# Composition of glass Bracelets and Rings from the Ayyubid-Mamluk Cemetery at Dohaleh, north Jordan

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## Abstract

Twenty-six glass bracelets and three finger rings from an Ayyubid-Mamluk (1179-1517 CE) cemetery at Dohaleh, North Jordan, have been analysed by electron microprobe. They fall into six compositional groups, based upon their alkali- and silica-related components. Groups A and F were made using Levantine plant ash but differ in their silica sources, they are typically decolourised using manganese. Groups B, C and E overlap in terms of silica-related components but may be sub-divided on the basis of alkali source; this appears to have been a mineral soda, probably from Anatolia. A single bracelet (Group D) shows characteristics of Mesopotamian glass. All groups show evidence of tin-opacification, but the colour palette of the mineral soda glasses is more restricted; furthermore, they were not decolourised using manganese. The results suggest that glass bracelets were being obtained from a wide range of sources.

Keywords: Glass bracelets, glass production, Ayyubid-Mamluk, Dohaleh, Jordan, electron microprobe.

## 1. Introduction

It is only recently that, in Jordan, ancient Islamic glass bracelets have been subjected to serious attention and study (Al-Bashaireh 2016, Boulogne 2007, Boulogne and Henderson 2009). The lower number of excavations at Islamic sites or cemeteries compared to those at sites of older periods, the higher degrees of disturbance of upper Islamic layers compared to lower ones, and the neglect or underestimation of these small finds might be the major reasons for this delay; see similar argument by Shindo (2001) and Spaer (1992).

During the 1990s excavations at the archaeological site of Dohaleh, north Jordan (Saleh 1991,1992,1993), a considerable amount of glass bracelets dated to the Islamic periods was uncovered from the Ayyubid-Mamluk cemetery and adjacent structures. The excavators at that

time were concerned about the presence of these ornaments in Islamic tombs which contradicts Islamic traditions that prohibit similar offerings to the dead. The bracelets themselves were overlooked and not studied in detail. The chemical composition of 27 glasses including a few bracelets, as well as bowls, bottles, glass sheets, and vessels were examined by Al-Ahmad (1994) who classified the studied glasses into soda-lime-silica and soda-lime-lead types. However, it is now understood that lead was typically added to a soda-lime base glass as part of the colouration process; this early work therefore needs to be revisited.

This article focuses on the chemical composition and production technologies of a larger corpus of Islamic bracelets and finger-rings uncovered 25 years ago from the Dohaleh cemetery. The article describes, gives parallels and classifies these samples based on recent work on glass bracelets (Spaer 1988, 1992, Shindo 2001, Steiner 2008).

## 2. Dohaleh archaeological site

Dohaleh or Khirbet Dohaleh is a rural archaeological site located approximately 25 kms southeast of Irbid, north Jordan (Figure 1). It occupies an area of about 8 hectares of an agricultural hill rising approximately 900m above sea level along the southern edge of the ez-Zagh valley. It is surrounded by other rural sites including Ya'mun, Khirbet el Kanis, Khirbet el Kanis el-Janubiyah, etc (Sari 1990). The site was surveyed in 1966-67 (Mittmann 1970, p. 77) and resurveyed in 1989 and excavated for four seasons 1990-1993 (Sari 1991,1993). The latest survey revealed various structures, tombs, caves, a mosque, wells, etc. The most important features found at the site are classical tombs, a Byzantine mosaic floor, the Ayyubid-Mamluk cemetery and a mosque. The site is dated from the Roman to the late Islamic periods based on the archaeological remains uncovered during the excavations, mainly ceramics, coins and architectural styles (Sari 1990, 1992, 1993).

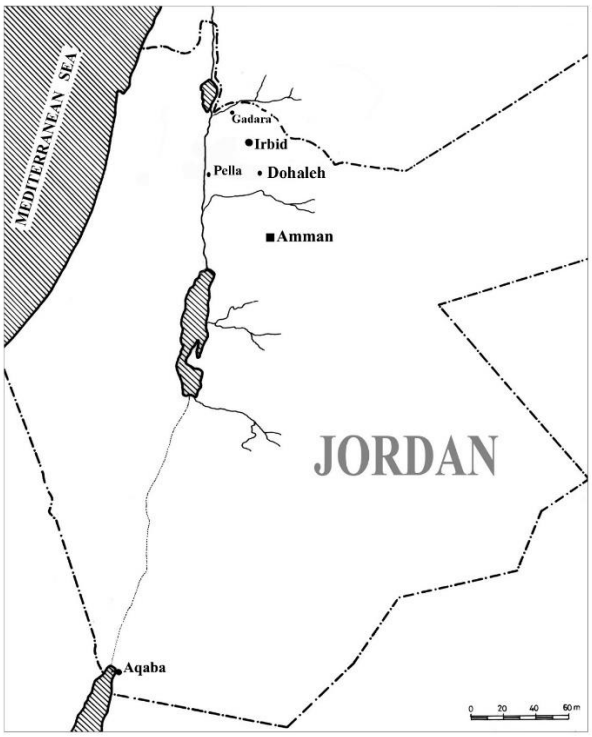


Figure 1. location map.

## 2.1. The Islamic cemetery

The second season of excavations (1991) uncovered, in area C, an Islamic cemetery comprising two successive levels of graves dug in the east-west direction. The cemetery comprised about fifty cist graves of different sizes depending on the age, sex and dimensions of the body of each individual. Children have small cists of about 0.5-1m (long), 0.5m (deep) and 0.3m (wide); while adults have larger cists of about 2m (long), 1m (deep) and 0.5m (wide) (Al-khasawneh 1994). The lower parts of the walls of the cists, where the dead was placed, were lined with flat stones to support the slab stones that cover the dead, and then the cist was filled with soil. The skeletons of the graves were buried according to the Islamic traditions; they were placed in the east-west direction and the skulls were facing south towards the holy Ka'aba in Mecca. The cemetery was dated to the Ayyubid – Mamluk periods (1169-1517 CE) according to the pottery sherds and coins found in the tombs (Sari 1990, 1991a, 1991b, 1993).

## 2.2. Ornamenting the deceased

To the contrary of Islamic traditions, most of the tombs were characterized by their content of several types of personal ornaments including bracelets, rings, earrings, pendants, beads, etc.

Beside metals, the most abundant ornaments are made of glass. The excavators of the site discussed this phenomenon and suggested different explanations. Firstly, the dead persons may belong to different ethnic groups which came into the region during the Ayyubid – Mamluk conquests and retained this ritual unchanged (Sari 1992a, 1992b, 1992c, 1993). Secondly, the dead persons died in groups, possibly due to natural disaster or infectious deceases like the plague which spread widely in the region during that period (Al-khasawneh 1994); therefore, it is possible that a fear of infection from touching the bodies caused the personal possessions to be left on the dead. However, this phenomenon has been recognized archaeologically in other sites in Jordan including Umm el-Naml cemetery at Gadara (Weber 1990:331-332), Khirbat Al-Mudayna (Thamad) (Daviau 2014), Tell Deir Alla (Steiner 2008), Umm el-Jimal (Al-Bashaireh 2016), Tell abu Sarbut (Steiner 1995, 1997), Khirbat Faris (Boulogne 2008).

### 2.3. Shaping technology of glass bracelets

The glass bracelets were manufactured in two basic techniques, resulting in seamed and seamless forms. Seamed bracelets were formed by bending a circular glass cane of a desired diameter, and joining its two ends. Most of the bracelets shaped using this technique have a circular cross section or are spirally twisted (Spaer 1988, 1992). The second technique (the most common technique used during the Islamic periods) rotated a hot gather of glass around a tapered metal rod ("mandrel") and reheated it until reaching the desired shape; therefore, the inner part of the bracelets is flat and their cross section is semi-circular, triangular or semi-elliptical (Spaer 1992, Spaer 2001). The majority of the Dohaleh bracelets selected for analysis (15 of26 in total) and rings (3) were shaped using the seamless technique; however, several (11 bracelets) show seams (for details see table 1). According to the classification of Spaer (1992, 2001), twelve of the 25 bracelets and the three rings under investigation have applied coloured decoration (Spaer 1992, 2001's fourth category), ten of them are spirally twisted (Spaer 1992, 2001's third category ), while four are plain (Spaer 1992, 2001's first category). It is worth noting the absence of the second category of Spaer 1992, 2001's classification (bracelets with tooled or molded decorations) which were usually produced during the period between the 3$^{rd}$ and the 7$^{th}$ century AD (Spaer 2001:194).

