



Chemical characterisation of glasses from Mantai, Sri Lanka and Bilad al-Qadim, Bahrain from the 8th to the 13th centuries AD and their interpretation in the wider context of the Maritime Silk Road and trade within the Islamic World.

Submitted in September 2020, in partial fulfilment of the conditions for the award of the degree
MRes Archaeological Science.

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I hereby declare that this dissertation is all my own work, except as indicated in the text.

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Acknowledgements:

I would like to thank my supervisor, Dr. Julian Henderson, for his help and support through writing this work and for sparking my interest in ancient glass in the first place. I would also like to thank my head of postgraduate studies, Dr. Chrysanthi Gallou and my Special Topic 2 tutor Dr. Christopher Loveluck for their help and support through this course. Additional thanks must be given to my course mates Dominic Harte and Imogen Worrell as well as my proof-reader in chief, Jake Troy and my ever-supportive family.

Abstract:

The main aim of this work is to use the chemical characterisations of these glasses from Bilad al-Qadim, Bahrain and Mantai, Sri Lanka to ascertain their compositional type and provenance if possible. Using this information, the main objective is then to compare this data to contemporary datasets of glass assemblages from the region to make inferences about the nature of trade at these sites, in the context of the Indian Ocean region under the influence of the Islamic World and the Maritime Silk Road in which these interactions took place. In total, data from 53 samples were studied by electron probe microanalysis, dating between the 8th and 13th centuries AD. These assemblages included vessel and window fragments, raw glass and one sample of glaze from a kiln. The glasses from Mantai formed two main compositional groups - one made with mineral soda and one with a vegetal soda source, the first of which was identified as being of the m-Na-Al type, made locally to South India and Sri Lanka, while the second group is more likely to have come from the Islamic Middle East. There are also two main groups seen in the results from the Bahrain glasses, separated by their alumina and manganese contents and magnesia/potash ratios, with the former likely from the Syro-Palestine region and both coming from the Islamic World. These results show the trade relationship of Mantai to the Islamic World and the demand there for glass from this region, despite a local manufacture, with the site playing the role of entrepôt, a link between the Islamic World and Indian Ocean trade circuits. The results from Bahrain indicate a high degree of integration into the Islamic World with the potential importation of colourless glasses here associated with the mosque.

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Chapter 1. Introduction:

The period of the 8th to 13th centuries AD in the Islamic World following the 7th century AD conquest can be described as a period of transition, firstly political, then religious and cultural before being seen materially. It is this slight delay which makes the glass of this period of particular interest, here a distinctly Islamic style and chemical compositions begin to emerge, a transition for the industry of glassmaking on two fronts – from the traditional Byzantine and Roman which had dominated since the 8th century BC, to the new Islamic industry (Phelps et al., 2016). Not only was there a shift in the geography of this production but there was a major change in the use of raw materials, specifically from a mineral evaporite source of soda (natron) to using ashes of halophytic plants, as attested by the work of Phelps et al. on Palestinian glass (2016). The change from the use of mineral natron as a soda source is first seen archaeologically in the Middle East before the technology changed in Egypt, which most likely indicates a gradual reduction in access to this resource, a natural process of the evaporite drying up (Phelps et al., 2016). This compositional change occurring in tandem with great cultural and political changes makes the study of glass from this region and time so important, with the movement from a centralised production model which had been in place for 1600 years to a decentralised model making use of a resource that had not been used for centuries in response to the gradual drying up of Egyptian natron sources (Phelps et al., 2016).

In their 1961 work Sayre and Smith put forward two compositional types of glass as being from the Islamic period, namely the high lead (1000-1400 AD) and high magnesia (HMG) (800-1400AD) types, the latter of which corresponds to samples analysed in this work (Sayre and Smith, 1961) (Henderson, 2002). Other chemical compositions identified through analysis after this from this region and time include high alumina glasses from India and South Asia, which will be discussed further due to making up a significant portion of the analyses from Mantai. During this period the production of glass in the Islamic World was largely carried out at the caliphate capitals, such as Samarra, al-Raqqa and Baghdad, which featured large-scale urban industrial complexes. After an initial period of experimentation with glass melt recipes as evidenced at al-Raqqa these productions were done under conditions of tight control and regulation, including raw material use of plant ashes which gave these glasses lower soda but higher alkali levels than those made before (Henderson, 2002).

In terms of glasses from South and South East Asia and the Indian Ocean region, in the late 1st millennium BC and early 1st millennium AD coastal locations such as Arikamedu in India and Phu Khao Thong in Thailand were points of entry and distribution to their hinterlands from the rest of the Indian Ocean region, as well as having evidence for local manufacture of m-Na-Al (high alumina) glass (Dussubieux et al., 2012). Here there are three spheres of trade including long distance trade between South and South East Asia with the Roman and Byzantine worlds suggested – the very early (5th–2nd/1st century BC), the early (3rd/2nd centuries BC–4th century AD) and the late (4th century AD onwards). This shows long distance relations pre-existing the Islamic conquest and the regional demand for glasses outside of what was locally produced which would continue and grow in the period of study (Dussubieux et al., 2012).

While the subtype of m-Na-Al known as m-Na-Al 1 was more prevalent in the time of the Arikamedu and Phu Khao Thong glasses, a second sub-group known as m-Na-Al 2 had become the most prevalent of the high-alumina glasses by the time of this study, exemplifying the changes and range of Indian Ocean trade by this time (Wood et al., 2016). This later production is believed to originate in either South India or Sri Lanka, with Mantai itself proposed as a possible site of production and is found across the Indian Ocean region as well as East Africa and some sites in the South of Africa, including Zanzibar. There is therefore an extension of this long-distance maritime link between the

Persian Gulf, Indian Ocean and the East coast of Africa, with finds and results from Zanzibar illustrating trade between this site and South East Asia and direct trade with the Islamic World in the compositions found here, including glasses from the Middle East, indicating participation in a proto-global network (Wood et al., 2016).

Focussing on two island sites, one in the Persian Gulf from the context of a mosque in Bahrain and one being Mantai in Sri Lanka, occupying an important geographical location in terms of the Indian Ocean, and the chemical compositions of the glass assemblages recovered this work intends to look at the influence of trade in a maritime context under the dominance of the Islamic World both in terms of trade and glassmaking. This is in addition to the fact that the Indian Ocean has evidence for its own glass production but maintains trade and acquisition of glasses from the Middle East. Through this, data from two locations under-represented in terms of glass compositional analysis will also be considered. This will provide a new view of these glasses and their composition when their major and minor elemental characteristics are determined by electron probe microanalysis (EPMA) and interpreted through this perspective in accordance with the aim I have set out.

1.2. Statement of Aims:

Research Aim: To use the chemical characterisations of these glasses to make inferences about the nature of trade in the Indian Ocean region in order to inform wider inferences concerning trade in the Islamic World and the place of this within the Maritime Silk Road, specifically the Indian Ocean and Persian Gulf regions.

Research Objectives:

1. To analyse these glasses by use of electron probe microanalysis for major and minor elemental characterisation to determine the compositional types of glass present.
2. To compare the results of these characterisations to known contemporary datasets from a variety of site types connected to the locations from which these glasses were excavated and obtained in order to contextualise my data and gain information about the provenance of the Mantai and Bilad al-Qadim glasses and their raw materials.
3. To use this characterisation and comparison to known types from contemporary sites in order to make inferences about the organisation of glass production and trade in the Indian Ocean region under the influence of the Islamic World and how this fits into the wider context of the long-distance trade routes of the Maritime Silk Road.

Chapter 2. Site Descriptions:

2.1. Mantai, Sri Lanka:



Figure 1. Map of Sri Lanka with Mannar District in the North-West highlighted, image from <https://silk-n-spice.blogspot.com/2011/06/sunny-sri-lanka-miracle-on-budget.html>, accessed 02/06/2020.



Figure 2. Map of Mannar District, Sri Lanka with the location of Mantai highlighted. Image from: <http://investsri Lanka.blogspot.com/2010/03/sri-lanka-to-spend-rs-4bn-to-develop.html>, accessed 02/06/2020.

