Harding, 1964). Many of the designs appear to reflect those of marvered or protruding styles applied to bangles from other regions, but this coating technique is easily identifiable when viewing fragment cross-sections, which reveal that the decoration is roughly applied to the surface only.

It remains unclear whether Kawd am-Saila was also a primary glass production site, or just a secondary workshop specialising in glass bangles using imported (or recycled) glass from elsewhere. However, the current understanding of how common glass recycling was in the medieval Islamic period is extremely limited, and there is currently little evidence to suggest that routine large-scale recycling formed a major component of production at Middle Eastern glass workshops. It has been suggested that Kawd am-Saila was the medieval site of ‘al-Lakhaba’ near Aden, a primary glass production site first referenced during the 13th century by Ibn al-Mujawir in the *Tārīkh al-Mustabṣir* and featured in the *Geniza letters*, which became a heavily populated village that made glass bricks for transport to Aden in the 16th century, according to al-Kayyib Bā Abū Makhrāma (Goitein, 1974; Lane and Serjeant, 1948; Margariti, 2007: 60–63, 67; Boulogne and Hardy-Guilbert, 2010; Lambourn, 2018). However, there is no mention of glass bangles being manufactured there, which may indicate al-Lakhaba supplied Kawd am-Saila with raw glass. Nonetheless, although yet to be scientifically verified, it seems archaeologically likely the raw components for this primary glass were sourced relatively locally. Although there is evidence of imported raw glass at some early Islamic glass production centres, such as al-Raqqa (Henderson et al., 2004), these are primarily high quality decolourised glasses used for fine vessels, not everyday utility objects and adornments, such as glass bottles and bangles.

Révoil, who visited an abandoned medieval site near a mosque with a water well and aqueduct in Aden during the 19th century, may have been the first to record Kawd am-Saila, reporting evidence of glass kilns, frit and bangles on the surface (Révoil, 1883: 279–280). However, the first verified account comes from Lane and Serjeant during an archaeological expedition to investigate various sites across Aden in 1941, identifying burnt-brick kilns, glass waste and numerous bangle fragments at Kawd am-Saila (Lane and Serjeant, 1948). They also recorded frit and glass bangle fragments at 10th–14th century sites al-Habil and Zinjibar, of which their local guide informed them there were many other similar medieval sites throughout Aden (Lane and Serjeant, 1948). Aden was described as being ‘plentiful’ in glass bangle surface finds by Harding, who undertook further archaeological surveys of medieval sites in the area (Harding, 1964: 17–18). Doe described Kawd am-Saila as a 300m tell with various broken glass fragments on its surface, including vials, waste and bangles of a type common to other Aden and Abyan sites, concluding Kawd am-Saila had supplied the wider area (Doe, 1963).

Excavations in Aden and Abyan in 1994 further confirmed green glass ingots, slag, frit, waste, glass vessels and bangles of the same designs as those from Kawd am-Saila, presenting evidence of industrial glass production activities at other sites (King and Tonghini, 1996). This suggests that there may have been multiple glass workshops in Yemen, but it is unclear whether any of these also produced glass bangles. Thus, it is debatable whether these typologically distinct ‘Yemeni-type’ bangles found at multiple sites throughout the region were all produced at Kawd am-Saila, which would suggest a relatively large-scale production for the local region, or whether there were many active bangle workshops in the area employing the same distinct design techniques.

Ethnographic research into traditional glass bangle-making using the seamless ‘two-mandrel’ technique agree that a skilled bangle-maker could produce one plain bangle per minute, or one decorative type every 10 minutes, resulting in between 50 and 500 bangles a day per worker (Gaborieau, 1977; Ivleva, 2018). Annual output is difficult to

¹ Although Somaliland has been politically autonomous since 1991, currently it is not internationally recognised as a separate state.

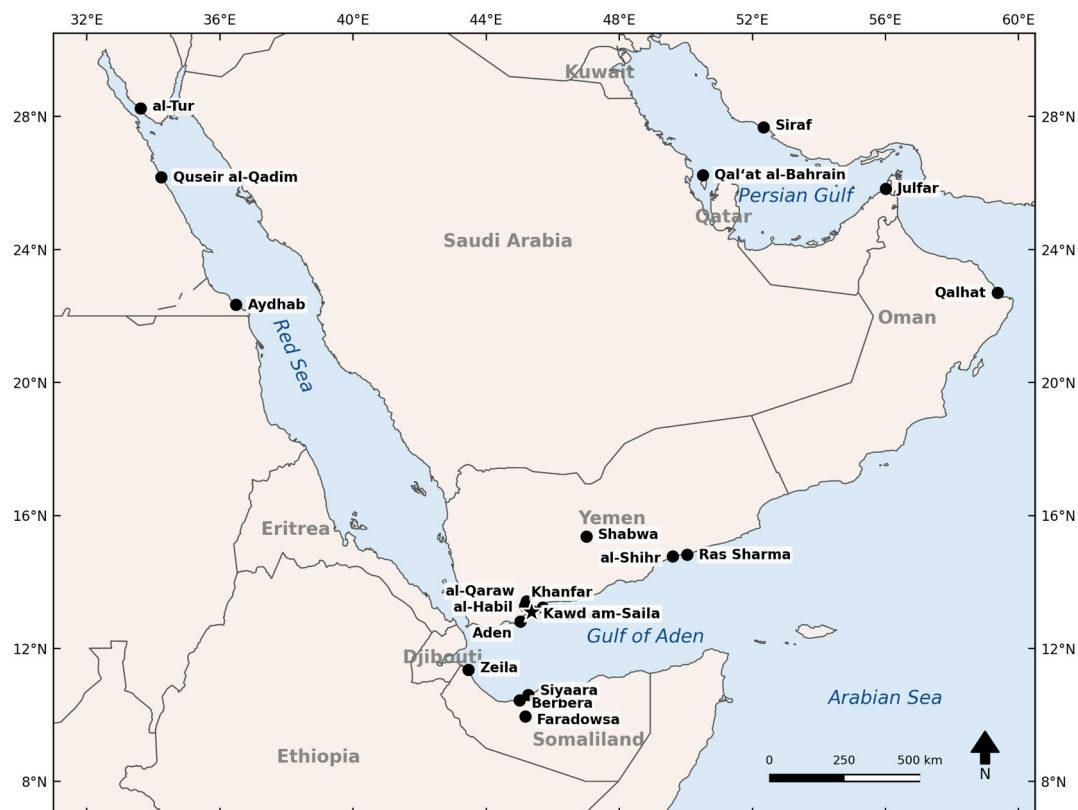


Fig. 1. Map depicting sites with bangles that have been identified as typologically consistent with those from the workshop of Kawd am-Saila in the Aden region of Yemen, mentioned in the study © Nash-Pye.

calculate, as it depends on the number of active furnaces, because most traditional clay furnaces were used intermittently in bursts with a team of three to four artisans working cooperatively (Lababidi, 2021; Lababidi et al., 2023). Although the scale of production did not match that of Roman or Late Ottoman glass production, the Kawd am-Saila furnaces could well have generated the relatively high levels of output to supply a strong regional demand of glass bangles throughout Yemen.

Excavations at al-Shihr in the Hadhramaut district produced over 500 14th–17th century glass bangle fragments with evidence of a short-lived 16th century glass workshop (Hardy-Guilbert, 2005: 71, 73; Hardy-Guilbert and Ducatez, 2004: 128–130, 142). Boulogne and Hardy-Guilbert claimed most fragments dated to the 14th–16th centuries and appear to be of common styles from Kawd am-Saila, so were probably imported from there, whereas those of 17th century strata are most likely Indian imports, based on their designs (Boulogne and Hardy-Guilbert, 2010: 142). However, it is certainly possible al-Shihr produced its own local variations of these ‘Yemeni-type’ bangles, whilst the workshop was active during the 16th century. Unfortunately, despite intentions to analyse some of these bangle fragments and crucibles from al-Shihr at the British Museum, it is the understanding of these authors that no analysis was ever undertaken.

Apart from numerous Yemeni sites, typological parallels for these distinctive ‘Yemeni-type’ bangles have been observed amongst 14th–16th century collections elsewhere, particularly at sites along the African Red Sea and Gulf of Aden coastlines, such as at al-Tur, Quseir al-Qadim and ‘Aydhāb, Zeila, Berbera, Faradowsa and Siyaara (Whitcomb

and Johnson, 1979; Shindo, 2001; González-Ruibal et al., 2021; Torres Rodríguez et al., 2020: 33, Fig. 6). At least one ‘Yemeni-style’ fragment with a yellow and red ‘paste’ mock-marver design had previously been published from Julfar (al-Mataf) in the UAE (Hansman, 1985: 80, Fig.18.k).² Several of these types also feature in Monod’s illustrations from Kawd am-Saila in Yemen (Monod, 1978: no.1, 24, 14 and 13) and an illustrated example from mixed surface finds collected from sites in Ethiopia (Monod, 1975: no.28). However, without good quality coloured photographs, it is difficult to ascertain what percentage of previously published bangle collections may have contained ‘Yemeni-type’ imports.

Although portable glass objects, such as beads and bangles, are often found further afield, recent unpublished research by the lead author indicates that the primary markets for bangles were mostly regionally localised, with far fewer quantities of these designs and compositions being found inter-regionally. This rules out a mass export market of Islamic glass bangles in the medieval period and appears instead to suggest that one (or a few) specialist glass bangle production centre(s) supplied most of the regional demand for bangles. A known example is Hebron in Palestine, which appears from typological and unpublished compositional reviews to have produced most bangles for the Levant and surrounding ‘*Bilad al-Sham*’ area, from the 14th–16th centuries, until the production became more centralised and state-controlled, resulting in a larger Late Hebron export operation under the Ottomans to Anatolia and Egypt (Al-Jubeih, 2008). Likewise, although small quantities of distinctive Indian glass bangles have been identified outside of the Indian

² This is similar to British Museum bangle KAS.20 from Kawd am-Saila and AF1935.0709.94–95 from Somaliland, featured in this study. Common designs, such as those with matt coated yellow and red trail prunts, have also more recently been identified by the lead author amongst other unpublished collections from the Persian Gulf and Southern Arabian coastlines.

subcontinent during 14th–17th centuries, most appear to have been produced for the localised markets, only experiencing increased mass-production and export to the Middle East from the 18th century onwards.