## 3. Materials and Analytical method

Details of the 26 bracelet and 3 ring fragments selected for chemical analysis performed

at the Wolfson Archaeological Science Laboratories, UCL are provided in (Table 1). Ground and polished samples were vacuum-coated with carbon and analysed using a JEOL JXA 8100 electron microprobe operated at 15 kV accelerating voltage, 15 nA beam current and a magnification of 800x, so that the area analysed was approximately 150 x 110 µm. Three areas of each colour were analysed and the results averaged. Analysis of Corning Museum archaeological glass standards A and B indicated relative errors better than 2% for Na and Si, and better than 10% for most other elements in the compositional ranges of interest.

## 4. Results

*Base glasses*

Analytical data are presented in Table 2. The samples have been divided into six compositional groups, A to F, on the basis of the components in the base glass. All are soda-lime-silica glass and the majority have both $K_2O$ and MgO concentrations in excess of 1.5%, consistent with a plant ash source of alkali. Groups B and C, however, have marginal concentrations of MgO, at around one percent, although $K_2O$ is higher, ranging from 1.4%-3.8% (Fig. 2).

The groupings in terms of MgO and $K_2O$ are supported by the other ash-related components, CaO and $P_2O_5$ (Fig. 3). The majority of the glasses, represented by Groups A and F, show strong overlap and represent essentially the same plant ash material. Group D is a strong outlier (Fig. 2), but the four analyses in Group D represent different colours on a single bracelet, number 27. Groups B and C share similar characteristics in terms of low MgO, CaO and $P_2O_5$ but are separated in terms of $K_2O$ (Fig. 2). While Group E has MgO closer to typical plant ash glass (Fig. 2), it is on the edge of the range and its low CaO and $P_2O_5$ overlap with Group C (Fig. 3).

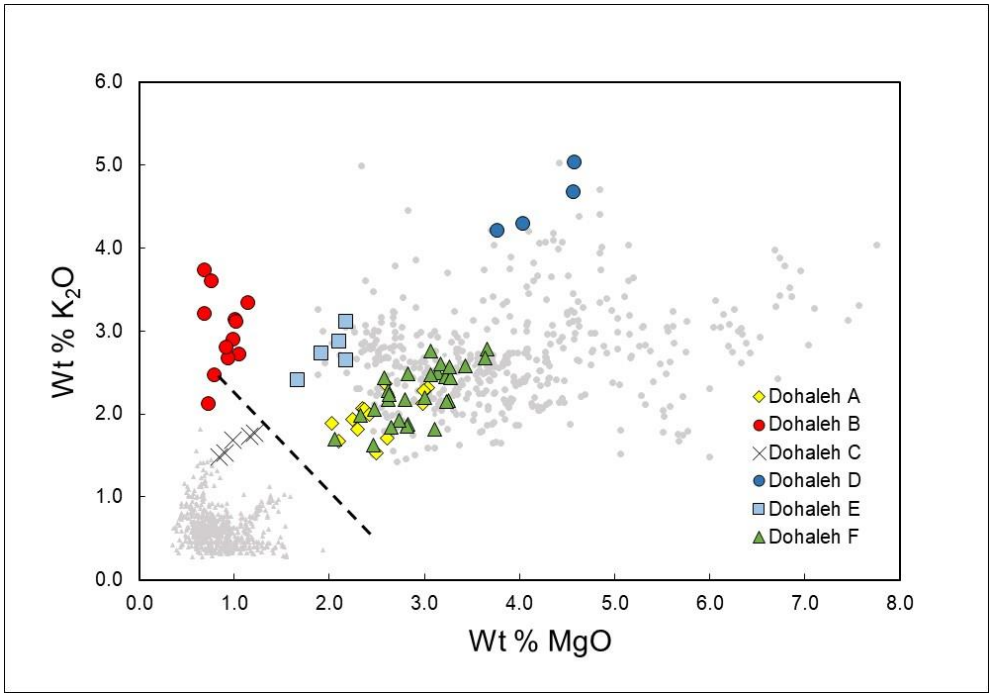


Fig. 2. Potash and magnesia contents of the reduced compositions of the Dohaleh glasses, relative to typical natron (grey triangles) and plant ash (grey circles) types from the Mediterranean and the Middle East. Base diagram modified from Freestone (2021).

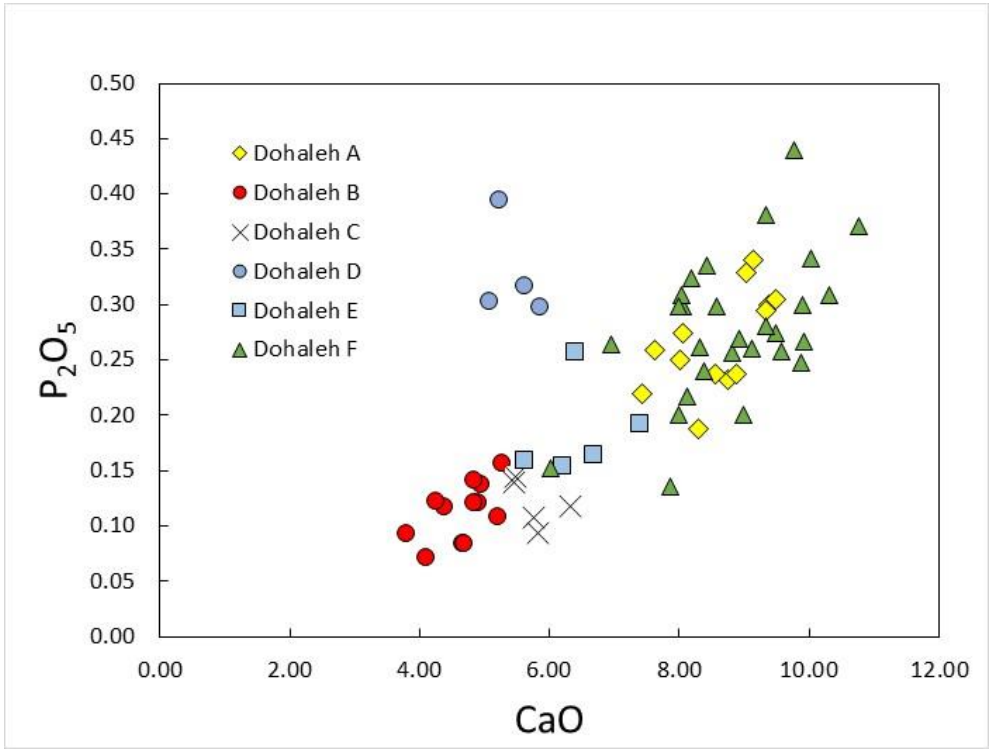


Fig. 3. Reduced lime and phosphate contents of the glasses.