The site of Mantai is in the North-Western tip of Sri Lanka, in the modern day Mannar district as seen in Figures 1 and 2, with its exact location at $8^{\circ} 57.5'$ North by $79^{\circ} 57.5'$ East (Carswell, 1996). The settlement is 6km from the town of Mannar, 300m away from the coast and close to the riverbank of the Malwatu Oya/Aruvi rivers delta (Shinde, 1987). This port settlement has been linked to the regional capital at the time of study, Anuradhapura, which is located approximately 80 kilometres south of the site (Pradines, 2016). Its location is at least partly responsible for the importance of the site and reason for its settlement due to its proximity to Adam's Bridge, a series of small island reefs between Sri Lanka and South India across the Gulf of Mannar. Adam's Bridge blocks the passage of large sea vessels through this gulf, thus giving need for a port settlement, which may have had some control over this bridge, at strategic position between the Islamic and Chinese worlds (Carswell, 1996).

There have been multiple excavations at the site of Mantai since its first exploration in the 16th century by the Portuguese during their occupation of Sri Lanka, with the first major investigation being in 1887 under W.J.S Boake who claimed to find evidence of palace structures and roads. Further excavations were undertaken in 1907 under John Still, which produced little material, 1926-28 under A.M. Hocart, the first archaeologist to realise the cultural importance of the site and another small investigation in 1950 by S. Sinmuganathen (Shinde, 1987). The most important excavation of Mantai was conducted beginning in 1980 and lead by John Carswell, after he questioned how so much Chinese celadon was present in Syria, despite the unlikely logistics of the wares being transported via land (Carswell, 1996). Lustre shards of Chinese and Islamic origin were discovered at the site and a trench revealed a link from the double outer moat to the central mound, as well as evidence of occupation since the second millennium BC (Carswell, 1996). The third excavation campaign under Carswell in 1984-1986 uncovered a large amount of material dating to

the 7th-9th centuries AD, including brick and mortar structures. This was the last campaign carried out by Carswell here due to the decline in political stability of the region, however he recovered and removed as much material as possible for the investigation of the site (Carswell, 1996).

Through these investigations a rough chronology for the occupation sequence at Mantai has been derived, beginning in the second millennium AD, seen from Carswell's 1982 season of excavation with a Mesolithic era settlement based on a hunter/gatherer/fisher economy prior to a Megalithic settlement (Carswell, 1996)(Shinde, 1987). Later phases of occupation have yielded more material and thus can be dated more closely, with the Early Historic lasting from the 2nd century BC to the 2nd century AD, followed by the Intermediate from the 3rd century to 8th century AD and the Early Medieval from the 9th-11th century AD. After this phase of occupation, the settlement was destroyed in the Chola invasion and subsequent capture of Sri Lanka (Shinde, 1987). Occupational sequencing was done using wooden beams dating between the 1st-3rd century AD and mound development which occurred between the 9th-10th century AD, the same time as the defensive circuits with a peak in settlement development around 650 AD where the site remained of high status until its destruction (Pradines, 2016)(Kingwell-Banham et al., 2018).

Mantai during the period of my focus was extensive in size, measuring approximately 30 hectares, 8m above sea level with the habitation deposit estimated to be 12m in thickness (Shinde, 1987). For over 1000 years it functioned as a port emporium between both South India and Sri Lanka and the Near and Far Eastern realms (Carswell, 1996). It was shaped like a horseshoe with a double moat and double rampart wall, made of low mud walls and thus unlikely to be defensive as their primary function, with the moats more likely to be for rainwater storage. The moat dates earlier than the large tank found 10km away, also for water storage, as this would have negated the need for a double moat, thus approximate dates have been given as the 2nd-4th century AD for the moat and the 5th century AD for the tank (Shinde, 1987). The intact nature of the site is owed to its location in the arid zone combined with erosion protection from the monsoon cycles and the fact that unlike in South India, the habitation soil was not used for wall construction or crop manuring. However, these factors also make the land unsuitable for agriculture, meaning the focus of the site would have been trade based, including for basic foodstuffs, and the link to Anuradhapura even more important (Shinde, 1987).

The evidence of long-distance trade involving Mantai is exemplified by the material culture recovered, including Rouletted ware and Red and Black ware ceramics which prove the link from this site to Arikamedu, as well as Ctesiphon, Samarra and Nishapur through Indian Ocean trade (Shinde, 1987) (Pradines, 2016). 97% of all analysed glass prior to this study have found they are related to 8th-12th century AD contexts in the Islamic world, most notably the influences from Sasanian glass and glass from Siraf, Iran which was highly prized in the Chinese world. This is likely a reflection of the use of raw glass or cullet from Islamic sites in bead production which probably occurred here or nearby, with Mantai being a terminus of the bead trade from both the East and West, exhibiting 19 different bead types (Pradines, 2016). The main functions of the site seem to have consisted of being a trade and transshipment centre, partly playing the role of a Chinese intermediary but towards the later part of its occupation becoming more focussed on trade with the Islamic Persian Gulf (De Saxcé, 2016). This will have included some localised networks for raw materials and goods distribution and both land and sea networks, the former likely being local and inter-regional (Coningham, 2002).

2.2. The al-Khamis mosque at Bilad al-Qadim, Bahrain:

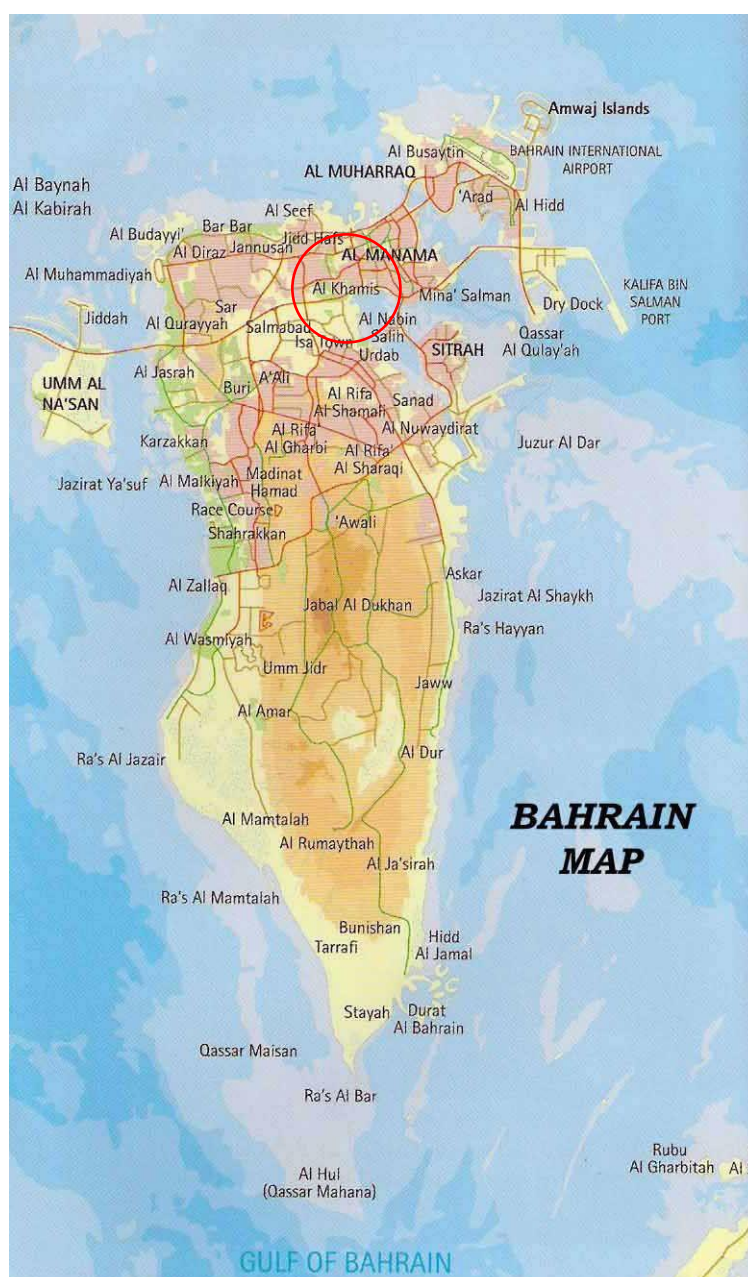


Figure 3. A map of Bahrain with the location of the al-Khamis mosque highlighted, image from www.mapsoftheworld.net/mapsofasia/mapsofbahrain, accessed 06/06/2020.