The recent review by Nash-Pye et al. (2025) of known high-alumina plant-ash glasses from Central Asia (Brill, 1999; Chinni et al., 2023; Rehren et al., 2010; Schibille et al., 2024; Meek et al., 2025), which included Islamic glass bangles from Ghazni in Afghanistan (Fiorentino et al., 2019) and Siraf in Iran, offers a potential model for Islamic glass production and distribution. Compositional characteristics reveal primarily regionally localised production and distributions of glass, with CA3 types being local to Uzbekistan (Rehren et al., 2010; Chinni et al., 2023; Schibille et al., 2024) and CA1 convincingly attributed to Turkmenistan (Meek et al., 2025; Nash-Pye et al., 2025). It represents the majority of the glass fragments from Merv in Turkmenistan (48 fragments) and is best characterised by elevated alumina (typically c. 4.5–7.5 wt% Al_2O_3), TiO_2 (ca. 0.2 wt%) and Zr (ca. 100 ppm) (Schibille, 2022; Meek et al., 2025; Nash-Pye et al., 2025). Compositional evidence indicated that components for this kind of everyday low-quality glass with high impurities were probably sourced locally within the region.

Ethnographic research into traditional *Masaga* glass bangle makers in Bida, Nigeria reveal very similar practices regarding their choices of local materials, reflecting practices thought to date back several hundred years, including use of the siliceous red sands of Bida and ash from the plants in the Lake Chad region, Sokoto, and Kano (Lababidi et al., 2023). The traditional black ‘bikini’ glass bangles produced are extremely visually and compositionally similar to the highly bubbled and streaked Yemeni glass, also containing characteristically high impurities (3.07–4.96 wt% Al_2O_3 ; 0.27–0.48 wt% TiO_2 ; 1.31–1.92 wt% Fe_2O_3 (Nadel, 1940; Lababidi et al., 2023), suggesting a very similar *chaîne opératoire*. If Kawd am-Saila was purely a secondary production workshop, primary production was most likely sourced within a relatively short transport distance of the surrounding region. Secondary workshops are most typically situated on the outskirts of villages near the primary glass markets of major cities, such as Merv (Schibille, 2022; Meek et al., 2025). However, because these bangle kilns were small, short-lived and located on settlement outskirts, they often remain archaeologically elusive (Trivedi, 2021).

The practice of exploiting local resources for Islamic glass bangle production is similarly found amongst ethnographic accounts of the well-known glass bangle production in the industrial area of Hebron in Palestine. Visually typical ‘Hebron-type’ bangles were produced in the Mamluk period from sand sourced at the nearby village of Bani Na'im in the Hebron Hills, around 5 miles away (Korfmann, 1966: 48–61). Plant-ash is more portable and therefore more widely traded, for example the 10th century Arabic geographer al-Mukaddasi informs us that it (*shnan* (*kali*)) was widely exported from Aleppo in Syria for glass production (Ashtor, 1992: 482).³ For Hebron glass production, plant-ash was purchased from local Bedouins, sourced from salt-resistant (halophytic) plants around the Dead Sea, approximately 15 miles away (Seetzen, 1859: 49; Loret, 1884: 327). *Salicornia fruticosa* (syn. *Arthrocnemum fruticosum*) is the reported variety of plant harvested by Bedouins from this region (Perrot et al., 1885: 330–331). Studies of Egyptian and Syrian plant-ashes used in glassmaking identify salt-tolerant halophytic plants from coastal, salt-marsh and desert environments as likely sources for soda-rich ash, including genera such as *Salsola*, *Salicornia* and *Suaeda* (Tite et al., 2006; Barkoudah and Henderson, 2006). However, these should be treated as plausible ash sources rather than secure identifications for specific archaeological

glasses, as it has yet to be established to what extent glass compositions were affected by plant species, growing environment, ashing and purification practices, batch proportions and furnace conditions (Henderson et al., 2009). In a South Arabian context, *Salicornia*, *Salsola* and *Suaeda* represent plausible candidate sources due to their occurrence in Yemen's coastal and *sabkha* environments (Gmelin, 1776; Al-Hawshabi and El-Naggar, 2015).

Visually recognisable ‘Yemeni-type’ bangle production at Kawd am-Saila may have followed the same *chaîne opératoire* of aforementioned medieval glass bangle production centres, employing raw glass made from locally sourced raw materials. Archaeological evidence suggests that this primarily served local markets, such as Aden, Hadhramaut and possibly nearby Somaliland, with far smaller quantities disseminating further afield. However, these presumptions have yet to be tested through compositional analysis. The discovery of a collection of over 100 glass bangle fragments from Kawd am-Saila in the Middle East Department of the British Museum thus presented a rare opportunity to define stylistic types, colours and compositions of an Islamic production site collection and comparative typologically coherent collections.

3. Materials & methods

Although Kawd am-Saila has long been recognised as a c.14th–16th century glass bangle workshop with evidence of glass furnaces and production waste, its glass has never previously been analysed. In 2021, Simpson identified an overlooked collection in the Department of the Middle East comprising 138 glass bangle fragments, one glass vial and two waste fragments from Kawd am-Saila. These surface finds were collected in 1965 by Philip Cambridge while stationed with the British RAF in Aden, and donated to the British Museum in 1995 (Figs. 2 and 3). Twenty representative fragments were selected from this assemblage for analysis, together with four typologically similar fragments from nearby al-Karf Road collected in 1938 by Harold Ingrams and donated by his daughter to the British Museum in 2012 (Fig. 2). All are of the same typological styles illustrated by Monod (1978). However, the published descriptions and illustrations do not fully convey the distinctive appearance of the glass and frit coating, either macroscopically and under magnification, which further supports earlier observations of a workshop with a characteristic production technique.

The typologically comparative collection of 13 glass bangle fragments from Somaliland were collected during surveys and excavations of 17 sites dating primarily to the 15th–16th centuries led by Alexander Tancred Curle (OBE) between 1930 and 1940 in the historic Zeila region on the then Ethiopian-Somaliland border. They were donated to the British Museum Department of Africa, Oceania and the Americas (AOA) in 1935 (Fig. 4) (Clifford, 1936; Curle, 1937: 315, 322; Torres Rodriguez, 2022). Zeila is an area of Somaliland surrounding the major trade port on the Gulf of Aden, connecting the Horn of Africa with the western Indian Ocean trade network and neighbouring Yemen (Curle, 1937: 321). Additionally, two complete bangles from Somaliland were also donated to the AOA amongst a miscellaneous collection in 1933 by Colonel H.G.C Swayne, thought to have been a contemporary set acquired from a bazaar during the 1890s (Swayne, 1895) (Fig. 3). They are of the same design and colour as one of the fragments from Kawd am-Saila (KAS.22), which is notably different from the others found at the production site. These intact samples were therefore analysed to determine whether they were compositionally distinct from the other visually different looking fragments and compositionally coherent with KAS.22 of the same design, which may therefore indicate it is an intrusive find.

Scanning electron microscopy with energy dispersive X-ray spectrometry (SEM-EDX) and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) have proven to be extremely successful for identifying different compositional groups of Islamic glass in recent years (Freestone, 2002; Henderson et al., 2004; Henderson et al., 2016; Schibille et al., 2018; Schibille, 2022; Meek et al., 2025).

³ Plant-ash (and treated soda-ash and mineral soda) is well documented as a widely traded commodity for not only glassmaking but soap, textiles and paper manufacture throughout the medieval Islamic period, whereas heavy raw silica sources for ordinary glass production are generally understood to have been obtained locally.



Fig. 2. Glass bangles collected by Philip Cambridge from the production site of Kawd am-Saila (KAS) in Aden in 1965 and those collected from al-Karf Road (AKR) in Aden (Yemen). Image © Nash-Pye, © The Trustees of the British Museum. (For a colour version of this image, the reader is referred to the Web version of this article.)

Twenty fragments were selected for scientific analysis to represent the different designs and colour combinations observed amongst the Kawd am-Saila collection.⁴ These selected samples, and the four from nearby al-Karf Road (AKR), registered at the British Museum were first analysed using SEM-EDX at the Department of Scientific Research in the British Museum. Small fragments from the selected Kawd am-Saila and al-Karf Road bangles were mounted in resin blocks, polished and carbon coated for analysis. The mounted samples were also analysed by LA-ICP-MS at IRAMAT-CEB, Orléans (France). For details of the analytical protocol and calculation of quantitative data see [Gratuze \(2016\)](#) and [Schibille](#)

[et al. \(2024\)](#).

Analysis on the collections from Somaliland were carried out at the Institute of Archaeology, University College London on an Applied Spectra J200 Tandem LA/LIBS system coupled to an Agilent 7900 quadrupole ICP-MS ([Fig. 4](#)). The tuning procedure is outlined in [Charlton and Miše \(2024\)](#). The beam diameter was set to 50 µm with the repetition rate of the laser set at 12 Hz. Three ablation spots were chosen 0.2 mm apart and data collection was preceded by a pre-ablation of at least 20 s to avoid readings from corroded glass on the exterior. The calibration and quantification procedure is detailed in [Charlton and Miše \(2024\)](#), following the internal standardisation method of [Gratuze \(2016\)](#) and using a linear regression model for calculating the response factor of [Neff \(2012, 2017\)](#). Five SRMs were used for calibration. Sheffield 3 and Corning glasses A and D were used because of their

⁴ Where possible, different colours in polychrome samples were also analysed, although this proved difficult with the frit-coated colours.