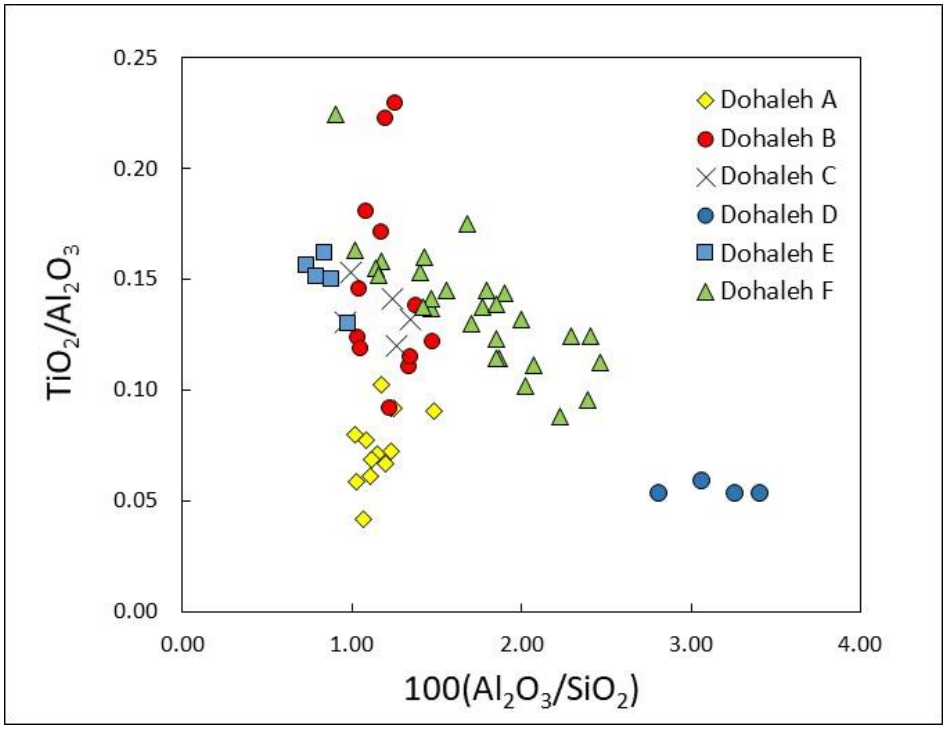


Fig. 4. Sand-related components for the six identified groups.

Turning to the silica-related components (Fig. 4), these clearly separate Group A from Group F, indicating different sand/quartz sources. Once again, there is a clear separation of group D/bracelet 27. There are significant overlaps between the three Groups B, C and E, which low $Al_2O_3$, typically less than 1%. The colourless glass of Group B has exceptionally high $SiO_2$, around 75%. Very pure sands or quartz pebbles are likely to have been used as sources of silica for these groups. Group F has alumina contents typically over 1% which separate it from Group A, while Group D has $Al_2O_3$ approaching 2% suggesting it was made using sand. $Fe_2O_3$ is relatively low in the base glasses, typically less than 0.5% in glasses which were not deliberately coloured.

*Colorants and opacifiers*

Opaque and translucent glasses occur in all of the glass groups except Group D where bracelet 27 is composed only of opaque colors. The compositions indicate that the glasses were opacified using lead-tin technology, as expected for the period (Tite et al 2008). Fig. 5 indicates the remarkable consistency of the approach, irrespective of base glass group.PbO:$SnO_2$ ratios are approximately 2:1 for the opaque white and turquoise glasses, opacified by $SnO_2$, whereas they are approximately 5:1 for the opaque yellow, orange and green glasses, opacified by lead stannate. Higher lead:tin ratios are typical in glasses opacified with lead stannate which were prepared using an intermediate lead-tin-silicate glass, termed an "anime" (Heck et al. 2003;

Tite et al. 2008; Matin 2019). According to Matin (2019), a Pb:Sn ratio of 3.5 separates glasses opacified with lead stannate from those opacified with tin oxide. The present results are consistent with this principle but the Pb:Sn ratios are closer to the separating ratio than for many of the glasses in her compilation. This may be a chronological issue, as most of the glasses in Matin (2019) date to before the 12th century CE.

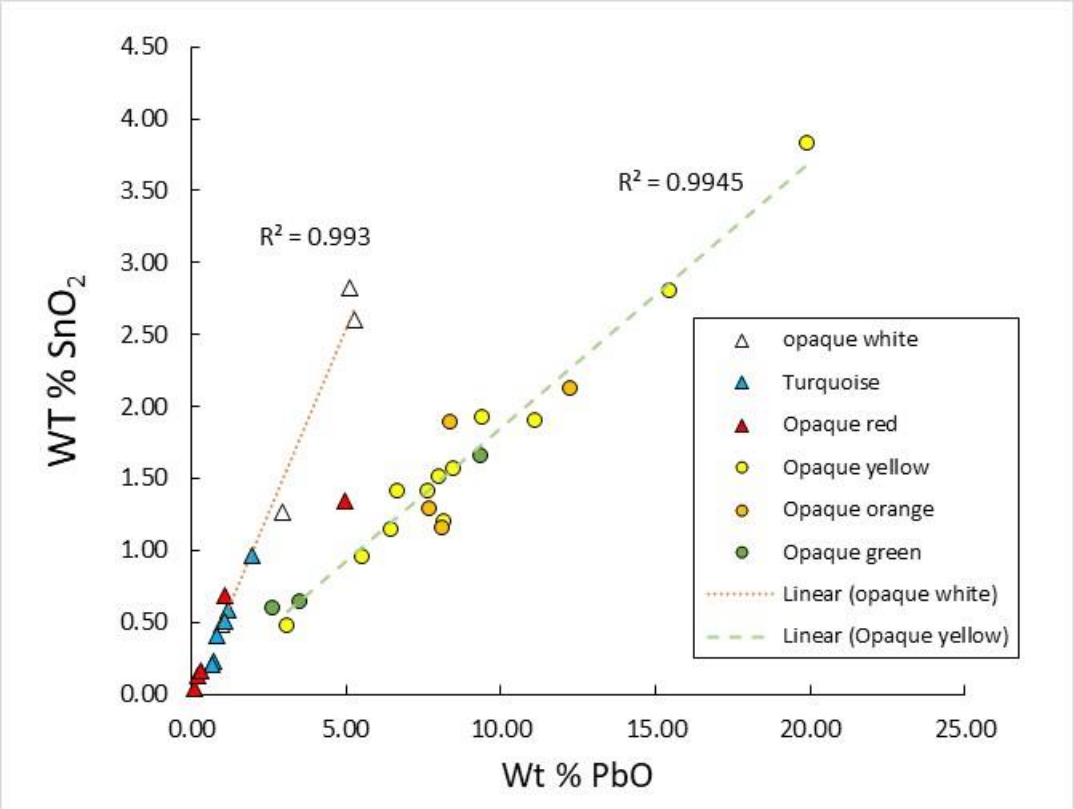


Fig. 5. Tin and lead oxide contents of the opaque glasses

Turning to the individual colors, opaque red glasses are colored by copper at levels of c. 1-4% CuO, with high $Fe_2O_3$ concentrations, which are likely to have facilitated the precipitation of copper metal. Pb:Sn ratios of the red glasses, tend to conform to the typical ratio of the whites and blues or lie between the two trends (Fig. 5). However, it should be borne mind that the reds are likely to have been colored using copper alloy scale and unintentionally added tin or lead may therefore be present.

Opaque yellow, while opacified with a fairly constant Pb:Sn ratio, has a wide range of lead contents from c. 3% to c. 20%. Opaque green is similar to yellow with c. 1% CuO to produce the green color in conjunction with the yellow lead stannate particles. Opaque orange, which has a similar Pb:Sn ratio seems typically to be a variant of yellow with little to distinguish it

compositionally, with the exception of a single example (DoH 25) which is a variant of red, with elevated iron and copper.

Intentional decolorization with manganese is apparent only in Groups A and F; in addition to a number of purple glasses probably colored by the $Mn^{3+}$ ion which have MnO in excess of 2%, most of Groups A and F contains MnO between 0.3 and 1.5%, typical of deliberate addition (Table 2). Groups B, C and E on the other hand, contain MnO about or below 0.1% and frequently below detection limits of around 0.02%; these are levels typical of sand with some minor additions, perhaps due to recycling of glass from other sources.