The site from which the Bahraini samples come from is the al-Khamis mosque situated in what was the main Islamic centre of Bahrain - Bilad al-Qadim, from the 9th-13th century AD (Insoll et al., 2016). This site is in the North Eastern part of Bahrain, approximately 10km from present-day Manama (Whitehouse, 2003). The exact coordinates of the site of the al-Khamis mosque are 26.2° North, 50.5° East and 13m above sea level (<http://thesacredcity.ca/khamis.html>, accessed 07/06/2020). This mosque is thought to be the oldest in Bahrain and part of the oldest Islamic site on the islands, with its time of establishment being in the 8th century AD and major use continuing until the 14th century AD. It became known by the name al-Khamis or Suq al-Khamis mosque from the 19th century due to the market held next to it on Thursdays (Tsuruta et al., 2019). This reflects the two major site complexes at Bilad al-Qadim, with one being the mosque, a former Shi'a shrine and fort and the other being the adjacent market and residential area (Insoll, 2002).

There have been three major excavations in the history of the al-Khamis mosque, the first of which was an excavation and partial reconstruction by the Government of Bahrain in the 1950's (Tsuruta et al, 2019). Further investigation was undertaken by the French team Mission Archeologique Française under Monik Kervran beginning in 1986 from which a floor plan was made, and three architectural phases identified. Finally, a 21st century English team have been doing further work including plans for site renewal and a museum on site (Tsuruta et al., 2019). The most likely sequence of architectural phases from current evidence is that the main mosque was succeeded in the location by a Shi'a shrine and a fortified dwelling, during the primary span of occupation (9th-13th centuries AD) this was a multifunctional site featuring residences and markets. This is from the latest English-led investigations begun in 2001 and are ongoing (MacLean and Insoll, 2003).

As far as the mosque itself the main construction likely occurred 1124-5 AD under the Shi'a 'Uyunid governor al-Malik al-Fadil Abu 'Abd Allah Mohammed b. al-Fadl, with the first minaret constructed 1131-2 AD under Abu Sinan. It is likely that the second minaret or a restoration of the first occurred between 1323-4 AD and that both minarets and the mosque were constructed to their fullest extent by 1582 AD (Potts, 2016). The French excavations identified three construction phases, the first of which is represented by the *qibla* (Western) wall and a piece of floor made of limewashed earth. From this it was thought that the structure had been L-shaped, 8.75m wide next to a graveyard including a tomb which may predate the mosque (Whitehouse, 2003). More material is evident of Phase 2, which gave a clear plan of the building being 8m wide and 6.3m deep, with the preserved *qibla* wall, reused ashlar blocks for new lateral walls and a façade. Each wall featured a single entrance with teak columns and a rectangular courtyard west of the structure (Whitehouse, 2003). The third phase is harder to distinguish and relates mainly to the minarets, and here the epigraphic and textual evidence is helpful, including the *qibla* stone inscriptions, which provide evidence for the Shi'a nature of the mosque and show the presence of two minarets by the 15th century AD (Potts, 2016).

As previously mentioned, this site was multi-functional, reflecting the nature of Bilad al-Qadim and Islamic identity in medieval Bahrain, the focus of the Early Islamic Bahrain Project which considered the mosque alongside the Ain Abu Zaydan spring and the Abu Andra cemetery. This showed the first occupation of the site to have been in the 8th-9th century AD, with a peak in settlement importance in the 11th-13th century AD before a decline to a village level of occupation by the 14th century AD (Insoll et al., 2016). The structure of the mosque is typical of the Umayyad dynasty with the 11th century AD prayer hall and courtyard prior to the 12th century AD expansion under the 'Uyunid dynasty. An additional feature of the mosque was a water tank and supply comparable to the one at the Barbar temple where its primary use was for ablutions (Insoll et al., 2016). The nearby burial mound corresponds to the use of the mosque in its temporal range and peak of use and is likely a natural dune used for Islamic burial purposes based on the alignment and lack of grave goods. The spring is associated with the mosque, possibly reserved for the Sheik, and mainly used between the 11th-13th centuries AD, with some residual materials from the previous three centuries. (Insoll et al., 2016). The al-Khamis mosque has parallels with medieval mosques uncovered at Siraf, Iran, Oman and Samarra and seems to belong to a group of mosques with a wide geographical and temporal range from the 9th century AD. The main features of the al-Khamis mosque that make it suitable for inclusion in this group are its courtyard with access, cemetery association, minarets and small internal dimensions (Whitehouse, 2003).

Evidence from the al-Khamis mosque and wider excavation at Bilad al-Qadim show the links of Early Medieval Bahrain to the wider Islamic world and various trade routes, with ceramics from India, Iran, Mesopotamia and China as well as Fatimid dinar which can aid us in our reconstruction of the contact between the Shi'a Fatimids and Carmathians who resided in Bahrain at this time and were

both groups of Ismaili Shi'a Muslims (Insoll, 2002) (Insoll, 2005). Prior to Islamic control of Bahrain the area was under Sasanian influence and Bilad al-Qadim was a prosperous coastal settlement engaging in trade with the Persian Gulf and its commercial impact rose under Islam from the 6th century AD, with a shift in focus of trade to include the Indian Ocean trade network (al-Naboodah, 1992). Imports to the region included metals, textiles, slaves, and ivory with the region playing a major role in the export of pearls, beads, and dyes. Transshipment was also a focus of this settlement due to the geographic position of Bahrain at a crossroads of trade and place importance in both the Sasanian and Islamic worlds and the material evidence indicates intense participation in Indian Ocean trade as a place on popular Islamic migration and pilgrimage routes, additionally stimulating trade with the Islamic world (al-Naboodah, 1992).

Chapter 3. Literature Review:

3.1. Glassmaking in the Islamic World, a history and overview:

3.1.1. A brief history of glassmaking:

The first artificially produced glass dates to over 5000 years ago and likely was the adventitious result of a glassy by-product of metallurgic or ceramic glazing processes or in the making of the vitreous material faience. Formed by the fusion of silica sources such as sand, containing lime from shells or quartz with a soda-rich flux (containing sodium carbonate) such as a mineral evaporite (e.g. natron) or halophytic plant ashes which are also lime bearing, which serve as a flux to reduce melt temperature, the first vessels were core-formed, using clay or dung, often to emulate semi-precious stones (Chopinet, 2019, 1-6). The origin of glass is in the Middle East, with Egypt and Mesopotamia suggested as places where the first glassmaking occurred. Glass was first produced in large quantities in the Late Bronze Age (approximately 1500 BC) in the same region, with a notable decline in production following the Bronze Age collapse (Ball, 2017). The innovation of blowing glass using rods occurred in the 1st century BC in Palestine and begat the first mass production of glass, leading to the increased use of the material under the Romans (Chopinet, 2019, 1-6). It was this recipe, a Roman low magnesium soda-lime glass made using sand and natron which dominated between 800 BC to 800 AD – the beginning of the Islamic period (Henderson, 2002).