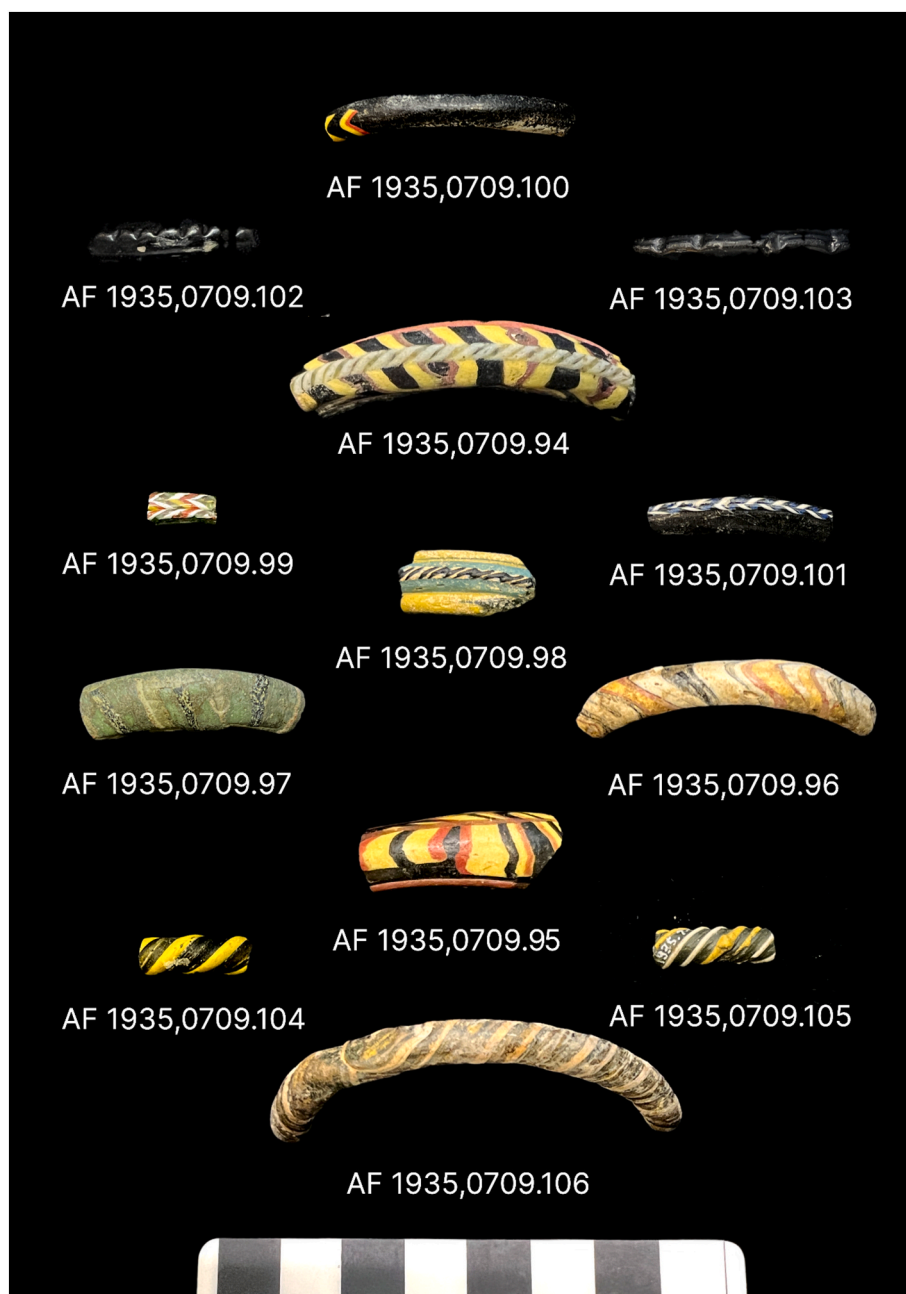


Fig. 3. Glass bangles collected from 15th–16th century sites in Somaliland during the early 20th century by Alexander Tancred Curle. Image © Nash-Pye, © The Trustees of the British Museum. (For a colour version of this image, the reader is referred to the Web version of this article.)

similarity in composition to ancient glasses. NIST 610 and 614 contain elements in trace amounts that are lower than (or not present in) the Corning glasses. Analytical accuracy and precision for both collections were assessed through repeated analyses of certified reference materials (Corning B and NIST SRM 612). Major and minor elements generally showed accuracies within approximately 5% of accepted values and relative standard deviations of <5%, while most trace elements showed accuracies within approximately 10% of accepted values (see Supplementary Data Standards). Trace-element concentrations were normalised to Upper Continental Crust (UCC) values after Rudnick and Gao (2003).

This study adopts an exploratory, plot-based comparative approach to define and test compositional groupings first and uses PCA as a secondary tool to assess separation between established and newly defined groups. Multiple elements were manually compared, with particular

attention given to major oxides SiO_2 , Al_2O_3 , CaO , Fe_2O_3 , TiO_2 , Na_2O , MgO , P_2O_5 and K_2O (wt% oxide) and trace elements Zr, Cr, Sr, B, Li and Cs (ppm), including the REEs.⁵ Identifying the origin of these components is not always clear and it is acknowledged that some are (or can be) introduced by either the glass former, stabilisers or modifiers. In plant-ash glasses strontium, for example, can be imparted based on the plant's environment and ashing process but is also present in mineral-based glasses, indicative of the geological origin and processing of the silica employed. Thus, the chosen suite of elements provides a range of variables that allow known plant-ash glass compositions from across the

⁵ Only elements exhibiting the greatest compositional variability and discriminatory power between groups were retained for PCA and the principal comparative plots.



Fig. 4. Complete set of glass bangles acquired from a bazaar in Somaliland in the late 19th century by Colonel H.G.C Swayne and four compositional outlier fragments from Kawd am-Saila, Yemen. Image © Nash-Pye, © The Trustees of the British Museum. (For a colour version of this image, the reader is referred to the Web version of this article.)

Middle East to be plotted as comparative baselines.

4. Results

Scientific analysis reveals a unique soda-lime-silica plant-ash-based glass composition for 83% of the samples from Kawd am-Saila (c. 14th–16th century), hereafter referred to as ‘KAS’ glass (Table 1). Plotting key elements of KAS against established Islamic regional glass groups shows that they differ significantly from other known plant-ash compositions but are compositionally consistent with the four surface finds from nearby al-Karf Road (AKR) and the small collection from Somaliland (15th–16th century). The most notable characteristic of KAS glass is elevated alumina concentrations (>4 wt%), ranging between c. 4–9 wt% Al_2O_3 (mean c. 4.5 wt%). Across the analysed samples TiO_2

concentrations range from c. 0.25–0.40 wt%, Fe_2O_3 from c. 1.3–2.1 wt%, and Zr from c. 95–140 ppm, with light rare earth elements (LREEs) consistently elevated and internally coherent (La 11–18 ppm; Ce 22–35 ppm; Pr 2.3–4.5 ppm; Nd 9–17 ppm).⁶ Strontium concentrations are moderate (c. 300–460 ppm), while chromium remains relatively constrained (c. 25–40 ppm), producing stable Cr/La ratios. Potash contents are low (K_2O c. 1.8–3.2 wt%), whereas magnesia is comparatively elevated (MgO c. 4.5–6.5 wt%), resulting in MgO/CaO ratios clustering around unity. Variability within the KAS group is limited and

⁶ LREE is used here in the conventional sense for the early lanthanides; in this study we highlight La–Nd (La, Ce, Pr, Nd), which are consistently elevated in the KAS group.

Table 1

Compositional results of analysed glass bangles from medieval sites Kawd am-Saila and al-Karf Road, Yemen, various contemporary sites in Somaliland with associated object information, typology and figure references.