A single analyzed glass, sample 19, is colored deep blue with 0.06% cobalt oxide, while turquoise glasses typically contain 1-2% CuO. The turquoise colors are not strongly opacified but somewhat cloudy with significant but low concentrations of PbO and $SnO_2$ ranging from c. 1 to 3% in total. Less easily described as turquoise but also on the blue-green spectrum are a number of other copper-colored glasses, containing varying amounts of lead and tin, but typically translucent. Black glasses are variable in composition and may contain elevated iron, copper or manganese. Where these are not present in high concentrations it is likely that the black coloration is due to reduction of transition metals in the glass, possibly to sulfide complexes.

Most of the colors are spread across several of the base glass groups and are not restricted to a single production. However, of opaque white, is confined to Group F as are the purple glasses, which also occur only in Group F. Groups B, C and E contain no example of opaque red.

## 5. Discussion

No polychrome bracelet is made with glass from more than one of the identified groups. Overall, the results suggest at least four and possibly as many as six different production groups in the bracelet assemblage. Groups A, D and F are clearly separated in terms of sand-related components, suggesting different production locations, while Groups B, C and E cluster together in terms of alumina, silica and titania (Fig. 4), although they can be separated in terms of their alkalis and alkaline earths (Figs 2, 3).

The high MgO/CaO ratio and $Al_2O_3$ concentration of Group D suggest that this is of Mesopotamian origin (Phelps 2018). However, its $K_2O$ content is rather high (Fig. 2), so a more distant origin (Iran, Central Asia) cannot be ruled out. Groups A and F represent the majority of the glass, and have similar potassium, magnesium, calcium and phosphorus oxides (Figs. 2

and 3). They are fully consistent with plant ash glass of the Levantine region. The clear difference between these two groups in terms of sand-related components (Fig. 4) suggests two separate production locations, presumably in greater Syria and/or potentially two production technologies, with Group A using crushed quartz and group F using a less pure sand. In their earlier study of bracelets from Jordan, Boulogne and Henderson (2009) identified a "plant ash" glass type. Their plant ash group corresponds well to our Group F, as shown in Fig. 6.

Interpretation of Groups B, C and E is more problematic. The low MgO and $P_2O_5$ contents of these glasses are not a good match for plant ash-based glass and do not match previously analyzed plant ash glasses from the region (Fig. 2). Boulogne and Henderson (op. cit.) identified a small group of five glasses which also had low MgO and $P_2O_5$ and suggested a mineral source of alkali. This seems a likely explanation for the characteristics shown by Groups B and C, and to a lesser extent by Group E, which is also related by its similar silica-related components. Boulogne and Henderson's (op. cit.) mineral alkali glass also shows similar silica-related components to Groups B, C and E possibly reflecting a common origin (Fig. 6). These groups are also related in the absence of added MnO as a decolorizer. Their color palette seems more restricted than the Levantine plant ash glasses in the apparent absence of opaque red and white, although a larger data set would be needed to confirm this provisional observation. The variability in alkali-related elements between these groups (Figs. 2, 3), although they have similar silica-related compositions (Figs. 4, 6), may indicate a single production center receiving different consignments of alkali. In the light of recent work showing Byzantine exploitation of soda springs in western Anatolia for glassmaking (Schibille 2011, Rehren et al 2015, Tite et al. 2016, Swan et al. 2018), an origin of the alkali in Anatolia seems probable. Trace element analysis for indicator elements such as boron and lithium would be required to confirm this hypothesis. Whether these bracelets were made in and imported from Anatolia, or made from glass produced locally using imported Anatolian alkali is also to be determined. Even so, the common correlation between PbO and $SnO_2$ in the yellow glasses across the groups suggests that all were produced within a shared understanding of lead-tin coloration technology.

Henderson and Boulogne (2009) identified a high-alumina group of glass bracelets which they attributed to an Indian production. We have not identified this type in the present study, but this may reflect differences in chronology, as their sample extended into the Ottoman period.

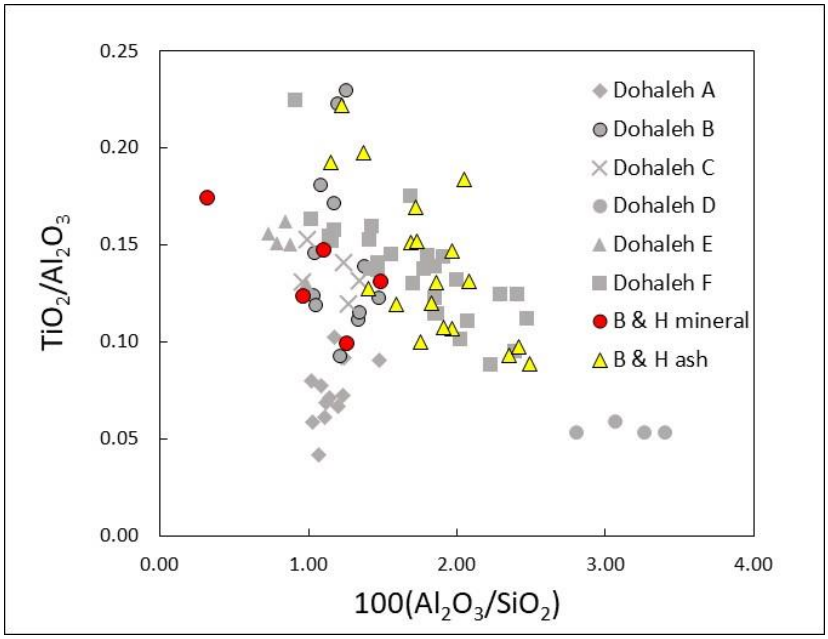


Fig. 6. Plant ash and mineral glass groups of Boulogne and Henderson (2009) compared with the glass from the present study.

## 6. Conclusions

The Ayyubid-Mamluk bracelets and rings from Dohaleh, Jordan fall into two major categories, based upon plant ash (Groups A and F) or mineral alkali (Groups B, C, E) soda sources. These two types were previously recognized by Boulogne and Henderson (2009). Sub-divisions within the two categories reflect the use of different silica sources (Groups A and F) or different consignments of alkali (Groups B, C, E). An imported bracelet from Mesopotamia has also been identified (Group D). The plant ash glasses of Groups A and F are based upon raw materials available in the Levant while the origin of the mineral soda is suggested to have been more distant, probably in Anatolia. The color palette of the glass made with mineral alkali appears more restricted than that of the Levantine glasses and they do not show evidence of manganese decolorization. While trace element data are required to further investigate the possibility that these were imported from Anatolia, it is clear that the Dohaleh bracelets have a wide range of sources and may have been transported over long distances.

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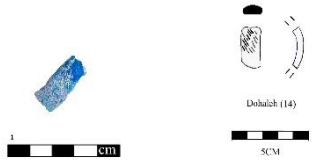
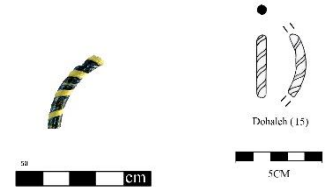
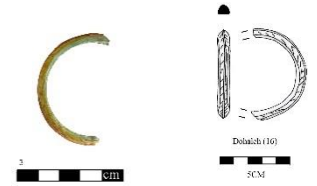
1 Table 1. The samples' description, classification, shaping techniques, photos and drawings.

| Sample N. | Year/area/sq/locus/pail/# | Spaer (1992,2001)'s classification: Type (sub-type), shaping technique. | Brief description | Photos and drawings |
|---|---|---|---|---|
| (Doh14) | Doh90.A.C4.000.1(12) | 1st Plain Bracele: (Semicircular-flat), Seamless. | **Semi-circular to flat section, blue frame.** |  |
| (Doh15) | Doh90.A.C4.001.4(44) | 3rd Spirally twisted Bracelet (Added symmetrically fused trail), Seamed. | **Circular section, black frame, coarse yellow twisted trail.** |  |
| (Doh16) | Doh93.A.A4.001.7(100) | 4th Bracelet with applied colored decoration (Semi-circular, trail decorated), Seamless. | **Semi-circular D-shape section, Light green frame, twisted trail of yellow and orange on sides, untwisted orange trail in the middle.** |  |
| (Doh17) | Doh93.A.A4.001.4(91) | 4th Bracelet with applied colored decoration (Obliquely pointed, trail decorated), Seamless. | **Obliquely pointed section, black frame, trail of green, blue and brown colors in meander pattern.** |  |