3.1.2. What is meant by ‘the Islamic World?’

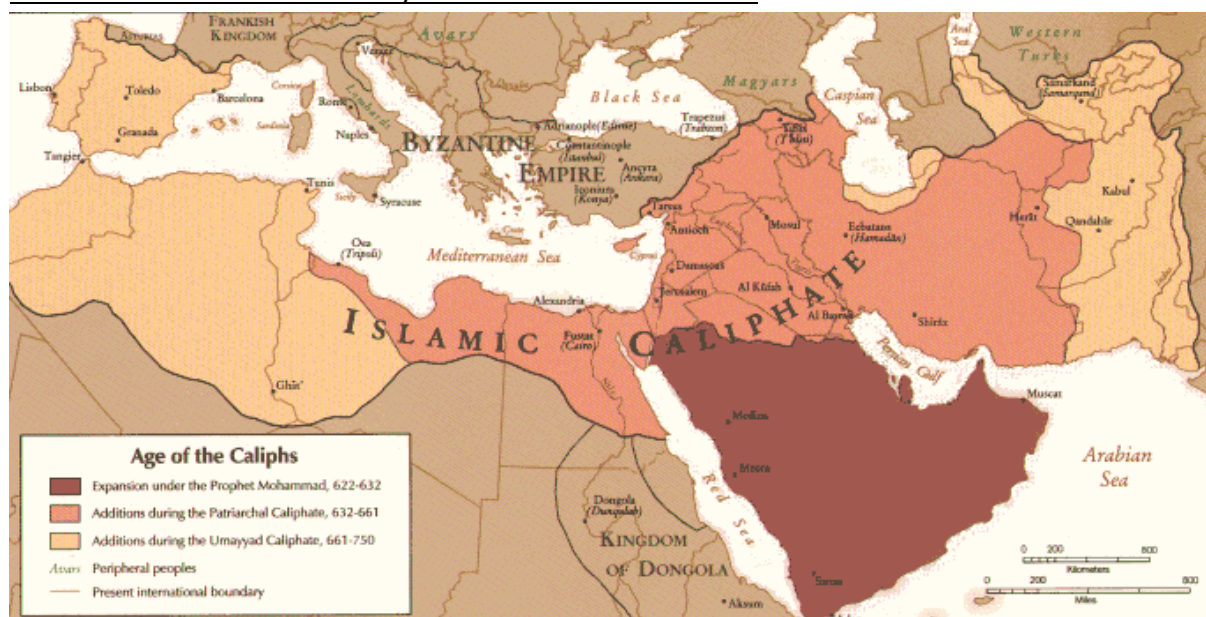


Figure 4. A map of the extent of the Islamic World in the 11th century AD, showing eras of expansion and lands claimed during those periods and under which dynasty (https://upload.wikimedia.org/wikipedia/commons/2/20/Age_of_Caliphs.png, accessed 21/06/2020)

As a landscape, pre-Islamic Arabia was characterised by nomadic tribes from 500 BC, as told in oral traditions of the areas. Mecca existed pre-Islam as a place of political and ceremonial events, including a shrine and although the term ‘town’ may be over-generous, there is evidence of mercantile activity from the 7th century AD (Peters, 2003, 29-32). Allah was worshipped here prior to the life of the prophet Muhammed, who is thought to have been born in the 570’s AD and have been a mortal prophet of the God of Abrahamic religion, here called Allah. The most likely date of the first revelation of Muhammed is around 610 AD and was spread orally, with the literal meaning

of Quran being from the word '*qeryana*' – meaning recital, developing into a more formalised liturgy at Medina (Peters, 2003, 40-46). The prophet Muhammed originated Islam in Mecca and Medina in this way and through this religion and the concept of '*umma*' (one united Muslim community) achieved unification of the dispersed groups of Arabia (Lapidus, 1992). The formal date of the beginning of the Islamic era was decided as 622 AD by the caliph Umar, and by 629 AD Medina was under the control of Muhammed, with Mecca following in the next year and the prophet being hailed as Lord of Arabia between 628-632 AD via conversion of local groups by raids. The descendants of two such converts would go on to rule the later Islamic dynasties of the Abbasids and the Umayyads in Baghdad and Damascus respectively (Peters, 2003, 51-63). From this time until his death in 632 AD the prophet Muhammed was commander of the Islamic lands of Arabia with highest power over legal, executive and military decisions. After his death Abu Bakr was chosen to be the new caliph of the amassed region (Peters, 2003, 93-94). In terms of the line of power from Muhammed the unified Arabia was ruled supremely in state and religious matters first by the prophet himself and then the Rashidun caliphate from 632-660 AD, until the first Muslim civil war, leading to the division of Sunni and Shiite Muslims over the rights of power of the caliphs due to the line of succession of Muhammed (Lapidus, 1992). The Shiite division only recognised the descendants of Muhammed to be caliphs, thus the succession from Ali ibn Abi Talib, his son-in-law and cousin due to the preservation of the prophets' relationship with Allah. The Sunni division differed in that they recognised the historical ascension of the caliphs to have a chosen leader build the caliphate and enforce the rules of Islam, seeing them not as rulers of divine right, but secular kings (Lapidus, 1992). After the Arab conquests of the 7th century AD the early caliphate greatly expanded under the client forces of local tribes and became increasingly secular until the peak of the Islamic World in the 11th century whereby religious and state communities were distinct and a 'golden age' of trade, innovation and inspiration had begun (Lapidus, 1992). On the basis of this power consolidated by the prophet the Islamic faith spread quickly under the Khalifahs until 661 AD, after which the growing Islamic world was controlled by various dynasties over differing areas at different times. Geographically, the peak extent of the control of the Islamic dynasties was in the 11th century AD, covering a vast expanse from Spain to Central Asia, and influences far beyond. The Abbasid and Umayyad dynasties governed vast and united Islamic states, with succeeding states being smaller regional dynasties, such as the Ottomans, Safavids and Mughals (Henderson, 2013, 252-278).

3.1.3. The Major Influences of Islamic Glassmaking:

By the time of the 7th century AD Arab conquest locations in the Islamic World were involved in the production and working of glass, but there was not an immediate Islamic style of glassmaking until the 9th century AD (Carboni and Sabah, 2001) (Phelps, 2018, 236-282). Prior to the establishment of Islamic glass in the 9th century AD, most glasses were made in tank furnaces using Belus river Levantine sands and Egyptian natron, although there was a small amount of plant ash glass made by the Sasanians, it was not developed due to the lack of the structure of society necessary to foster such innovation (Henderson, 2013, 252-278, 279-305). The first glasses made under Islamic rule were made using glass recipes and techniques from the Roman/Byzantine and Sasanian traditions including glass blowing, the use of moulds and decorative application of glass to vessels (Carboni and Sabah, 2001). As well as the continuation of the way glass was made by artisans in formerly Byzantine and Sasanian lands, their function seems to have been continuous, most prominently in terms of interior architectural decoration. This is seen in the use of glass tesserae for mosaics such as at Hagia Sophia in 537 AD, a Byzantine cathedral, and the building of a palace at Ctesiphon by the Sasanian Khusrau I after the sacking of Antioch (Saba, 2016). The continuation of the use of these

techniques in the lands conquered by Islamic rulers that were centres of glass production and working, such as Syria, Iraq and Egypt are likely the reason for the continuing prominence of glass mosaics under the Umayyad dynasty, the most notable of which is the earliest surviving Islamic monument, the Dome of the Rock in Jerusalem dated to 691 AD (Saba, 2016). It is thought that part of this artistic link was drawn from the use of Byzantine mosaicists being invited to work on Islamic project, with mosaic, tile work and inlay in particular being continued decorative traditions through the transition from Byzantine and Sasanian to Islamic rule (Labatt and Appleyard, 2004). The reason for the persistence of these traditions is likely due to Sasanian and Byzantine artisans in now Islamic regions working in their own learned styles but under Muslim patrons. This meant when a distinct Islamic style of art in glass did emerge, it contained a blend of Iranian and classical themes and motifs, merged with Islamic function (Department of Islamic Art, 2001). The Umayyad dynasty is often regarded as a formative period in Islamic art and led to a time where a distinct and unique style emerged, usually categorised by dynasty. Within this overarching Islamic style there stemmed many regional and national styles with their own characteristics but retaining the basic unifying theme of Islamic art - full surface decoration. The four major components of the Islamic style of ornament are figural representation, geometric and vegetal patterns and calligraphy, with the vegetal and geometric styles being most prominent in art made of glass (Department of Islamic Art, 2001).