Site	Object No	Composition	Bangle type	Colour	Diameter	Figure
Kawd am-Saila, Yemen	KAS.1: 1995,0229.151	KAS	Impressed notch vertical lines; domed Sections (F4b-S2a)	Glossy black-looking	4.5 cm	2
Kawd am-Saila, Yemen	KAS.2: 1995,0229.152	KAS	Impressed, tool or moulded squares; peaked cross section (F1c-S2b)	Glossy black	6 cm	2
Kawd am-Saila, Yemen	KAS.3: 1995,0229.153	m-Na-Al 2	Impressed notch vertical lines; peaked sections (F4a-S2b)	Glossy black	4.5 cm	4
Kawd am-Saila, Yemen	KAS.4: 1995,0229.154	KAS	Plain and featureless; domed section (A1a-S2b)	Glossy dark blue	6.5 cm	2
Kawd am-Saila, Yemen	KAS.5: 1995,0229.155	KAS	Plain and featureless; two flat domed canes (A1b-S3b)	Glossy dark moss green	7 cm	2
Kawd am-Saila, Yemen	KAS.6: 1995,0229.156	KAS	Plain with notable streaking; domed section (A2a-S2a)	Glossy moss green	5 cm	2
Kawd am-Saila, Yemen	KAS.7: 1995,0229.157	KAS	Plain with notable streaking; domed section (A2a-S2a)	Glossy dark moss green	6.5 cm	2
Kawd am-Saila, Yemen	KAS.8: 1995,0229.158	KAS	Plain with notable streaking; domed section (A2a-S2a)	Glossy moss green	6.5 cm	2
Kawd am-Saila, Yemen	KAS.9: 1995,0229.159	KAS	Plain with notable streaking; peaked section (A2a-S2b)	Matt bright green	5 cm	2
Kawd am-Saila, Yemen	KAS.10: 1995,0229.160	KAS	Streaked colour coated with trail prunts; domed section (E2b-S2a)	Dark with matt red and yellow	5.5 cm	2
Kawd am-Saila, Yemen	KAS.11: 1995,0229.161	KAS	Streaked colour coated with trail prunts; domed section (E2b-S2a)	Dark with matt red and yellow and white	5 cm	2
Kawd am-Saila, Yemen	KAS.12: 1995,0229.162	KAS	Colour coated raised central cane with trail prunts; layered two flanking canes section (E2c-S3c)	Dark with matt red and yellow	4.5 cm	2
Kawd am-Saila, Yemen	KAS.13: 1995,0229.163	KAS	Coloured coated with trail prunts; two domed section (E1c-S3b)	Dark with matt red and yellow	5 cm	2
Kawd am-Saila, Yemen	KAS.14: 1995,0229.164	KAS	Coloured coated streaks and trail prunts; domed section (E2a-S2a)	Dark with matt red and yellow	5 cm	2
Kawd am-Saila, Yemen	KAS.15: 1995,0229.165	KAS	Coloured coating splash; two domed section (E1d-S3b)	Glossy moss green with matt yellow	7 cm	2
Kawd am-Saila, Yemen	KAS.16: 1995,0229.166	Western Khurasan	Marvered twist, three cane, chevron; flat section (C3d-S2c)	Dark with matt red and yellow	5 cm	4
Kawd am-Saila, Yemen	KAS.17: 1995,0229.167	KAS	Raised speckled (crumb); domed section (D1a-S2a)	Dark with matt red	6.5 cm	2
Kawd am-Saila, Yemen	KAS.18: 1995,0229.168	KAS	Coloured coating splash; three domed section (E1d-S3c)	Dark with matt yellow	7 cm	2
Kawd am-Saila, Yemen	KAS.19: 1995,0229.169	m-Na-Al 2	Marvered large, flattened dots; trapeze section (C1b-S2c)	Dark blue with red	5 cm	4
Kawd am-Saila, Yemen	KAS.20: 1995,0229.170	KAS	Coated mock marvered twist, pattern; layered two flanking cane section (E3a-S3c)	Dark with matt red and yellow	5 cm	2
Kawd am-Saila, Yemen	KAS.21: 1995,0229.171	KAS	Coated flat trail prunts; domed section (E2c-S2a)	Dark with matt red and yellow	5 cm	2
Kawd am-Saila, Yemen	KAS.22: 1995,0229.172	m-Na-Al late 19th century	Marvered twist, central cane flat waved and dual cane either side; flat section (C3f-S2c)	Natural colourless with glossy orange, yellow and black	6 cm	4
Kawd am-Saila, Yemen	KAS.23: 1995,0229.173	KAS	Coated coloured streaks; domed section (E1b-S2a)	Dark with matt green décor	5.5 cm	2
Kawd am-Saila, Yemen	KAS.24: 1995,0229.174	KAS	Twisted with trails; round section (B2a-S1a)	Black with matt white trail	5.5 cm	2
Al-Karf Road, Yemen	AKR.1: 2012,6029.84	KAS	Plain streaked; peaked section (A2a-S2b)	Dark, corroded	5.5 cm	2
Al-Karf Road, Yemen	AKR.2: 2012,6029.85	KAS	Marvered flattened canes with inlays; flat section (C5a-S2c)	Glossy black with yellow, red and white décor	6 cm	2
Al-Karf Road, Yemen	AKR.3: 2012,6029.86	KAS	Plain streaked; peaked section (A1-S2a)	Dark, corroded	5.5 cm	2
Al-Karf Road, Yemen	AKR.4: 2012,6029.87	KAS	Coated streaks and lines; domed section (E1b-S2a)	Dark with yellow décor	4.5 cm	2
Somaliland	(AF094) Af1935,0709.94	KAS	Coated mock marvered twist, pattern and twisted central cane; layered two flanking cane section (E3a-S3c)	Dark with matt red and yellow	5 cm	3
Somaliland	(AF095) Af1935,0709.95	KAS	Coated mock marvered twist, pattern and twisted central cane; layered two flanking cane section (E3a-S3c)	Dark with matt red and yellow	5 cm	3
Somaliland	(AF096) Af1935,0709.96	KAS	Coated mock marvered twist, pattern and twisted central cane; layered two flanking cane section (E3a-S3c)	Corroded dark with yellow, red and white	4 cm	3
Somaliland	(AF097) Af1935,0709.97	KAS	Coated mock marvered twist, pattern and twisted central cane; layered two flanking cane section (E3a-S3c)	Corroded dark with mint green and white	4 cm	3
Somaliland	(AF098) Af1935,0709.98	KAS	Coated raised central cane with central zigzag trail; layered two flanking canes section (E3a-S3c)	Dark moss green core with matt mint green, yellow, white and black	NA	3
Somaliland	(AF099) Af1935,0709.99	KAS	Marvered flat three cane twist central cane (zigzag); flat section (C3c-S2c)	Transparent light green core with colourless, white, yellow and red twist	NA	3

(continued on next page)

Table 1 (continued)

Site	Object No	Composition	Bangle type	Colour	Diameter	Figure
Somaliland	(AF100)	KAS	Coated mock marvered inlay vertical curved on core cane; domed section (E4a-S2a)	Dark glossy black core with yellow and red decoration	4.5 cm	3
Somaliland	(AF101)	KAS	Marvered flat two cane central twist (arrow design)	Dark glossy black core with white and blue	5.5 cm	3
Somaliland	(AF102)	KAS	Impressed notch vertical lines; domed Sections (F4b-S2a)	Glossy black	NA	3
Somaliland	(AF103)	KAS	Impressed notch vertical lines; domed Sections (F4b-S2a)	Glossy black	5.5 cm	3
Somaliland	(AF104)	KAS	Surface wrapped twisted trail; round section (E2a-S1a)	Matt black with matt yellow	NA	3
Somaliland	(AF105)	KAS	Twisted trails; round section (E2a-S1a)	Matt black with matt yellow and white	4 cm	3
Somaliland	(AF106)	KAS	Twisted trails; round section (E2a-S1a)	Corroded black with corroded red-brown and yellow	5.5 cm	3
Bazaar, Somaliland	(AF87)	m-Na-Al late 19th century	Marvered twist, central cane flat waved; flat section (C3f-S2c)	Natural colourless with glossy orange wash, yellow and black (brown?)	6.5 cm	4
Bazaar, Somaliland	(AF88)	m-Na-Al late 19th century	Marvered twist, central cane flat waved; flat section (C3f-S2c)	Natural colourless with glossy orange, yellow and black (brown?)	6.5 cm	4

does not define sub-groups, with observed dispersion primarily affecting minor and trace elements rather than the major compositional framework (Table 2; Fig. 5).⁷ The elements were chosen as they have been shown to reliably distinguish composition groups based on raw materials used for the base glass (Henderson et al., 2016; Schibille, 2022; Freestone, 2023).

When compared with other known high-alumina plant-ash glasses from Central Asia, KAS glass is notably higher in titanium (mean 0.3 wt % TiO₂) but lower in silica (averaging 55 wt% SiO₂). The composition of the plant-ash component also deviates significantly, with KAS glass showing lower potash concentrations (c. 2.5 wt%) but higher magnesia (~5 wt%) compared to Central Asian glass from Merv (Meek et al., 2025). The relationship between Al₂O₃ and the MgO/CaO ratio is particularly effective in distinguishing regional plant-ash glass traditions, as it reflects differences in both silica mineralogy and plant-ash recipes. While elements such as Al, Ca and Mg may each be introduced via either the silica source or the plant-ash, the elevated alumina observed in these compositions exceed typical concentrations reported for plant-ash alone (Henderson et al., 2004, 2016), indicating a dominant contribution from the silica component, supplemented by the ash flux.

By contrast, elevated MgO remains chiefly controlled by the composition of the plant-ash flux. Consequently, MgO/CaO ratios capture meaningful technological and geological variation while remaining sensitive to multiple inputs. This demonstrates that similar ratios can arise through different combinations of geological and technological pathways (raw materials and production practices), reinforcing that no single ratio is diagnostic in isolation. For example, 'Eastern Mediterranean' glasses typically display reduced MgO/CaO ratios, consistent with the combined effect of lime-rich calcareous silica sources and a comparatively limited contribution from Mg-rich ash. 'Eastern Khurasan' (Central Asian) v-Na-Al glasses also display low MgO/CaO ratios, but in this case due to low absolute concentrations of both CaO and MgO, associated with alumina-rich, non-calcareous silica sources and ash recipes that are not Mg-rich. By contrast, 'Mesopotamian' glasses exhibit comparatively elevated MgO/CaO ratios, reflecting a greater relative influence of Mg-rich plant-ash alongside lower lime input from the silica source. The newly defined 'South Arabian' glass combines an alumina-rich silica signature with elevated MgO/CaO ratios, indicating a relatively stronger contribution from Mg-rich plant-ash alongside reduced lime input from the silica.

Trace-element contrasts further distinguish KAS and CA1 glasses, with KAS enriched in TiO₂, Fe₂O₃, Zr and LREEs reflecting iron- and

heavy-mineral-bearing sediments, whereas CA1 shows higher CaO, Sr and Cr/La ratios, consistent with carbonate-influenced alluvial and aeolian silica sources. A clearer differentiation can, therefore, be seen when using principal component analysis (PCA) to plot these compositional groupings (Fig. 6). A minor separation within the Somaliland KAS samples was observed along a secondary PCA axis (PC2), driven primarily by variability in Zr, Th and rare earth elements (REEs) (Fig. 7). However, this divergence accounts for a small proportion of total variance and reflects variation in a limited subset of elements (compared to PC1, which incorporates multiple major and minor components), and shows no correlation with typology, colour, or object-level sampling. It is therefore interpreted as reflecting minor batch-level or local sedimentary variation rather than a distinct production group.⁸

Four samples (KAS.3, KAS.16, KAS.19 and KAS.22) analysed from the Kawd am-Saila collection at the British Museum are compositionally distinct from the main KAS group (see Fig. 4). Only KAS.16 contains a plant-ash flux and is most similar to 'Western Khurasan' compositions, such as earlier G1–2 glasses from northeast Iran and so-called 'Low Zr' glass from Siraf, Iran (Swan et al., 2017; Schibille et al., 2022). Typologically, it also differs, appearing to be marvered (Type C) rather than a frit-coated design (Type E). The remaining three Kawd am-Saila outliers are high-alumina mineral soda (m-Na-Al) glasses with <1.5 wt% MgO and >4 wt% Al₂O₃ and are therefore South Asian in character (Dussubieux et al., 2010). KAS.3, KAS.19 and KAS.22 do not match in their entirety any fully published m-Na-Al subtype compositions to date. However, the typologically coherent suspected late 19th-century KAS.22 fragment and the intact 1890s Somaliland pair group together and differ from the other South Asian (m-Na-Al) fragments, indicating a chronological shift in silica source and, thus, origin.

5. Discussion

Glass compositions from the Islamic Middle East that show no evidence of recycling or mixing, are neither modern nor imported, and fall outside the regional compositional framework established by Nash-Pye et al. (2025), are likely to represent production regions that have yet to be geochemically characterised. As the KAS glass does not correspond with any currently recognised Islamic glass production group, the compositional consistency of much of the material analysed in this study supports the identification of a coherent production-site assemblage. Given that Kawd am-Saila was a known glass workshop and Yemen was an area with a history of glass production and export from at least the

⁷ The results represent what is understood to be natural levels of variation within a coherent group for each element presented.