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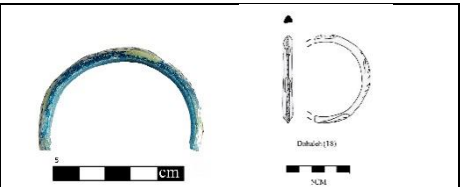
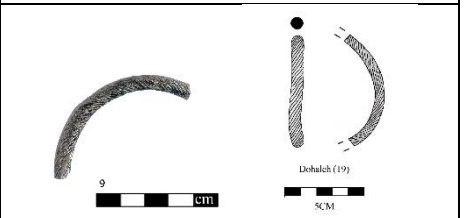
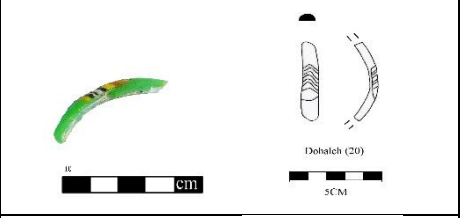
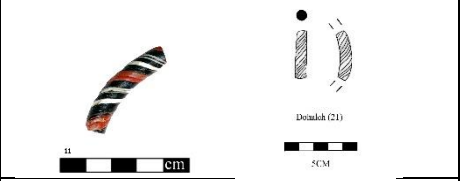
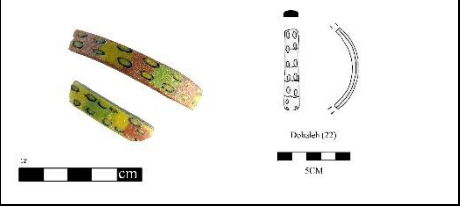
| (Doh18) | Doh93.A.OA4.000.2(10) | 4th Bracelet with applied colored decoration (Semi-circular, trail decorated), Seamless. | **Semi-circular D-shape section, blue frame, light green frame, single twisted trail on top in white and black, yellow green patches on sides.** |  |
| (Doh19) | Doh93.A.OA3.003.6(111) | 3rd Spirally twisted Bracelet. (Monochrome without further decorations), Seamed. | **Circular section, spirally twisted, black, single trail.** |  |
| (Doh20) | Doh92.A.F6.001.3(7) | 4th Bracelet with applied colored decoration (Semi-circular, applied patches), Seamless. | **Semi-circular D-shape section, light green frame, added patches of wavy yellow, black, white and orange stripes.** |  |
| (Doh21) | Doh93.A.C10.000.1(105) | 3rd Spirally twisted Bracelet (Added symmetrically fused trail), Seamed. | **Circular section, black frame, twisted white and reddish-brown single trail.** |  |
| (Doh22) | Doh91.A.D6.006.10(264) | 4th Bracelet with applied colored decoration (Flat, mosaic eyes), Seamless. | **Flat section, green frame, oval yellow shapes with black boundaries, orange, yellow and green alternating stripes.** |  |

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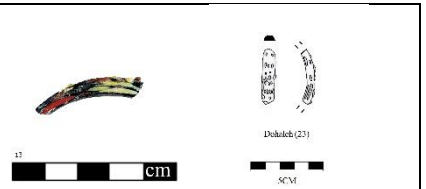
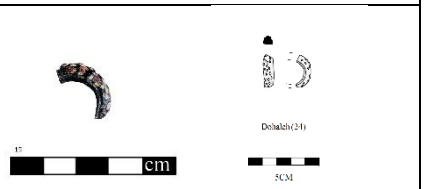
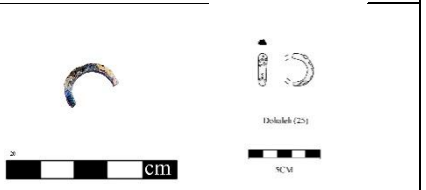
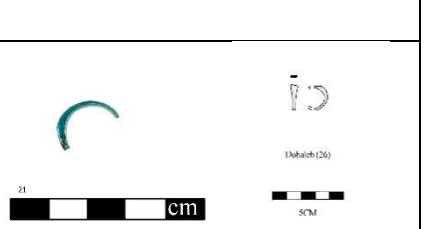
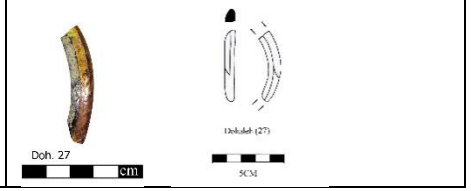
| (Doh23) | Doh91.C.OF15.005.5(211) | 4th Bracelet with applied colored decoration (Semi-circular, combined patches and prunts), Seamless. | **Flattened semi- circular section, black frame, prunts of yellow and reddish brown, and elongated patches of yellow, reddish brown and yellowish blue colors.** |  |
| (Doh24) | Doh90.A.D4.001.1(143) | 4th Ring with applied colored decoration (Semi-circular, applied prunts), Seamless. | **Semi-circular section, black frame, reddish brown, yellow and white prunts.** |  |
| (Doh25) | Doh91.A.E6.003.7(247) | 4th Ring with applied colored decoration (Semi-circular, combined applied patches and prunts), Seamless. | **Semi-circular section, black frame, red prunts and white, yellow and brown elongated patches.** |  |
| (Doh26) | Doh91.A.BU.002.6(104) | 1st Plain ring (Semicircular-flat), Seamless. | **Semi-circular section, blue frame, (lost decorations?).** |  |
| (Doh27) | Doh91.C.OF.012.13(78) | 4th Bracelet with applied colored decoration (Evenly pointed, applied trail (coating), Seamless. | **Evenly pointed section, black frame, decorated in yellowish brown coat (trail) on top.** |  |

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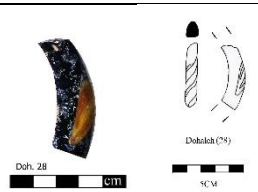
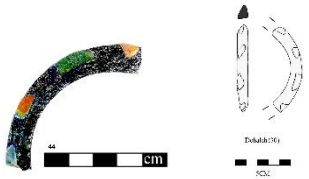
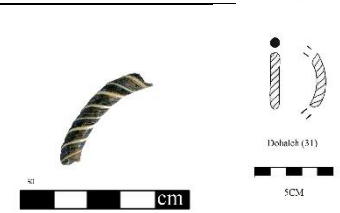
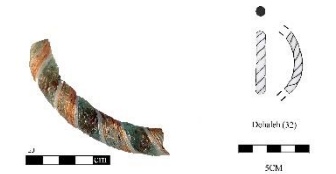
| (Doh28) | Doh91.A.D5.002.W(267) | 4th Bracelet with applied colored decoration (Obliquely pointed, applied patches), Seamless. | **Obliquely pointed section, black frame, patches in yellow and orange.** |  |
| (Doh29) | Doh91.A.E5.000.(2) | 4th Bracelet with applied colored decoration (Obliquely pointed, trail decorated), Seamless. | **Obliquely pointed section, black frame, trail of green and brown color in a meander pattern.** |  |
| (Doh30) | Doh91.C.OF16.002.13 | 4th Bracelet with applied colored decoration (Obliquely pointed, applied patches), Seamless. | **Obliquely pointed section, black frame, orange, green and blue patches.** |  |
| (Doh31) | Doh93.A.A4.001.7(100) | 3rd Spirally twisted Bracelet (Added symmetrically single trail), Seamed. | **Circular section, spirally twisted, black frame, white single and light brown single trail.** |  |
| (Doh32) | Doh90.A.D3.000.2(32) | 3rd Spirally twisted Bracelet (Added symmetrically fused trail), Seamed. | **Circular section, spirally twisted, greenish frame, fused, white and coarse orange single trail.** |  |