3.1.4. The Natron-Plant Ash Transition Period and Early Islamic Glass:

The emergence of a distinct Islamic style of art in glass occurring in the 9th century comes at the same time as a major event in the history of glassmaking, the movement from the use of mineral soda deposits (e.g. natron) to the use of halophytic plant ashes as an alkali flux in primary glassmaking alongside a change in location of production (Phelps et al., 2016). The main prompt for this change in raw material usage was the drying up and lack of access to the necessary mineral deposits, with most glasses prior to 1000 AD being made from Egyptian mineral soda, as categorised by Sayre and Smith. This homogenous type indicates the model of production to have been due to the constant use of raw materials at a small number of primary glassmaking sites (Henderson, 2002). This decline in sources of natron was a gradual process meaning that the centralised Byzantine glass production preceded the last significant making of natron glass under the Umayyad dynasty and the Early Abbasid. Due to the gradually restricting access, just before the use of plant ash became dominant, there was a large influx of Egyptian imports due to their priority access to natron (Phelps et al., 2016). In the 7th-8th centuries AD it can be seen that there was little Islamic control over the primary production of glass, as the Arab conquest saw major political and social change in the region, but comparatively little material changes, but as the deposits dried the natron glass industry greatly declined and by the 9th century AD the supply of glass from the region diminished also (Phelps et al., 2016). The effect of the decline in access to natron is shown in analyses of Late Byzantine and Early Islamic tank furnace glasses, where the higher natron type Levantine 1 becomes lesser common over time than Levantine 2, a lower natron recipe used when production was moved under Islamic rule to Bet Eli'ezer (Brems et al, 2018). In the 8th-9th centuries in the Islamic world a time of innovation and experimentation is seen archaeologically regarding glass primary production and recipes. At Ramla there is continued use of known types into the 8th century, but then a shift in recipes and imports can be seen. All three glass compositional groups identified at Ramla begin to show recipe alteration concurring with the beginning of the Abbasid dynasty, as well as an increase in the use of plant ashes as flux (Phelps, 2018). At both Ramla and Bet Eli'ezer a phase of regional distinction can be seen while adjusting to resource supply with an 'Islamic type' identified from the 8th century AD, this may also be seen as experimentation, as is the interpretation of the great glass

slab which failed at Bet She'arim (Henderson, 2002). The palatial complex at al-Raqqa best illustrates this transition, the emergence of the new Islamic tradition and the nature of industry in the Islamic world, with four compositional groups being identified by electron probe microanalysis and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). The complex was occupied across the transition period of the 8th-12th centuries AD and was the capital of the Abbasid caliphate between 796-808 AD (Henderson et al., 2016). Of the four groups, three use plant ashes as a soda source with variable silica sources (sand and quartz) and one uses natron. The examination of the glasses found at this site show the first known production of an Islamic high magnesia plant ash and quartz recipe to replace the Roman/Byzantine natron and sand predominant recipe. Two of the types (1 and 3) are homogenous and well reproduced indicating a well-controlled process carried out by skilled artisans (Henderson et al., 2016). Type 2 sits between the natron and plant ash groups and may be reflective of mixing alkali sources or recycling but type 4 has the widest compositional range and fits the criteria of an experimental glass recipe – a major feature of the emergence of Islamic glass and startling archaeological evidence of experimentation (Henderson et al., 2016). It can thus be seen that by the 9th century AD there was the creation of distinctly Islamic glass compositions from industrial experimentation over time, with al-Raqqa as a key site for evidence of this. The large-scale production of glasses using plant ash technology was sanctioned and funded by the caliphs, making the revival of the use of plant ash as a glass ingredient quintessentially Islamic (Henderson, 2013, 279-305). Prior to the 9th century the Islamic World leaders had little control over glass production and artistic input of the workers to their crafts and a general continuation of the old glassmaking traditions was seen (Henderson, 2013, 252-278). However, the 9th century was the time that from the former Sasanian and Roman/Byzantine influences a uniquely Islamic glass tradition was forged, made possible by the centralisation and organisation of the Early Umayyad and Abbasid dynasties which fostered innovation and experimentation in craft industries (Henderson, 2013, 279-305). 640 AD saw the beginning of glass production on a huge scale in an urban environment under the caliphs which oversaw artisanal innovation of various technologies including a distinct phase of reaction to external difficulties in material sourcing (Henderson, 2002). From scientific analysis of glasses from this transition period a decentralised model for the production of Islamic glass becomes clear, including regional and sub-regional hubs for glassmaking, recipes being specific to form and regional specialisation in the form of diagnostic decoration (Henderson et al., 2016). With these new compositions and such a highly developed industry the 9th century AD also saw distinctly Islamic artistic forms and styles in glass, notably relief-cut decoration, lusterware, gilding and enamelling with the most common forms being mosque lamps, bottles and beakers as well as the necessary everyday wares (Henderson, 2013, 252-278). Through this transition a uniquely Islamic glass was produced and well-recognised by the 9th century AD both compositionally and artistically.

3.1.5. Middle and Late Islamic Glass:

The Early Islamic period is usually considered to have been between the 7th-12th centuries AD when the caliphates were consolidated and power as well as geographical extent of the empire was at its peak. The Middle Islamic age is from the 12th-14th century AD and is the golden age both in terms of the Islamic World and glass production within it. Although this period does see the caliphates change in region and power and conflict is not uncommon, commercial enterprises including glass trade was steady and maintained, even throughout major dynastic changes (Henderson, 2013, 252-278). Once set up in the 8th-9th centuries the next 800 years of Islamic rule a decentralised model of glassmaking production was established characterised by its broad geographic zones and regional sub-zones (Henderson et al., 2016). Production in this period was highly regulated and was undertaken in principal production centres which moved as the caliph did and with the supply of raw materials.

This would typically be in terms of an industrial complex associated with the caliphs' residence in the dynastic capital, with examples of such centres being Aleppo, Baghdad and Cairo. As the dynasties split and became more regional in the Middle and Late Islamic period, production tended to stay in Syria and Egypt due to the access to raw materials of established recipes (Henderson, 2013, 252-278). This variation in the extent of the domain of the various dynasties prompted changes in artisanal techniques and raw materials, with the Ayyubid and Mamluk dynasties seeing a rise in the use of gilded and enamelled ornaments and mosque lamps being the defining vessel form of the era (Henderson, 2013, 252-278). The idea of later production being focussed in Syria and Egypt after losing parts of Persia and Mesopotamia can be seen in the mosque lamps recovered from Cairo and Ctesiphon in the 14th-15th centuries AD which bear Egyptian style and decoration, but compositionally are of Levantine origin (Henderson et al., 2016). The major division of the Islamic world into regional dynasties mainly occurred between the 15th-16th centuries AD, and was a major part of the Late Islamic period up to the 19th century AD. A major facet of this period in glass working was the Ottoman involvement in the glazing industry from 1419, which saw groups of artisans moved for projects, including the Masters of Tabriz, with some examples of this work seen in minarets and mosques (Henderson, 2013, 252-278). The powers these regional dynasties had were lesser in comparison to the Abbasid and Umayyad dynasties, but were still significant, with three large regions being established after the collapse of the Timurid dynasty in Iran and the Mamluk dynasty in the Near East (Carboni, 2001, 275-281). In Iran the Safavid, Zand and then Qajar dynasties held power until the 19th century AD, whereas in Anatolia the Ottoman empire was established in 1281 which not only maintained power into the 19th century but expanded as a vast and powerful empire in its own right. The Mughals reigned prevalently in India between the 14th-19th centuries AD and played an integral part in Indian Ocean trade. The dynasties in all regions patronised the arts but not in the way that the 10th-14th century dynasties had facilitated innovation, and as such no glass of these dynasties can be linked to royal patrons, unlike those preceding them and a general decline in the glass industry occurred from the 15th century AD (Carboni, 2001, 275-281). Mughal India differs in terms of glass production, continuing to make decorated beads and bangles, as well as a specialisation in opalescent forms while still producing everyday wares as far as the 19th century AD. Even here the influence of European glassmaking, especially Venetian, can be felt, as they overtake the monopoly of glass production. There is a notable gap from the 13th-17th century AD of glass in Iran, with the last development there being long necked vessels, and there are records of glass imports from Venice to the region. The Ottomans establish a local manufacture in the 18th century AD at Istanbul, but their glass making ends with the collapse of the empire (Carboni, 2001, 275-281). It can be seen that the peak of glass production and trade was best facilitated under the early unifying Islamic dynasties, and that from the 15th century AD onwards, the Islamic world was replaced as the premium glass production centre of the world.