⁸ Future analysis incorporating a larger Somaliland dataset and additional suspected bangle production sites in the Aden region may allow this minor variability to be evaluated further.

Table 2

Average compositions and standard deviations of glass bangle fragments from production site in Kawd am-Saila (KAS) in Yemen, nearby site al-Karf Road, Yemen and bangle fragments from Somaliland using the two sets of LA-ICP-MS data. Both core and decorative glass is included, and Oxides and Cl are given as wt%.

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	Mg/CaO	Mg/K ₂ O
Kawd am-Saila KAS	Avg n = 31	19.1	5.76	5.60	55.3	0.36	0.62	2.66	5.40	0.32	0.20	1.65	2.20
	StDev	1.6	0.85	1.04	2.79	0.06	0.14	0.46	0.63	0.05	0.41	0.24	
Al-Karf Road KAS	Avg n = 7	19.3	5.65	5.43	54.4	0.35	0.64	2.59	5.60	0.31	0.34	1.53	2.20
	StDev	2.1	0.57	0.98	2.37	0.05	0.09	0.27	0.64	0.02	0.37	0.09	
Somaliland KAS	Avg n = 23	19.0	5.09	5.06	55.4	0.36	–	2.26	4.78	0.37	0.37	1.90	1.91
	StDev	2.2	0.81	1.19	4.29	0.07	–	0.43	0.78	0.09	0.58	0.35	

Site	Li	Cr	Rb	Sr	Zr	La	Ce	K ₂ O/P ₂ O ₅	Cr/La
Kawd am-Saila KAS	Avg n = 31	7.47	30.6	30.6	382	110	14.3	27.7	7.28
	StDev	0.87	4.88	4.93	53.9	9.63	2.03	3.80	
Al-Karf Road KAS	Avg n = 7	6.73	32.0	29.6	369	111	14.4	27.7	7.46
	StDev	0.58	1.96	3.67	48.7	4.14	1.79	3.11	
Somaliland KAS	Avg n = 23	7.43	32.1	23.2	382	121	15.0	30.5	7.53
	StDev	1.23	6.53	9.76	86.6	18.1	2.31	4.55	2.14

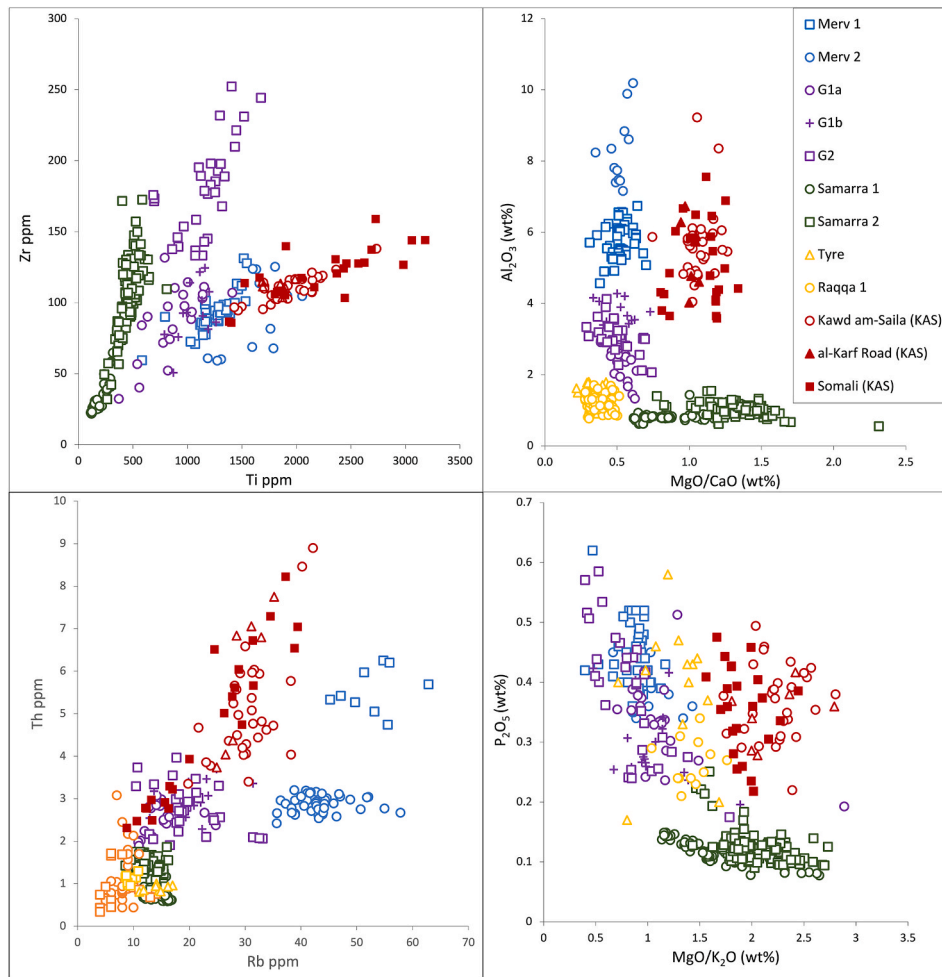


Fig. 5. Results based on combined LA-ICP-MS data. Elements separate the major regional glass groupings Eastern Mediterranean in yellow, Mesopotamia in green, Western Khurasan in purple and Eastern Khurasan in blue. Data: Eastern Mediterranean in yellow, represented by Tyre in Lebanon (Freestone, 2002), al-Raqqa 1 in Syria (Henderson et al., 2004), Samarra 1 and 2 in Iraq (Schibille et al., 2018), G1a-b and G2 from Iran (Schibille et al., 2022), Merv 1 and Merv high-alumina from Turkmenistan (Meek et al., 2025). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

c.12th century (trans. Hirth and Rockhill, 1911: 120, 227), a reasonable interpretation is that KAS glass represents a previously uncharacterised category of South Arabian production. A small quantity of glass bangle fragments from various Persian Gulf sites with the same visual characteristics have likewise been visually identified by the lead author as part of a wider doctorate project, including several fragments from Qalhat in Oman and Qal'at al-Bahrain. One fragment identified from Siraf, Iran

and one from Julfar, UAE were also analysed using LA-ICP-MS and found to be of the same KAS composition, results of which will be published in due course.

The most instantly definable characteristic of KAS glass is elevated alumina concentrations (c. >4 wt%), usually associated with the region of Central Asia (see Dussubieux et al., 2010; Swan et al., 2017: 110; Siu et al., 2020; Schibille, 2022; Nash-Pye et al., 2025). Other known

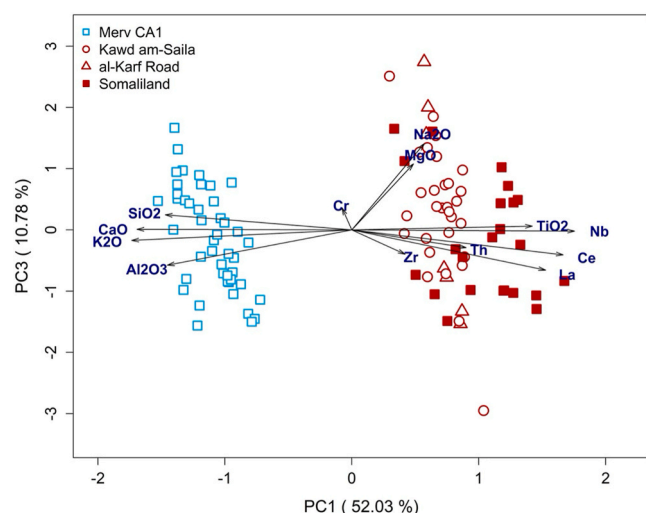


Fig. 6. PCA results based on combined LA-ICP-MS data of two known v-Na-Al glass groups with different silica sources, CA1 in blue and KAS in red separated primarily through minor trace elements. Data: Merv 1 (CA1) (Meek et al., 2025). The percentages on the axis correspond to how much each principal component contributes to the total variation. The elements were chosen as they have been shown to reliably show differences between composition groups based on raw materials used for the base glass. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

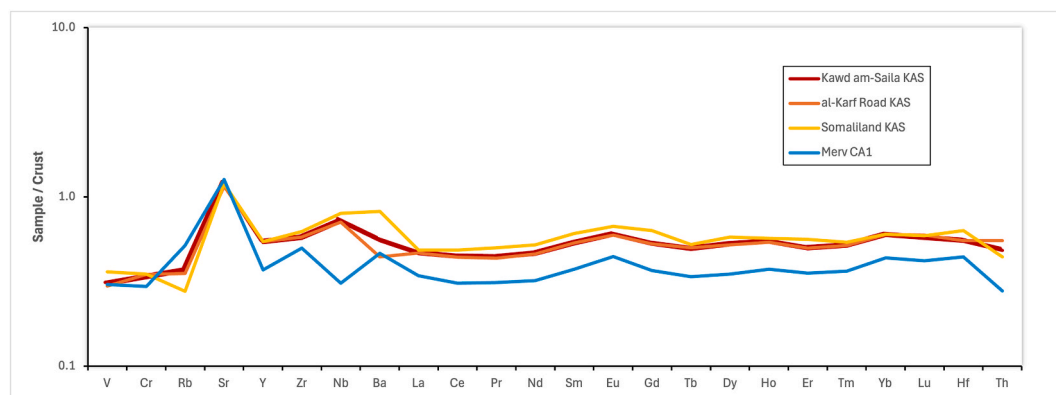


Fig. 7. Upper Continental Crust (UCC)-normalised multi-element spider diagram demonstrating the compositional coherence of the proposed KAS groups, particularly across the rare earth elements (REEs). UCC normalisation values after Rudnick and Gao (2003). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

v-Na-Al Islamic glass bangles, such as those from Ghazni in Afghanistan (GH02 is CA2 type and GH04 and GH22 are CA1 glass) and those from Siraf in Iran (CA2) are of these Central Asian compositions (Swan et al., 2017; Fiorentino et al., 2019). Although nine v-Na-Al glass bangle samples from Tell Abu Sarbut and Khirbat in Jordan (Boulogne and Henderson, 2009) were found to differ from the Central Asian samples (Nash-Pye et al., 2025), they also differ both typologically and compositionally from the proposed South Arabian group from Kawd am-Saila (Fig. 8a and b). Their extremely elevated titanium content thus represents an entirely alternate silica source from these proposed production regions, suggesting that ‘high-alumina glasses’ were likely more widespread than current publications indicate and not diagnostic in isolation for provenance attribution.