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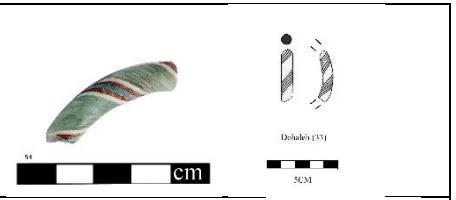
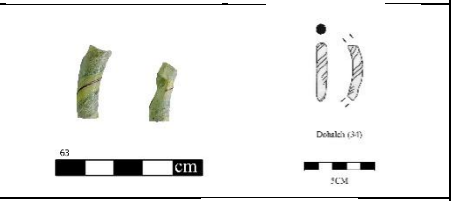
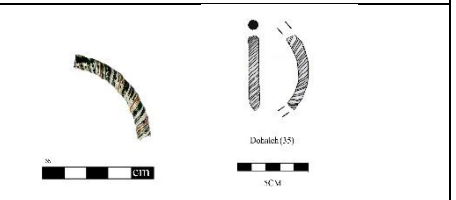
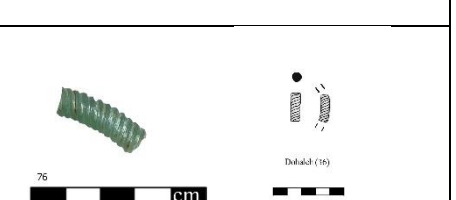
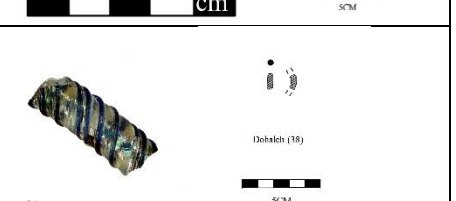
| (Doh33) | Doh93.A.OA3.002.7(109) | 3rd Spirally twisted Bracelet (Added symmetrically fused trail), Seamed. | **Circular section, spirally twisted, bluish green, fused, white, blue and brown single trail.** |  |
| (Doh34) | Doh91.A.D6.000.7(247) | 3rd Spirally twisted Bracelet (Added symmetrically fused trail), Seamed. | **Circular section, spirally twisted, light green frame, fused, white, dark brown and coarse yellow single trail.** |  |
| (Doh35) | Doh90.A.D3.002.24(130) | 3rd Spirally twisted Bracelet (Added symmetrically fused trail), Seamed. | **Circular section, small diameter, spirally twisted, black frame, white, yellow and reddish brown single trail.** |  |
| (Doh36) | Doh93.A.OA3.000.2(46) | 3rd Spirally twisted Bracelet (Added symmetrically fused trail), Seamed. | **Circular section, spirally twisted, light greenish blue frame, (lost trail decorations).** |  |
| (Doh37) | Doh93.A.A4.001.4(91) | 1st Plain Bracele: (Circular), Seamed. | **Circular section, dark blue frame, (lost decoration?).** |  |
| (Doh38) | Doh92.A.D7.000.5(50) | 3rd Spirally twisted Bracelet (Added symmetrically fused trail), Seamed. | **Circular section, spirally twisted, colorless frame, fused, lost decorations: black, dark brown and blue single** |  |

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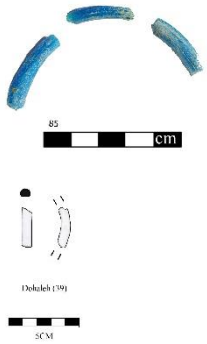
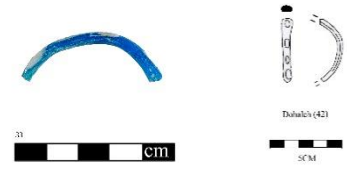
| | | | **trail, (lost trail decorations).** | |
| (Doh39) | Doh91.A.D5.12(97) | 1st Plain Bracele: (Circular), Seamed. | **Circular section, blue frame, 3 fragments, (lost decorations?).** |  |
| (Doh40) | Doh90.A.C4.000.1(11) | 4th Bracelet with applied colored decoration (Semi-circular, trail decorated), Seamless. | **Semi-circular section, light pale green frame, untwisted light green trail on bracelet's point, twisted trail on sides in yellow and orange.** |  |
| (Doh41) | Doh93.A.A3.000.3(42) | 4th Bracelet with applied colored decoration (Semi-circular, trail decorated), Seamless. | **Semi-circular section, blue frame, brown untwisted trails on top and bottom, (bottom trail mostly lost).** |  |
| (Doh42) | Doh92.A.D9.000.3(185) | 4th Bracelet with applied colored decoration (Semi-circular, applied patches), Seamless. | **Semi-circular D-shape section, blue frame, decorated with white oval patches.** |  |

Table 2. EPMA analysis of bracelets from Dohaleh, north Jordan, arranged by compositional groups (b.d. = below detection, typically <0.02, op=opaque/cloudy; tr=translucent, clls= colourless/natural; grn=green; wht=white; blk=black; brn=brown; tur=turquoise; pur=purple; or=orange, Also measured: CoO, present in 19 at 0.06%; Sb2O5, occasional trace; BaO, occasional trace).