3.1.6 Glass Compositions of the 1st Millennium AD:

Before the emergence of Islamic plant ash glasses the majority of glasses were comprised of a soda-lime-silica composition made from mineral soda, mostly natron from Egypt, and lime-bearing sands from the banks of the Levantine Belus river. These glasses are generally characterised as being high or low in magnesia depending on raw materials, with high more than 1.5% weight (wt) and low being below this (Freestone, 2006). After the Roman natron and sand low MgO glasses of the early first millennium AD, 5 major compositional categories are found across the Middle East from the 4th-7th centuries AD – Levantine 1, Levantine 2, Egypt 1 and Egypt 2 and HIMT (High iron manganese titanium). HIMT glasses are characterised by CaO contents of 5-6% wt, Fe₂O₃ contents between 3-4% wt, and positively correlated aluminium, iron, and titanium (Ceglia et al., 2015). Late Roman and

Byzantine low MgO natron glass with a gradual alumina and soda content increase from the 4th century AD is known as Levantine 1 type as seen at Jalame, to the 7th century AD composition being typified at Apollonia (Henderson, 2002). This was the predominant glass type in the region during this period, with primary production of Levantine 1 being a Syro-Palestinian tradition which monopolised the glass market (Ceglia et al., 2015). Levantine 2 contrasts to this type being the higher alumina, lower lime and low soda glass produced at Bet Eli'ezer between the 7th-8th centuries AD (Freestone et al., 2015). The glass type known as Egypt 1 is associated with Islamic primary production in the 7th-8th centuries AD at Wadi al-Natrun and is characterised by high magnesia (0.92-1.34% wt) and low lime (2.6-4.5% wt). This is a lesser common type of a very fine quality and may have been reserved to produce luxury glass-ware (Ceglia et al., 2015). Egypt 2 has higher lime contents with lower alumina than Egypt 1, divided into higher/lower soda subgroups, which are produced into the 9th century AD. Plant ash glasses do not appear in Egypt until this type ceases to be used, which may indicate the slow process of the diminished natron sources leading to this transition. This type is more common throughout the early Islamic world and declines at the beginning of the Abbasid dynasty (Schibille et al., 2019). After this there is a period of experimentation, with the short-lived use of glasses fused from plant ash and sand having been evidenced at al-Raqqā. This is considered an experimental technological step prior to the use of a plant ash and crushed quartz recipe which would become representative of Islamic glass also seen at al-Raqqā (Henderson, 2002) (Henderson, 1999). An additional group of glass types commonly found as Indo-Pacific beads is present throughout the Islamic period, thought to originate from India and Sri Lanka, such as those found at Quseir al-Qadim. The main types of these beads are known as v-Na-Ca (high MgO and K₂O with low Al₂O₃ made using plant ashes), v-Na-Al (high MgO, K₂O and Al₂O₃, also made with plant ashes) and m-Na-Al (low MgO and K₂O, high Al₂O₃, made with mineral soda) (Then-Obluska and Dussubieux, 2016). Found since the 2nd century AD, these beads are thought to have been made in centres in South India, Sri Lanka and later on the East African coast and were widely traded and thus commonly found throughout South East Asia and the Far East (Carter, 2016). Glasses of various types across all these regions and time periods have been compared to the results of the analysis of the Mantai and Bahraini glasses, to give the best chance of attaining a provenance for them.

3.2. Indian Ocean Trade:

3.2.1. The History of Long-Distance Trade in the Indian Ocean:

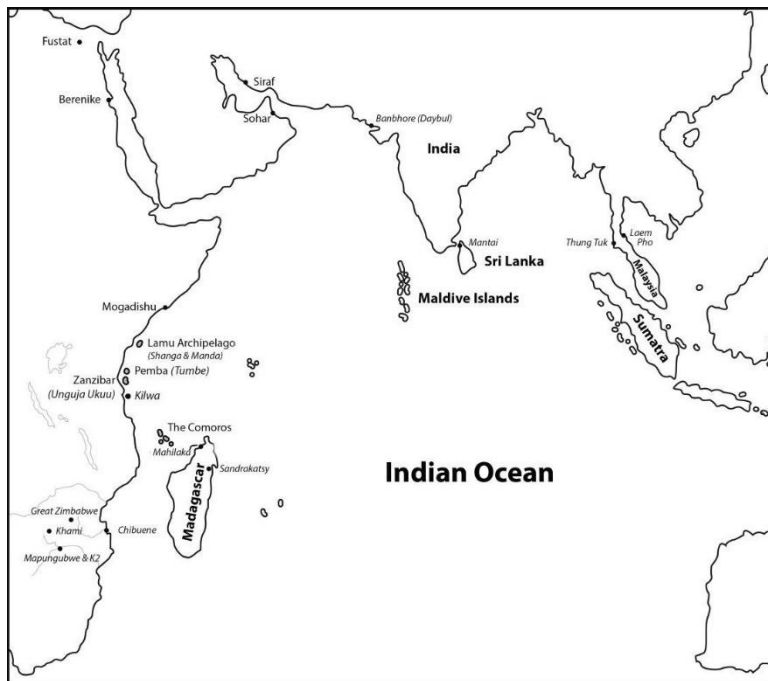


Figure 5. A map of the Indian Ocean region, from Wood, 2015, Figure 1, from <https://journals.openedition.org/afriques/1782>

Although trade in the Indian Ocean region is not well-documented until the presence of the Jewish and Islamic trade networks, a vast and long-lasting series of networks and trade preceded this. These networks were dependent on the monsoon seasonality which dictated seafaring and meant merchant activity involved being away from home for extended periods of time. However, the winds of the monsoon are what positioned the Indian Ocean region as a central trade hub of the ancient world. Over the Arabian Sea the monsoon winds blew south to west between June and October, and east to north during the

November to May period, allowing a predictable route of passage (Seland, 2013). The annexation of Ptolemaic Egypt gave the Romans control of the Red Sea and its ports, as well as the ability to monitor and tax imported and exported goods with material evidence for this seen from Egypt, Eastern Africa and India suggesting the late 1st century AD was the peak time for Indo-Roman trade. This strengthened the ties between the Indian Ocean, Red Sea and Persian Gulf in terms of trade. Roman participation in this trade network continued into the 2nd century AD with strength before its decline into the 3rd century AD likely due at least in part to the effects of the Antoine plague and civil unrest in Egypt (Cobb, 2015). This brought the Mediterranean more tightly into Indian Ocean trade, the Roman involvement marked a new era for Indian Ocean trade and even in post-Roman rule the Mediterranean participated more intensely as witnessed by the occupation at the Egyptian Red Sea ports, Roman finds across the region and literary accounts (Cobb, 2015).