Nonetheless, to entirely rule out a possible imported Central Asian glass variant, detailed comparisons between KAS and CA1, the largest known published group of high-alumina plant-ash glass (v-Na-Al), were undertaken (Nash-Pye et al., 2025). CA1 was identified in its highest

concentrations (48 analysed fragments) in assemblages from the Merv vicinity in Turkmenistan, which has average values of c. 6 wt% Al_2O_3 , 0.22 wt% TiO_2 and 96 ppm Zr (Meek et al., 2025). Although also high in alumina (>4 wt%), CA1 differs from KAS glass in having higher K_2O and CaO, lower Na_2O and TiO_2 , and a distinct trace-element profile characterised by elevated Sr, Zr and Cr. These differences demonstrate that similar alumina-rich plant-ash compositions can arise from distinct local sedimentary regimes (Meek et al., 2025; Nash-Pye et al., 2025). Its compositional signature indicates an alumina-rich silica source derived from mixed sediments, including feldspathic and carbonate-rich components, consistent with Central Asian sedimentary regimes in which loessic and alluvial-aeolian deposits contribute elevated Al_2O_3 (Schaeztl et al., 2018; Ghassemi and Garzanti, 2019; Li et al., 2025). CA1 glass is most plausibly compatible with silica derived from locally available sediments associated with an oasis setting, making the Merv (Murghab) oasis where the city of Merv is situated a strong contender, although this hypothesis has yet to be verified through direct geological or mineralogical analysis of potential silica sources.

By contrast, the KAS glass exhibits a distinct major- and trace-element pattern consistent with alumina-bearing feldspathic and iron-rich sediments accessible in southern Yemen. The elevated alumina content of the KAS glass requires a silica source that was intrinsically alumina-bearing, excluding quartz-pure sands and pointing instead to feldspathic and clay-bearing sediments.⁹ Microstructural features such as incomplete melting, abundant bubbles, and chemical heterogeneity further indicate production under relatively low peak temperatures and/or short firing durations, relative to the demands of the raw materials, rather than a single fixed temperature threshold. Under such conditions,

reduced dissolution kinetics, slower diffusion and inhibited bubble escape preserve the heterogeneous, bubble-rich microstructures observed in the KAS glass, insufficient to fully dissolve mineral inclusions or allow complete diffusive homogenisation (El-Anbaawy, 1985). These features are consistent with the use of ‘readily meltable’ sands in traditional furnaces, meaning compositionally impure, feldspathic and clay-bearing sands rich in alumina and iron, associated with low peak temperatures and/or short firing durations, while simultaneously promoting chemical heterogeneity under traditional furnace conditions (Shelby, 2005; Henderson, 2013).

In the Aden region, such materials would have been readily accessible within a short-distance procurement radius, particularly alumina-

⁹ ‘Feldspathic’ is not intended to imply a specific feldspar endmember; given the low K_2O of the KAS glass, a dominant K-feldspar contribution is unlikely, and any feldspar input is more plausibly plagioclase-rich, pending mineralogical confirmation.

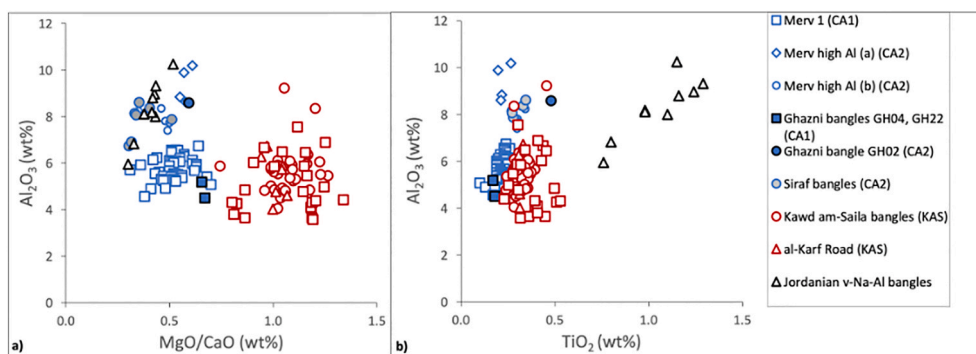


Fig. 8. Charts of Al_2O_3 and MgO/CaO and Al_2O_3 and TiO_2 concentrations in CA1-2 type bangles identified from Afghanistan and Iran, and KAS 2 type bangles identified from Yemen and Somaliland compared with those identified from Jordan. Data: British Museum bangles from Siraf in Iran (Nash-Pye et al., 2025); Bangles from Ghazni in Afghanistan (Fiorentino et al., 2019); v-Na-Al bangles from Tell Abu Sarbut and Khirbat Faris in Jordan (Boulogne and Henderson, 2009); Merv 1 and high Al in Turkmenistan (Meek et al., 2025). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

bearing feldspathic alluvial sands derived from wadi systems draining the western Yemeni highlands and volcanoclastic sediments associated with the Aden volcanic province (Baker et al., 1997; Garzanti et al., 2003, 2013; Ghandour et al., 2019). These kinds of mixed quartz–feldspar–clay sediments naturally contribute elevated Al_2O_3 alongside Fe_2O_3 and TiO_2 and require little or no beneficiation beyond basic selection and crushing, as they already contain network-modifying components within the sand matrix and reduce the dependence on highly purified quartz within an otherwise plant-ash-fluxed recipe. While alumina acts as a network former and increases melt viscosity once glass is formed, its presence within feldspathic and clay-bearing sands can facilitate vitrification under traditional furnace conditions when such sands replace high-purity quartz in otherwise comparable plant-ash recipes.

The KAS plant-ash component also differs from other known Islamic compositions and may reflect locally available halophytic plants in Yemen. One candidate is *Salicornia*, particularly *Salicornia fruticosa* (syn. *Sarcocornia fruticosa*), a highly salt-tolerant glasswort native to Yemen's coastal wetlands, salt marshes and saline mudflats (Al-Hawshabi and El-Naggar, 2015; WFO, 2026a). *Suaeda* species (sea-blites), including *Suaeda vermiculata* and *Suaeda aegyptiaca*, are also widespread along the Yemeni coast, representing another possibility. Alternatively, members of the *Salsola* genus (saltworts), such as *Salsola imbricata* (syn. *Caroxylon imbricatum*) and *Salsola kali*, are common across the Arabian Peninsula and Yemen's arid and semi-arid environments (WFO, 2026b). However, identifying specific taxa from archaeological glass remains impossible at present without further experimental and environmental studies.

A small number of samples from Kawd am-Saila represent imported m-Na-Al glass rather than local production. These differ fundamentally from the KAS group in flux type and major-element behaviour, indicating a South Asian mineral soda tradition (Dussubieux et al., 2010). While recent work has expanded the number of recognised m-Na-Al subtypes (m-Na-Al 7–12), full compositional datasets remain limited, preventing secure attribution of the KAS outliers to a specific subtype (Trivedi and Dussubieux, 2022: 222; Trivedi and Dussubieux, submitted; Dussubieux and Walder, 2022: Appendix B, 17–18). However, elevated uranium concentrations in the later intact set (AF 1933,1114.87–88) from Somaliland and typologically coherent fragment (KAS.22) from Kawd am-Saila, are consistent with m-Na-Al subtypes associated with northern India, supporting a late import horizon distinct from the medieval KAS production (Trivedi and Dussubieux, 2022; Dussubieux et al., 2024).

6. Conclusion

The identification of a unique geochemical composition for the Kawd

am-Saila glass bangles (KAS), and the same composition for the typologically coherent collection from Somaliland, has major implications for the provenancing of Islamic glass bangles in the Middle East. The combined compositional and typological cohesion demonstrates that trade between the Aden and Zeila regions during the 15th–16th century included the export of glass bangles. The occurrence of ‘Yemeni-type’ bangles amongst numerous 14th–16th century assemblages across the western Indian Ocean trade network, including the Red Sea and Persian Gulf, supports a tentative attribution of these objects to the c. 14th–16th century workshop of Kawd am-Saila. Future analyses of western Indian Ocean Islamic glass assemblages may reveal a wider distribution of this South Arabian production tradition than is currently recognised. Despite sharing elevated alumina concentrations with Central Asian glasses (CA1–3), this paper demonstrates that KAS belongs to a different regional production tradition. Alumina enrichment alone is therefore insufficient as a diagnostic indicator of geochemical production-zone provenance and may instead reflect multiple independent local production traditions. The definition of KAS provides a new compositional reference point for the identification and provenancing of Islamic plant-ash glasses and highlights the importance of South Arabia as a previously unrecognised centre of medieval glass production within the western Indian Ocean.

CRediT authorship contribution statement

C.K. Nash-Pye: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **A. Meek:** Writing – review & editing, Validation, Supervision, Resources, Investigation, Formal analysis. **N. Schibille:** Writing – review & editing, Validation, Resources, Formal analysis. **L. Richards:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Formal analysis. **M. Charlton:** Validation, Resources.

Data availability statement

All raw data is shared through Mendeley: <https://data.mendeley.com/datasets/5cd2swxdnb> Published: 25 July 2026 | <https://doi.org/10.17632/5cd2swxdnb.2>.

Permitted AI use statement

During the preparation of this work, the authors used ChatGPT (OpenAI) to assist with the generation of map-plotting code and the visualisation of archaeological site coordinates for Fig. 1. The authors reviewed and verified all coordinates, outputs and figure content and

take full responsibility for the content of the published article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

This work was supported by the AHRC Collaborative Doctoral Award scheme (grant number AH/T002573/1).