| Bracelet | Opacity | Colour | Group | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | $Na_2O$ | $K_2O$ | Cl | $SO_3$ | $P_2O_5$ | MnO | CuO | PbO | $SnO_2$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | tr | brn | A | 67.13 | 0.05 | 0.80 | 0.44 | 3.04 | 9.15 | 15.14 | 2.32 | 1.13 | 0.37 | 0.34 | 0.15 | b.d. | 0.08 | 0.01 | 100.16 |
| 17 | op | grn-yel | A | 62.85 | 0.05 | 0.68 | 0.37 | 2.27 | 7.92 | 12.03 | 1.79 | 0.72 | 0.19 | 0.25 | 0.68 | 0.24 | 7.65 | 1.25 | 98.94 |
| 17 | op | yel | A | 61.91 | 0.04 | 0.69 | 0.37 | 2.22 | 7.95 | 12.53 | 1.91 | 0.75 | 0.19 | 0.27 | 0.66 | 0.11 | 7.64 | 1.41 | 98.63 |
| 23 | tr | grn-blu | A | 66.95 | 0.04 | 0.69 | 0.40 | 2.89 | 8.48 | 11.31 | 2.05 | 0.58 | 0.24 | 0.23 | 1.22 | 1.10 | 0.60 | 0.07 | 96.86 |
| 23 | op | red | A | 59.97 | 0.05 | 0.69 | 4.36 | 2.51 | 8.00 | 9.78 | 1.65 | 0.54 | 0.20 | 0.18 | 0.82 | 1.44 | 4.95 | 1.34 | 96.48 |
| 28 | tr | brn | A | 66.40 | 0.07 | 0.81 | 0.48 | 2.46 | 9.27 | 16.10 | 1.51 | 0.83 | 0.31 | 0.30 | 0.22 | b.d. | b.d. | b.d. | 98.76 |
| 28 | op | yel | A | 62.67 | 0.03 | 0.67 | 0.40 | 2.55 | 7.48 | 12.32 | 2.32 | 0.71 | 0.24 | 0.25 | 0.54 | 0.45 | 6.45 | 1.14 | 98.20 |
| 29 | op | blk | A | 68.87 | 0.06 | 0.85 | 0.48 | 2.39 | 9.65 | 15.14 | 2.10 | 1.24 | 0.48 | 0.31 | 0.06 | b.d. | 0.09 | b.d. | 101.71 |
| 29 | op | yel | A | 61.76 | 0.05 | 0.69 | 0.41 | 2.02 | 8.84 | 11.00 | 1.88 | 0.63 | 0.19 | 0.24 | 0.56 | 0.02 | 9.38 | 1.93 | 99.60 |
| 30 | op | blk | A | 66.32 | 0.08 | 0.82 | 0.45 | 2.39 | 9.41 | 13.59 | 2.07 | 0.80 | 0.25 | 0.30 | 0.32 | b.d. | 3.46 | 0.64 | 100.89 |
| 30 | op | yel | A | 64.95 | 0.08 | 0.76 | 0.47 | 2.40 | 8.94 | 14.20 | 1.98 | 0.79 | 0.25 | 0.33 | 0.30 | b.d. | 3.12 | 0.47 | 99.03 |
| 30 | op | or | A | 59.51 | 0.05 | 0.61 | 0.34 | 2.08 | 7.34 | 11.24 | 1.66 | 0.70 | 0.17 | 0.22 | 0.57 | 0.07 | 12.25 | 2.12 | 98.93 |
| 37 | tr | grn-blu | A | 68.54 | 0.09 | 1.01 | 0.45 | 3.07 | 8.74 | 13.01 | 2.33 | 0.85 | 0.23 | 0.24 | 0.74 | 2.55 | 0.40 | 0.05 | 102.32 |
| 16 | tr | clls | B | 76.14 | 0.15 | 0.89 | 0.30 | 0.81 | 4.72 | 14.60 | 2.49 | 0.49 | 0.22 | 0.08 | b.d. | b.d. | b.d. | 0.01 | 100.91 |
| 16 | op | yel | B | 67.40 | 0.13 | 0.73 | 0.31 | 0.73 | 4.11 | 13.53 | 2.11 | 0.39 | 0.19 | 0.07 | b.d. | 0.07 | 8.47 | 1.57 | 99.79 |
| 34 | tr | clls | B | 75.07 | 0.11 | 0.79 | 0.33 | 0.70 | 4.42 | 14.09 | 3.75 | 0.96 | 0.10 | 0.12 | 0.13 | 0.04 | b.d. | 0.02 | 100.61 |
| 34 | tr | clls | B | 74.80 | 0.10 | 0.78 | 0.38 | 0.77 | 4.27 | 14.09 | 3.60 | 0.81 | 0.13 | 0.12 | 0.11 | b.d. | 0.04 | 0.02 | 100.01 |
| 34 | op | yel | B | 67.65 | 0.08 | 0.71 | 0.34 | 0.68 | 3.75 | 13.01 | 3.15 | 0.74 | 0.12 | 0.09 | 0.10 | 0.03 | 6.66 | 1.41 | 98.54 |
| 41 | op | tur | B | 70.14 | 0.20 | 0.88 | 0.47 | 1.16 | 5.25 | 15.15 | 3.35 | 0.72 | 0.29 | 0.11 | b.d. | 1.95 | 0.73 | 0.23 | 100.64 |
| 41 | op | or | B | 64.76 | 0.17 | 0.78 | 0.37 | 1.01 | 4.65 | 14.29 | 3.10 | 0.66 | 0.25 | 0.08 | b.d. | 0.17 | 7.68 | 1.29 | 99.26 |
| 42 | tr | tur | B | 70.28 | 0.08 | 0.86 | 0.38 | 1.06 | 4.90 | 15.86 | 2.70 | 1.03 | 0.22 | 0.12 | 0.08 | 1.19 | 0.69 | 0.20 | 99.65 |
| 40 | tr | clls | B | 75.12 | 0.11 | 1.01 | 0.38 | 1.06 | 5.42 | 15.14 | 3.19 | 0.98 | 0.07 | 0.16 | b.d. | b.d. | b.d. | b.d. | 102.64 |
| 40 | op | yel | B | 65.55 | 0.12 | 0.90 | 0.41 | 0.99 | 4.92 | 12.34 | 2.87 | 0.87 | 0.08 | 0.14 | 0.02 | 0.62 | 8.19 | 1.20 | 99.21 |
| 40 | op | grn | B | 63.92 | 0.12 | 0.94 | 0.47 | 0.95 | 4.86 | 12.78 | 2.67 | 0.89 | 0.05 | 0.12 | 0.02 | 1.50 | 9.34 | 1.65 | 100.27 |
| 40 | op | or | B | 65.96 | 0.10 | 0.89 | 0.37 | 0.92 | 4.81 | 13.15 | 2.78 | 0.81 | 0.08 | 0.14 | b.d. | 0.09 | 8.13 | 1.15 | 99.37 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | tr | grn-blu | C | 68.84 | 0.10 | 0.87 | 0.61 | 0.97 | 6.24 | 14.12 | 1.66 | 0.98 | 0.12 | 0.12 | 0.11 | 2.44 | 1.19 | 0.30 | 98.66 |
| 18 | tr | grn-blu | C | 63.23 | 0.11 | 0.85 | 0.45 | 0.86 | 5.49 | 12.36 | 1.46 | 0.81 | 0.11 | 0.10 | 0.03 | 0.35 | 7.28 | 1.93 | 95.42 |
| 18 | op | yel | C | 64.64 | 0.11 | 0.80 | 0.43 | 0.82 | 5.69 | 12.90 | 1.45 | 0.85 | 0.09 | 0.09 | b.d. | 0.14 | 8.02 | 1.51 | 97.55 |
| 39 | op | tur | C | 69.41 | 0.09 | 0.67 | 0.32 | 1.23 | 5.53 | 17.44 | 1.79 | 1.25 | 0.21 | 0.15 | b.d. | 1.38 | 1.10 | 0.51 | 101.07 |
| 39 | op | tur | C | 68.92 | 0.10 | 0.68 | 0.31 | 1.17 | 5.49 | 17.63 | 1.75 | 1.28 | 0.21 | 0.14 | 0.02 | 1.37 | 1.19 | 0.58 | 100.83 |
| 27 | tr | yel | D | 62.15 | 0.09 | 1.75 | 0.65 | 4.60 | 5.89 | 18.61 | 5.04 | 0.66 | 0.43 | 0.30 | 0.03 | 0.03 | b.d. | b.d. | 100.22 |
| 27 | op | yel | D | 55.51 | 0.10 | 1.70 | 0.71 | 3.82 | 4.80 | 15.22 | 4.04 | 0.50 | 0.49 | 0.28 | 0.58 | 0.08 | 5.53 | 0.95 | 94.32 |
| 27 | op | grn | D | 57.78 | 0.10 | 1.89 | 0.97 | 3.67 | 5.11 | 17.29 | 4.09 | 0.79 | 0.46 | 0.38 | 0.13 | 1.44 | 2.64 | 0.59 | 97.32 |