3.2.2 Indian Ocean Trade during the Islamic Period:

In terms of geography, the Indian Ocean in the Islamic period served as a link between Africa, Asia and the Mediterranean which gave it huge importance as a point of multicultural gathering and a hotspot for the diffusion of ideas and technologies (Burke III, 2009). The focus of Indian Ocean trade shifted towards South East Asia from the 7th century AD but it is uncertain whether Islam was a travelling ideology which rode the networks of exchange with the commercial goods or if they were simply circulating at the same time. The former is more likely due to travelling religion in Islam, for example pilgrimages and the Hajj, making the religion a more lived reality for many people along the Indian Ocean route between the Middle East and China (Tagliacozzo, 2014). The spread of Islam transmitted a moral critique of inherited power due to the view of the succession of the caliphs in

Sunni Islam into Southern and South-Eastern Asia, as well as technologies, such as those of water irrigation systems. It is through this view that Islam can be seen as a conduit for the acceleration of cultural and intellectual diffusion throughout the Indian Ocean region, especially in its early dynasties as it manifested itself in one government, language and religion (Burke III, 2009). The development of the Hindu-Arabic numeric system too was a unifying factor for the region and enhanced the economic and political expansion of the Islamic world, in one monetary administrative system (Burke III, 2009). The stability attained in the region after the Islamic conquest is conducive to a system of trade in the Indian Ocean as the centre of a world of connections in the mercantile and cultural sense through which Islam moved via significant maritime locations functioning as ports of trade or entrepôts, linking the two great powers of Islam and China (Ghosh, 2019). 6th century AD reunification of lands in China and South-East Asia also contributed to the urban development and organisation which made this network possible and the stability attained by the 9th century AD led to a reorganisation of trade in the Islamic and Chinese worlds to reflect the existing system in the Indian Ocean, with more of an onus on regional and segmented trade (De Saxcé, 2016). This can be exemplified by the Sri Lankan capital of Anuradhapura, which depended on riverine links to the maritime entrepôt of Mantai 80 km away. Excavation revealed material indicative of intense trade with both the East and West including Abbasid lusterwares, Mesopotamian Torpedo jars and blue glazed wares. This shows even inland sites of importance partaking in and relying on the connections facilitated by the international exchange of the Indian Ocean under the Islamic World (Coningham, Manuel and Shoebridge, 2016). In the first half of the second millennium AD the Indian Ocean region can be seen as the centre of gravity for the Islamic economy, as a link to the Far East and China. From this can be seen the changes in production technologies and the reciprocal relations of Tang Chinese and Abbasid dynastic industry at the peak of both of their power influence in the 9th-10th centuries AD (Stargardt, 2014). The nature of this interaction and, more importantly, the nature of Indian Ocean trade during the Islamic period can be illustrated from evidence recovered and interpreted from shipwrecks, such as the Intan, Cirebon and Belitung wrecks. The Belitung, the earliest of the wrecks, exhibits a particular juxtaposition between items considered to be high status or luxurious, and goods designed for an everyday use, but does not contain any Abbasid glass, likely due to the fact that it began its journey from China towards the Middle East (Stargardt, 2014). The contents of the Intan and Cirebon wrecks relay more information on the nature of trade in the Indian Ocean region, reflecting the visitation to multiple ports of trade or entrepôts and contained glass from the Abbasid Islamic world, which was highly prized in China, being the centre of the glassmaking world. The wrecks overall show the place of Indian Ocean trade as reaching its peak under Islamic influence, and the existence of a fledgling globalised network (Stargardt, 2014). The influence of Islam in trade occurring in this region is attested to in literary sources by Arab geographers, the presence of ritual items and iconography reflecting the intense contact with Islam and the reciprocal products these regions exported, including forest and sea products, such as pearls (Ghosh, 2019).

3.2.3. The Nature of Trade in the Indian Ocean in the First Millennium AD:

Trade in the first three centuries of the first millennium AD in the Indian Ocean were characterised by Roman use of the Red Sea ports of Egypt following its annexation into the empire as a maritime link from the Mediterranean to the Indian Ocean, and via this network – South and South East Asia and China. Commercial activity with the wider Indian Ocean world was funnelled by the Romans through these ports, notably Myos Hornos, Berenike and Clysma. The first two of these particularly occupied roles as entrepôts allowing control of import and export of goods in the empire and

taxation, receiving cargo from East Africa, India and Arabia while serving a transshipment purpose for everyday goods. At the height of these ports' involvement in trade literary sources such as Strabo attest to 120 ships being sent from Myos Hornos to India alone every year (Whitewright, 2007, 77-88). As aforementioned, from the 7th-11th centuries AD the Islamic Middle East established economic superiority in the region with strong links to their neighbours, the Indian Ocean and the Mediterranean following the decline of Roman control. At the time of Islamic expansion the caliphs were quick to build a monopoly on trade with the Far East and China, Indian Ocean, South and South East Asia, Byzantium, the Mediterranean and East Africa, unified by the monetary system based on gold dinar and silver dirham. This led to the emergence of an Indo-Islamic civilisation from the 11th century onwards, especially in East Africa under the Ghaznavids (Wink, 2002, 3-27). Once established this newly formed proto-global trade network was based on nodes of mercantile activity and hubs of craft production and distribution, and the links connecting them. The port cities and entrepôts connecting them took on a cosmopolitan nature as rival merchant groups jostled for control of maritime space, with the port of Kish taking precedence in the Persian Gulf and Dahlak being central to inter-regional trade in the Red Sea region (Margariti, 2008). 'Piracy' was also prevalent in the region, but in a form unlike that which we conceive today, as there is a distinction between actions of this nature in ones own interest as opposed to on behalf of a group, ethnicity or region. This was part and parcel of Indian Ocean trade at the time of the height of Islamic power, with cosmopolitanism maintaining the interconnected nature of trade at the time, giving it the mobility and dynamism a strong maritime commercial network requires. In addition, the freedom that mercantile activity gave to peoples of this region meant freedom from subjugation by agrarian elites and being tied to the land, giving the opportunity for geographic and social mobility to the ordinary person (Margariti, 2008). As the integral point in the long route between Eurasia, East Africa and China a culture of shipping involving people of many ethnicities had long been established and the port rulers were wise to use their maritime experience to enhance the advantages of their domains to elevate themselves. Kish overtook Siraf as the premier entrepôt of the Persian Gulf by its command of the routes to India while Dahluk was disadvantaged by the difficulty presented in its access by sailing, but made up for it with the products it offered to the market as well as taking advantage of its precarious waters to become an entrepôt specialising in salvage. These places exhibited state as well as mercantile power, with the ability to raise ships and the Ayyubid and Rasulid dynasties using considerable naval power to develop these ports into city states, with some activity that could be considered piracy at the time (Margariti, 2008). The nature of trade in the Indian Ocean was well established prior to the rise of Islamic power, but what did happen under Islam to modify this was the enlargement of religious and cultural ties as the religion spread east under the concept of *umma*, and Islam expanded both as a religion and way of life. Between the late 7th-15th centuries AD there was clear direction and structure to the huge trans-continental maritime traffic from South China to the Eastern Mediterranean (Chaudhuri and Chaudhuri, 1985, 36-44). The vast distance geographically and culturally of the consumers and producers meant that the traded commodities had to be made such that they could be easily economically and culturally integrated, thus the majority of trade occurred in shorter voyages following the direction of regional markets. A major development in this came by the 9th century AD with the rise of Malacca and the intermediate ports of Eastern Africa which became integral to the circuit by this time and increasingly urbanised by migrants from Arabia and South Asia (Chaudhuri and Chaudhuri, 1985, 36-44). Overall, the nature of Indian Ocean trade is seen in the power of the entrepôts which facilitated trade across such vast distances by breaking voyages up and calling along the coast, meaning more areas and their hinterlands were integrated into the circuit economically and culturally.