Acknowledgements

The authors thank the British Museum for access to the glass bangle collections in the Departments of the Middle East (ME) and Africa, Oceania and the Americas (AOA). Analytical work was carried out at the British Museum, CNRS Orléans and the UCL Institute of Archaeology, and the authors are grateful to the technical staff at these institutions for their assistance. Thanks are due to curators Sam Nixon and St John Simpson for facilitating the study of these collections, and to Jorge de Torres Rodriguez for drawing attention to the Somaliland assemblage. We also thank Mark Taylor for sharing comparative reference data on glass compositions. Any necessary permissions for the study and publication of the material were obtained. This research was supported by an AHRC-funded Collaborative Doctoral Award (CDA) research studentship (AH/T002573/1) undertaken at the University of Kent and the British Museum.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jas.2026.106677>.

References

- Al-Hawshabi, O.S.S., El-Naggar, S.M.I., 2015. Vegetation patterns and floristic composition of Yemen. *Current Life Sciences* 1 (3), 103–111.
- Al-Jubeih, N., 2008. Hebron glass: a centuries-old tradition. *This Week in Palestine* 117. https://web.archive.org/web/20101225071134/http://imeu.net/news/article0077_01.shtml. (Accessed 25 January 2008).
- Ashtor, E., 1992. Levantine alkali ashes and European industries. In: Kedar, B.Z. (Ed.), *Technology, Industry and Trade: the Levant Versus Europe*, pp. 1250–1500 (475–522). Hampshire (VT): Variorum.
- Baker, J.A., Menzies, M.A., Thirlwall, M.F., Macpherson, C.G., 1997. Petrogenesis of quaternary intraplate volcanism, Sana'a, Yemen: implications for plume-lithosphere interaction and polybaric melt hybridization. *J. Petrol.* 38 (10), 1359–1390. <https://doi.org/10.1093/petroj/38.10.1359>.
- Barkoudah, Y., Henderson, J., 2006. Plant-ashes from Syria and the manufacture of ancient glass: Ethnographic and scientific aspects. *J. Glass Stud.* 48.
- Boulogne, S., Hardy-Guilbert, C., 2010. Glass bangles of al-Shihr, hadramawt (fourteenth–nineteenth centuries), a corpus of new data for the understanding of glass bangle manufacture in Yemen. *Proceedings of the Seminar for Arabian Studies* 40, 135–148.
- Boulogne, S., Henderson, J., 2009. Indian glass in the Middle East? Medieval and Ottoman glass bangles from central Jordan. *J. Glass Stud.* 51, 53–75.
- Brill, R.H., 1999. *Chemical Analyses of Early Glasses*. Corning Museum of Glass, Corning, NY, pp. 1–2.
- Charlton, M., Mîse, M., 2024. Application of LIBS and LA-ICP-MS analysis to Hellenistic tableware. *The European Physical Journal Plus* 139 (10), 945. <https://doi.org/10.1140/epjp/s13360-024-05558-5>.
- Chinni, T., Fiorentino, S., Silvestri, A., Mantellini, S., Berdimuradov, A.E., Vandini, M., 2023. Glass from the Silk roads: insights into new finds from Uzbekistan. *J. Archaeol. Sci.: Rep.* 48, 103841.
- Clifford, E.H.M., 1936. The British Somaliland–Ethiopia boundary. *Geogr. J.* 87 (4), 289–302.
- Curle, A.T., 1937. The ruined towns of Somaliland. *Antiquity* 11 (43), 315–327. <https://doi.org/10.1017/S0003598X00012928>.
- Doe, D.B., 1963. Pottery Sites near Aden, vols. 3–4. *Journal of the Royal Asiatic Society of Great Britain and Ireland*, pp. 150–162.
- Dussubieux, L., Gratuze, B., Blet-Lemarquant, M., 2010. Mineral soda alumina glass: occurrence and meaning. *J. Archaeol. Sci.* 37 (7), 1646–1655.
- Dussubieux, L., Kanungo, A.K., Singh, P.L., 2024. Elemental analysis of glass artifacts from Sarethi (India): examining possible evidence of glass craft in northeastern Uttar Pradesh. *J. Archaeol. Sci.: Rep.* 57, 104645.
- Dussubieux, L., Walder, H. (Eds.), 2022. *The Elemental Analysis of Glass Beads: Technology, Chronology and Exchange*. Leuven University Press, Leuven.
- El-Anbaawy, M.I., 1985. *Geology of the Yemen Arab Republic*. El-Topy Press, Cairo.
- Fiorentino, S., Venezia, B., Schibille, N., Vandini, M., 2019. Streams across the Silk Roads? The case of Islamic glass from Ghazni. *J. Archaeol. Sci.: Rep.* 25, 153–170.
- Freestone, I.C., 2002. Composition and affinities of glass from the furnaces on the island site, Tyre. *J. Glass Stud.* 44, 67–77.
- Freestone, I.C., 2023. The archaeometry of glass. In: Pollard, A.M., Armitage, R.A., Makarewicz, C.A. (Eds.), *Handbook of Archaeological Sciences*, second ed. Wiley, pp. 835–852.
- Gaborieau, M., 1977. Bracelets et grosses perles de verre. *Fabrication et vente en Inde et au Nepal*. *Objets et Mondes* 17 (1), 112–117.
- Garzanti, E., Andò, S., Vezzoli, G., Dell'era, D., 2003. From rifted margins to foreland basins: investigating provenance and sediment dispersal across desert Arabia (Oman, U.A.E.). *J. Sediment. Res.* 73, 572–588. <https://doi.org/10.1306/101702730572>.
- Garzanti, E., Vermeesch, P., Andò, S., Vezzoli, G., Valagussa, M., Allen, K., Kadi, K.A., Al-Juboury, A.I.A., 2013. Provenance and recycling of Arabian desert sand. *Earth Sci. Rev.* 120, 1–19. <https://doi.org/10.1016/j.earscirev.2013.01.005>.
- Ghandour, I., Basaham, A., Haredy, R., Manaa, A., Al-Rabaki, K., Bawahidi, K., 2019. Geochemistry of the gulf of Aden beach sands, Al-Mukalla, Yemen: provenance and tectonic setting implications. *Acta Geodyn. Geomater.* 16 (1), 55–69. <https://doi.org/10.13168/AGG.2019.0005>.
- Ghassemi, M.R., Garzanti, E., 2019. Geology and geomorphology of Turkmenistan: a review. *Geopersia* 9 (1), 125–140. <https://doi.org/10.22059/geope.2018.265613.648416>.
- Gmelin, J.F., 1776. Digitized and accessed via Plants of the World Online (POWO). In: *Onomatologia Botanica Completa*, vol. 8. Royal Botanic Gardens, Kew, p. 798. <https://www.ipni.org/n/1013557-1>. 2026.
- Goitein, S.D., 1974. *Letters of Medieval Jewish Traders*. Princeton University Press, Princeton, NJ.
- González-Ruibal, A., Torres, J. de, Fernández, M.A.F., Barrio, C.M., León Juberías, G. de, 2021. Asia in The Horn: the Indian Ocean trade in Somaliland. *Archaeological Research in Asia* 27, 100289.
- Gratuze, B., 2016. Glass characterization using laser ablation–inductively coupled plasma–mass spectrometry methods. In: Dussubieux, L., Golitko, M., Gratuze, B. (Eds.), *Recent Advances in Laser Ablation ICP-MS for Archaeology*. Springer, Heidelberg, pp. 179–196.
- Hansman, J.F., 1985. *Julfar, an Arabian Port: Its Settlement and far Eastern Ceramic Trade from the 14th to the 18th Century*. Royal Asiatic Society of Great Britain and Ireland, London.
- Harding, G.L., 1964. *Archaeology in the Aden Protectorates*. Her Majesty's Stationery Office, London.
- Hardy-Guilbert, C., 2005. The harbour of al-Shihr, Hadramawt, Yemen: sources and archaeological data on trade. *Proceedings of the Seminar for Arabian Studies* 35, 71–85.
- Hardy-Guilbert, C., Ducatez, G., 2004. Al-Shihr, porte du Hadramawt sur l'océan Indien. *Sources et Archéologie. Ann. Islam.* 38, 95–157.
- Henderson, J., 2013. *Ancient Glass: an Interdisciplinary Exploration*. Cambridge University Press, Cambridge.
- Henderson, J., Chenery, S., Faber, E., Kröger, J., 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. *Microchem. J.* 128, 134–152.
- Henderson, J., Evans, J., Barkoudah, Y., 2009. The roots of provenance: glass, plants and isotopes in the Islamic Middle East. *Antiquity* 83 (320), 414–429.
- Henderson, J., McLoughlin, S., McPhail, D., 2004. Radical changes in Islamic glass technology: evidence for conservatism and experimentation with new glass recipes from early and middle Islamic Raqqa, Syria. *Archaeometry* 46 (3), 439–468.
- Hirth, F., Rockhill, W.W., 1911. *Chau Ju-Kua: his work on the Chinese and Arab trade in the twelfth and thirteenth centuries, entitled chu-fan-chi*. St Petersburg: Printing Office of the Imperial Academy of Sciences.
- Ivleva, T., 2018. Romano-British glass bangles. (Roman Finds Group Datasheet 9) Newcastle newsletter article. <https://www.romanfindsgroup.org.uk/datasheets>. (Accessed 20 August 2023).
- King, G., Tonghini, C., 1996. *A Survey of the Islamic Sites near Aden and in the Abyan District of Yemen*. School of Oriental and African Studies, University of London, London.
- Korfmann, M., 1966. Zur Herstellung nahtloser Glasringe. *Bonn. Jahrb.* 166, 328–348.
- Lababidi, L., 2021. Lost Legacy of Bida bikini. *The British Museum — Media*. <https://doi.org/10.25420/britishmuseum.14535420.v1>.
- Lababidi, L., Babalola, A.B., Gratuze, B., Rolland, J., Véron, E., Canizares, A., 2023. The making of bikini glass in Bida, Nigeria: ethnography, chemical composition, and archaeology. *Afr. Archaeol. Rev.* 40 (2), 397–424. <https://doi.org/10.1007/s10437-022-09494-6>.
- Lambourn, E.A., 2018. A mediterranean Society at Sea. In: *Abraham's Luggage: a Social Life of Things in the Medieval Indian Ocean World*. Asian Connections. Cambridge University Press, pp. 161–251.
- Lane, A.L., Serjeant, R.B., 1948. Pottery and glass fragments from the Aden littoral, with historical notes. *J. R. Asiatic Soc.* 80 (3–4), 108–133.
- Li, Y., Song, Y., Fitzsimmons, K.E., et al., 2025. Geochemical evidence indicates that deserts are not the dominant source of loess in Central Asia. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 653, 112440. <https://doi.org/10.1016/j.palaeo.2025.112440>.
- Loret, L., 1884. *La Syrie D'Aujourd'Hui*. Hachette, Paris.
- Margariti, R.E., 2007. *Aden and the Indian Ocean trade: 150 years in the life of a medieval Arabian port*. University of North Carolina Press.
- Meek, A., Simpson, S.J., Schibille, N., 2025. Tracing glass production in urban centres along the silk roads in the early Islamic period. *iScience* 28, 111845. <https://doi.org/10.1016/j.isci.2025.111845>.