| 27 | op | red | D | 59.58 | 0.11 | 2.03 | 3.12 | 4.54 | 5.59 | 17.08 | 4.63 | 0.55 | 0.46 | 0.31 | 0.11 | 0.90 | 0.09 | 0.04 | 99.13 |
| 14 | op | tur | E | 69.66 | 0.08 | 0.51 | 0.33 | 2.18 | 6.39 | 13.98 | 2.63 | 0.88 | 0.20 | 0.26 | 0.01 | 1.53 | 0.85 | 0.41 | 99.89 |
| 22 | tr | clls | E | 68.20 | 0.09 | 0.60 | 0.22 | 2.12 | 7.19 | 14.10 | 3.01 | 0.89 | 0.21 | 0.19 | 0.13 | b.d. | 0.07 | 0.03 | 97.06 |
| 22 | op | or | E | 59.50 | 0.08 | 0.50 | 0.23 | 1.81 | 5.83 | 12.10 | 2.56 | 0.76 | 0.20 | 0.14 | 0.03 | 0.04 | 8.36 | 1.89 | 94.02 |
| 22 | op | yel | E | 55.32 | 0.07 | 0.44 | 0.24 | 1.60 | 5.39 | 11.04 | 2.30 | 0.70 | 0.16 | 0.15 | 0.05 | 0.06 | 15.48 | 2.80 | 95.79 |
| 22 | op | blk | E | 64.94 | 0.08 | 0.64 | 0.29 | 2.03 | 6.41 | 13.07 | 2.74 | 0.67 | 0.21 | 0.16 | 3.41 | 0.33 | 0.72 | 0.15 | 95.84 |
| 15 | op | yel | F | 53.49 | 0.16 | 0.90 | 0.50 | 2.32 | 6.94 | 7.90 | 1.98 | 0.71 | 0.15 | 0.26 | 0.63 | 0.12 | 19.89 | 3.83 | 99.78 |
| 15 | tr | grn-blu | F | 66.71 | 0.18 | 1.33 | 0.97 | 3.11 | 9.46 | 10.79 | 2.80 | 0.80 | 0.20 | 0.39 | 1.01 | 2.27 | 1.00 | 0.33 | 101.34 |
| 19 | tr | blu | F | 68.26 | 0.13 | 1.52 | 0.91 | 3.20 | 8.03 | 11.45 | 2.12 | 0.72 | 0.23 | 0.32 | 1.04 | 0.17 | 0.02 | b.d. | 98.11 |
| 20 | tr | clls | F | 68.27 | 0.11 | 0.70 | 0.35 | 2.41 | 7.67 | 15.29 | 1.59 | 0.87 | 0.19 | 0.13 | 0.03 | b.d. | b.d. | b.d. | 97.60 |
| 20 | op | grn | F | 65.78 | 0.13 | 0.60 | 0.36 | 1.98 | 5.80 | 13.83 | 1.63 | 0.90 | 0.21 | 0.15 | 0.04 | 0.66 | 3.54 | 0.64 | 96.25 |
| 21 | tr | pur-brn | F | 67.24 | 0.20 | 1.62 | 0.81 | 3.02 | 7.87 | 9.84 | 1.76 | 0.72 | 0.30 | 0.21 | 3.35 | 0.06 | 0.03 | b.d. | 97.03 |
| 21 | op | blk | F | 62.25 | 0.18 | 1.43 | 3.24 | 2.76 | 8.11 | 9.50 | 1.83 | 0.82 | 0.19 | 0.25 | 0.81 | 4.42 | 1.03 | 0.70 | 97.52 |
| 21 | op | red | F | 62.04 | 0.17 | 1.53 | 3.33 | 2.74 | 8.18 | 9.75 | 1.81 | 0.83 | 0.21 | 0.23 | 0.82 | 4.12 | 1.06 | 0.69 | 97.50 |
| 24 | tr | pur-brn | F | 68.77 | 0.15 | 1.28 | 0.65 | 2.46 | 8.03 | 11.82 | 2.05 | 0.77 | 0.29 | 0.30 | 2.91 | 0.05 | 0.03 | b.d. | 99.57 |
| 25 | tr | pur-brn | F | 65.58 | 0.15 | 1.36 | 0.91 | 3.06 | 8.88 | 9.26 | 2.43 | 0.60 | 0.37 | 0.25 | 4.41 | 0.07 | 0.07 | 0.02 | 97.43 |
| 25 | op | or | F | 58.87 | 0.13 | 1.41 | 2.79 | 2.72 | 9.26 | 7.99 | 2.12 | 0.42 | 0.24 | 0.27 | 1.28 | 5.04 | 3.82 | 1.18 | 97.56 |
| 26 | tr | grn-blu | F | 67.38 | 0.16 | 1.19 | 0.61 | 3.11 | 8.26 | 9.98 | 2.07 | 0.67 | 0.32 | 0.29 | 0.88 | 1.10 | 0.27 | 0.10 | 96.40 |
| 31 | op | red | F | 70.11 | 0.19 | 1.33 | 0.73 | 2.64 | 8.46 | 9.76 | 2.29 | 0.80 | 0.19 | 0.34 | 2.17 | 0.55 | 0.64 | 0.35 | 100.54 |
| 31 | tr | blu | F | 69.95 | 0.18 | 1.30 | 0.61 | 2.62 | 8.03 | 10.20 | 2.17 | 0.77 | 0.20 | 0.31 | 1.43 | 0.78 | 0.92 | 0.45 | 99.90 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | op | wht | F | 69.37 | 0.18 | 1.25 | 0.64 | 2.60 | 7.91 | 9.80 | 2.20 | 0.75 | 0.22 | 0.30 | 1.55 | 0.72 | 0.96 | 0.49 | 98.93 |
| 32 | tr | clls | F | 65.17 | 0.12 | 0.76 | 0.29 | 3.22 | 9.91 | 15.45 | 2.45 | 1.10 | 0.26 | 0.27 | 0.88 | 0.03 | 0.02 | 0.02 | 99.96 |
| 32 | op | wht | F | 62.51 | 0.11 | 0.71 | 0.32 | 2.99 | 8.94 | 15.26 | 2.19 | 0.96 | 0.27 | 0.20 | 0.83 | 0.03 | 2.97 | 1.27 | 99.55 |
| 32 | op | yel | F | 56.54 | 0.10 | 0.65 | 0.27 | 2.71 | 7.94 | 14.07 | 1.91 | 0.85 | 0.25 | 0.20 | 0.72 | 0.11 | 11.11 | 1.91 | 99.36 |
| 33 | tr | clls | F | 69.07 | 0.14 | 1.01 | 0.44 | 3.64 | 9.86 | 10.69 | 2.77 | 0.96 | 0.19 | 0.30 | 0.40 | b.d. | b.d. | b.d. | 99.47 |
| 33 | tr | clls | F | 69.75 | 0.14 | 1.02 | 0.49 | 3.63 | 9.31 | 10.82 | 2.66 | 0.84 | 0.24 | 0.28 | 0.40 | b.d. | 0.02 | b.d. | 99.60 |
| 33 | op | wht | F | 64.19 | 0.14 | 0.90 | 0.45 | 3.24 | 8.73 | 9.36 | 2.41 | 0.78 | 0.23 | 0.25 | 0.36 | b.d. | 5.11 | 2.83 | 99.00 |
| 33 | op | red | F | 64.79 | 0.15 | 1.01 | 3.05 | 3.11 | 8.75 | 10.11 | 2.55 | 0.79 | 0.25 | 0.26 | 0.36 | 2.59 | 0.18 | 0.13 | 98.07 |
| 33 | op | tur | F | 66.09 | 0.15 | 0.94 | 0.50 | 3.41 | 9.52 | 9.82 | 2.57 | 0.86 | 0.24 | 0.26 | 0.40 | 1.80 | 1.97 | 0.97 | 99.48 |
| 35 | op | blk | F | 68.93 | 0.16 | 1.27 | 0.59 | 3.11 | 10.91 | 11.78 | 2.50 | 1.21 | 0.53 | 0.38 | 0.02 | b.d. | 0.02 | b.d. | 101.39 |
| 35 | op | wht | F | 64.35 | 0.14 | 1.10 | 0.55 | 2.61 | 10.00 | 10.15 | 2.47 | 0.90 | 0.19 | 0.25 | 0.76 | b.d. | 5.28 | 2.60 | 101.37 |
| 35 | op | red | F | 66.31 | 0.14 | 1.34 | 2.09 | 2.83 | 10.33 | 11.02 | 2.49 | 0.94 | 0.36 | 0.31 | 0.31 | 1.25 | 0.30 | 0.17 | 100.18 |
| 36 | tr | clls | F | 71.53 | 0.14 | 1.01 | 0.49 | 2.72 | 10.03 | 12.94 | 1.89 | 1.02 | 0.13 | 0.45 | 0.33 | b.d. | b.d. | b.d. | 102.70 |
| 38 | tr | clls | F | 70.56 | 0.15 | 1.30 | 0.73 | 3.37 | 10.33 | 11.56 | 2.64 | 0.82 | 0.23 | 0.35 | 0.91 | 0.09 | 0.03 | b.d. | 103.08 |

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