- Monod, T., 1975. À propos des bracelets de verre sahariens. *Bulletin de l'Institut Fondamental d'Afrique Noire* 37, 702–718.
- Monod, T., 1978. Sur un site à bracelets de verre des environs d'Aden. *Raydan* 1, 111–124.
- Nadel, S.F., 1940. Glass-making in nupe. *Man* 40, 85–86.
- Nash-Pye, C.K., Meek, A., Schibille, N., Simpson, S.J., 2025. High-alumina plant-ash (v-Na-Al) glass bangles from Siraf: clarifications on a Central Asian glass group (9th–14th century). *J. Archaeol. Sci.: Rep.* 62, 104970. <https://doi.org/10.1016/j.jasrep.2025.104970>.
- Neff, H., 2012. Laser ablation ICP-MS in archaeology. In: Lee, M.S. (Ed.), *Mass Spectrometry Handbook*. John Wiley and Sons, Hoboken, NJ, pp. 829–843.
- Neff, H., 2017. LA-ICP-MS analysis of pigments and slips from southern Chile. Technical report, Institute for Integrated Research in Materials, Environments, and Society, California State University, Long Beach.
- Perrot, G., Chipiez, C., Armstrong, W., 1885. *History of Art in Phoenicia and its Dependencies*. Chapman and Hall.
- Pirenne, J., 1976. Deuxième mission archéologique française au Hadramout (Yémen du Sud) de décembre 1975. *Comptes Rendus Séances Acad. Inscriptions Belles-Lett. (CRAI)* 120 (3), 412–426.
- Rehren, T., Osório, A., Anarbaev, A., 2010. Some notes on early Islamic glass in eastern Uzbekistan. In: Zorn, B., Hilgner, A. (Eds.), *Glass Along the Silk Road from 200 BC to AD 1000*. Mainz: Römisch-Germanisches Zentralmuseum, pp. 191–200.
- Révoil, G., 1883. Fours et ateliers d'émailleurs antiques à Cheikh-Othman, près d'Aden. *Revue d'Ethnographie* 2, 279–280.
- Rougeulle, A., 2015. Sharma: Un Entrepôt De Commerce Médiéval Sur la Côte Du Hadramawt (Yémen, Ca 980–1180), vol. 17. British Foundation for the Study of Arabia Monographs, Oxford.
- Rudnick, R.L., Gao, S., 2003. Composition of the Continental crust. In: Holland, H.D., Turekian, K.K. (Eds.), *Treatise on Geochemistry*. Elsevier-Pergamon, Oxford, pp. 1–64.
- Sankalia, H.D., Dikshit, M.G., 1952. Excavations at Brahmapuri (Kolhapur) 1945–56. Monograph Series, 5. Deccan College Post-Graduate and Research Institute, Poona.
- Schaetzl, R.J., Bettis, E.A., Crouvi, O., Fitzsimmons, K.E., Grimley, D.A., Hambach, U., Lehmkuhl, F., Marković, S.B., Mason, J.A., Owczarek, P., Roberts, H.M., Stevens, T., 2018. Approaches and challenges to the study of loess—Introduction to the LoessFest Special issue. *Quat. Res.* 89, 563–618. <https://doi.org/10.1017/qua.2018.21>.
- Schibille, N., 2011. Late byzantine mineral soda high-alumina glasses from Asia minor: a new primary glass production group. *PLoS One* 6 (4), e18970. <https://doi.org/10.1371/journal.pone.0018970>.
- Schibille, N., 2022. *Islamic Glass in the Making: Chronological and Geographical Dimensions*. Leuven University Press; Ithaca, NY: Cornell University Press, Leuven.
- Schibille, N., Klesner, C., Neuville, D.R., Stark, S., Torgoev, A.I., Mirzaakhmedov, S.J., 2024. Geochemical variations in early Islamic glass finds from Bukhara (Uzbekistan). *Geochemistry* 84 (1), 126078. <https://doi.org/10.1016/j.chemer.2024.126078>.
- Schibille, N., Lankton, J.W., Gratuze, B., 2022. Compositions of early Islamic glass along the Iranian Silk Road. *Geochem.* 82 (4), 125903. <https://doi.org/10.1016/j.chemer.2022.125903>.
- Schibille, N., Meek, A., Wypyski, M.T., Kröger, J., Rosser-Owen, M., Wade Haddon, R., 2018. The glass walls of Samarra (Iraq): Ninth-century abbasid glass production and imports. *PLoS One* 13 (8), e0201749. <https://doi.org/10.1371/journal.pone.0201749>.
- Seetzen, U.J., 1859. *Reisen durch Syrien, Palästina, Phönizien, die Transjordan Länder*. In: Kruse, F. (Ed.), *Arabia Petraea Und Unter-Aegypten*, vol. IV. Berlin: Reimer.
- Shelby, J.E., 2005. *Introduction to Glass Science and Technology*, second ed. Royal Society of Chemistry, Cambridge.
- Shindo, Y., 1987. Glass bracelets from the Fustat site in Egypt (Trans. Japanese). The Bulletin of the Graduate Division of Literature of Waseda University, Special Issue, issue 14, pp. 93–108.
- Shindo, Y., 2001. The classification of the Islamic glass bracelets from al-Tur, Sinai. In: *Senri Ethnological Studies*, vol. 55. National Museum of Ethnology, Osaka, pp. 73–100.
- Siu, I., Henderson, J., Qin, D., Ding, Y., Cui, J., Ma, H., 2020. New light on plant-ash glass found in Africa: evidence for Indian Ocean Silk Road trade using major, minor, trace element and lead isotope analysis of glass from the 15th–16th century AD from Malindi and Mambui, Kenya. *PLoS One* 15 (8), e0237612. <https://doi.org/10.1371/journal.pone.0237612>.
- Spaer, M., 1992. The Islamic glass bracelets of Palestine: Preliminary findings. *J. Glass Stud.* 23, 44–62.
- Swan, C.M., Rehren, T., Lankton, J., Gratuze, B., Brill, R.H., 2017. Compositional observations for Islamic glass from Siraf, Iran, in the Corning Museum of glass collection. *J. Archaeol. Sci.: Rep.* 16, 102–116. <https://doi.org/10.1016/j.jasrep.2017.08.020>.
- Swayne, H.G.C., 1895. *Seventeen Trips Through Somaliland: a Record of Exploration and Big Game Hunting, 1885 to 1893 Being the Narrative of Several Journeys in the Hinterland of the Somali Coast Protectorate, Dating from the Beginning of Its Administration by Great Britain Until the Present Time, with Descriptive Notes on the Wild Fauna of the Country*. London: R. Ward.
- Tite, Shortland, Maniatis, Kavoussanaki, Harris, 2006. The composition of the soda-rich and mixed alkali plant-ashes used in the production of glass. *J. Archaeol. Sci.* 33.
- Torres Rodriguez, J. de, 2022. The medieval archaeology of Somaliland. *Oxford Research Encyclopedia of Anthropology* (online). <https://doi.org/10.1093/acrefore/9780190854584.013.566>. Published 18 May 2022. (Accessed 29 July 2022).
- Torres Rodriguez, J. de, González-Ruibal, A., Franco Fernández, M.A., Gutiérrez de León Juberías, P., Martínez Barrio, C., Minguito Palomares, A., Jama, A.D., 2020. The 2020 field season at the medieval settlement of fardowsa (Somaliland). *Nyame Akuma* 93, 28–35.
- Trivedi, M., 2021. Glass bangles in South Asia: production, variability and historicity. In: Kanungo, A.K., Dussubieux, L. (Eds.), *Ancient Glass of South Asia – Archaeology, Ethnography and Global Connection*. Springer Nature and IIT Gandhinagar, Singapore and Gandhinagar.
- Trivedi, M., Dussubieux, L., 2022. Inland from the sea: rethinking the value of mineral soda alumina drawn glass beads from medieval North India. In: Dussubieux, L., Walder, H. (Eds.), *The Elemental Analysis of Glass Beads: Technology, Chronology and Exchange*. Leuven University Press, Leuven, pp. 221–244. <https://doi.org/10.2307/j.ctv2z9fzr0.16>.
- Trivedi, M. and Dussubieux, L. (submitted). Mineral Soda alumina glass revisited: new compositional groups and problems of supply, scale and use. *J. Archaeol. Sci.*
- Von Saldern, A., 1980. *Ancient and Byzantine glass from Sardis*. Cambridge University Press, Cambridge.
- WFO, 2026a. *Salicornia L.* Published on the Internet. <http://www.worldfloraonline.org/taxon/wfo-4000033839>. (Accessed 11 June 2026).
- WFO, 2026b. *Salsola L.* Published on the Internet. <http://www.worldfloraonline.org/taxon/wfo-4000033876>. (Accessed 11 June 2026).
- Whitcomb, D.S., 1988. Islamic archaeology in Aden and the Hadhramaut. In: Potts, D.T. (Ed.), *Araby the Blest: Studies in Arabian Archaeology*. Museum Tusculanum Press, Copenhagen, pp. 176–263.
- Whitcomb, D.S., Johnson, J.H., 1979. *Quseir al-Qadim 1978: Preliminary Report*. American Research Center in Egypt, Cairo and Princeton.