3.2.4. Mantai and Bilad al-Qadim as Emporia in Indian Ocean trade:

During the Islamic period the four major civilisations commercially interacting in the Indian Ocean region were the Far East, especially China, Islam, India and a focus of trade from the 8th-9th centuries AD – South-East Asia. These regions experienced significant urbanisation through the expansion of Islam, and in the Far East with the reorganisation of these lands in the 6th century AD (De Saxcé, 2016) (Chaudhuri, 1990, 80-81). Emporia in the Indian Ocean was the foundation on which the structure of regional trade functioned throughout the Islamic period. The basic model was that commercial emporia had the means and power to distribute economic products further into the surrounding hinterlands, as well as to use the viable and desired products of the region to trade for economic benefit and to gain access to otherwise unavailable goods (Chaudhuri and Chaudhuri, 1985, 98-105). Investigations at Mantai have given indications of it being a typical maritime entrepôt, with its central position giving it access to links in all directions and major civilisations. The finds have linked it to the old Sri Lankan capital of Anuradhapura and indicate the port to have been a centre of religious, political and cultural exchange and having a major role as an intermediary between the Islamic and Chinese worlds throughout its occupation (De Saxcé, 2016). This is mainly due to its geographical position and established link to South India via Adam's Bridge, giving it maritime access to the other ports and markets along the coasts of India, East Africa and the rest of South East Asia. More than a node of mercantile activity, Mantai served as a hub of trade between the Arabian Sea, India and the Bay of Bengal, with archaeobotanical evidence indicating its use as a transshipment centre for basic cereal foods and some exotic foodstuffs. The array of foods at the port transshipment area contrast to those found in the occupational part of the settlement show the presence of a cosmopolitan population, active in the trade of consumer goods, the transshipment of organics and exchange of spices, ceramics and, notably, glass beads (Kingham-Banham et al., 2018). The connection of Mantai to Anuradhapura was by river and brought produce far into the hinterland of the port, providing access to craft complexes where ceramics, bitumen and more glass beads have proven this link, cementing its function as one of the most important emporia in Sri Lanka, if not the premier at this time (Coningham, 2016, 31-52). Ceramic proxies including Rouletted ware have confirmed the importance of Mantai as an entrance point between Sri Lanka and South India, as well as the importance of the country rising under Islam as a hub linking the Persian Gulf and Red Sea being fully integrated into the Indian Ocean network and reaching far beyond (Seland, 2014). Bilad al-Qadim in Bahrain shares a fortunate position in terms of its strategic location and is like Mantai in the fact that it served as a regional centre of commerce as well as its position in wider trade. Again, the settlement has maritime access to all areas involved in Indian Ocean trade, and these connections necessarily run through here due to sea conditions rendering direct navigation past unsafe, whereas Bahrain can be accessed through the unchanging monsoon winds (Seland, 2014). Trade from this location had been encouraged with the Persian Gulf region prior to the establishment and spread of Islam and under the influence of the Abbasid dynasty it gained additional links to the Far East, India and Arabian Gulf. Due to the position of an existing coastal town at Bilad al-Qadim the settlement was prime for maritime trade and was a target for control being near the Sasanian border in early Islamic empirical expansion. Due to its location, under Islam it became a crossroad for not only traders, but also pilgrims to holy sites in the Middle East, increasing the intensity of activity of the port in Indian Ocean trade, where its main roles were transshipment, cloth redistribution and the export of pearls and dates (al-Naboodah, 1992). The excavations and considerations of material from Bilad al-Qadim show it to have been the centre of Islamic activity in Bahrain from the Early Islamic period, and that the people there would have primarily been Muslims. In addition to the Chinese ceramics and Abbasid glass, findings of butchered pig, considered haram in the Islamic faith, reveal the cosmopolitan nature of the site and its function

as a busy node of mercantile activity (MacLean and Insoll, 2003). From this it is shown that both Mantai and Bilad al-Qadim functioned as cosmopolitan emporia of the Indian Ocean but under the considerable influence of Islam, as witnessed by the recovered material evidence, into the 14th century AD.

Chapter 4. Materials and Methods:

4.1. Materials:

Sample Number:	Site of Origin:	Colour:	Description:
MANT1	Mantai	Cobalt Blue	Raw Glass
MANT4	Mantai	Opaque Orange	Raw Glass
MANT5	Mantai	Pale Green	Raw Glass
MANT6	Mantai	Opaque Red	Disc
MANT8	Mantai	Intense Dark Brown	Raw Glass
MANT9	Mantai	Pale Green	Vessel Base
MANT10	Mantai	Translucent Purple	Raw Glass
MANT12a	Mantai	Red	Raw Pulled Glass
MANT12b	Mantai	Turquoise	Raw Pulled Glass
MANT13	Mantai	Colourless	Plate
MANT14	Mantai	Cobalt Blue	Raw Glass
MANT15	Mantai	Blue	Undiagnostic
MANT17	Mantai	Aqua Green	Raw Glass
MANT19	Mantai	Turquoise	Raw Crucible Glass
MANT20	Mantai	Opaque Red	Raw Glass
MANT21	Mantai	Colourless	Tesserae
MANT22	Mantai	Intense Dark Green 'Black'	Raw Glass
MANT23	Mantai	Opaque Red	Raw Glass
MANT24	Mantai	Pale Green	Flask
MANT25	Mantai	Colourless	Bowl
MANT26	Mantai	Cobalt Blue	Bottle Neck
MANT27	Mantai	Emerald Green	Bowl
MANT28	Mantai	Pale Olive Green	Flask
MANT30	Mantai	Intense Dark Green 'Black'	Armlet

Table 1. Summary of glasses from Mantai analysed.

4.1.1. Glasses analysed from Mantai:

Of the glasses obtained from Mantai, Sri Lanka there are 23 samples analysed summarised in the table above. There are two major glass types present in this assemblage, the larger being a soda-lime-silica composition, and the other being soda-silica-alumina. Of the glasses analysed 52% of the samples have been identified as raw glass, and almost every colour present in the assemblage is represented here as raw glass, including cobalt blue, pale green, opaque orange, dark brown, red and turquoise. 26% of the samples have been identified as vessel form fragments including flasks, bowls and bottles, mostly in shades of green, cobalt blue and some being of colourless appearance. The remainder of the samples (22%) are represented by one colourless tesserae, a piece of intense dark green or 'black' armlet, an undiagnostic blue fragment, a piece of opaque red disc glass and a colourless piece of plate glass. In terms of colour and appearance, four samples are opaque glass (3 red and 1 orange), three are colourless and three are an 'intense dark colour' close to black, but two are green and one is brown. The rest of the samples are various blues, either pale (possibly natural) and cobalt, greens (again some are likely natural), aqua and turquoise. Notably there is one translucent purple and one transparent red sample in the assemblage.

4.1.2. Glasses analysed from Bahrain:

Sample Number	Site of Origin:	Colour:	Description:	Estimated Date:
BAH1	Police Mosque	Not given	Glaze from Kiln	
BAH3	Al-Khamis	Cobalt Blue	Armlet	
BAH4	Al-Khamis	Brown	Vessel Rim	
BAH5	Al-Khamis	Colourless	Handle Tip	
BAH6	Al-Khamis	Colourless	Flat Flask Base	
BAH7	Al-Khamis	Colourless	Flattened Rim Flask	
BAH8	Al-Khamis	Cobalt Blue	Vessel Fragment	
BAH9	Al-Khamis	Turquoise Translucent	Vessel Fragment	
BAH10	Al-Khamis	Colourless?	Ribbed Mould Blown Neck Bottle Fragment	
BAH11	Al-Khamis	Opaque Turquoise	Armlet	
BAH12	Al-Khamis	Colourless	Thick Vessel Rim	
BAH13	Al-Khamis	Colourless	Flask Rim	
BAH14	Al-Khamis	Colourless	Thick Bowl Rim	
BAH20	Police Mosque	Cobalt Blue	Undiagnostic	8th to early 9th c. AD
BAH21	Police Mosque	Green	Flask	8th to early 9th c. AD
BAH22	Police Mosque	Pale Blue	Flask	9th to 10th c. AD
BAH23	Police Mosque	Colourless	Undiagnostic Vessel Fragment	9th to 10th c. AD
BAH24	Police Mosque	Aqua	Window	9th to 10th c. AD
BAH25	Police Mosque	Pale Green	Base Plate	9th to 10th c. AD
BAH26	Police Mosque	Pale Cobalt Blue	Kick	9th to 10th c. AD
BAH27	Police Mosque	Pale Green	Base	9th to 10th c. AD
BAH28	Al-Khamis	Turquoise Translucent	Undiagnostic	11th c. AD
BAH29	Al-Khamis	Pale Blue	Base	11th c. AD
BAH30	Al-Khamis	Colourless	Rim	11th c. AD
BAH31	Al-Khamis	Colourless	Base	11th c. AD
BAH32	Al-Khamis	Pale Purple	Shoulder Flask	11th c. AD
BAH33	Police Mosque	Purple	Rim	Mid 11th to 12th c. AD
BAH34	Police Mosque	Dark Purple	Rim	Mid 11th to 12th c. AD
BAH35	Police Mosque	Green	Pedestal Base	Late 12th to 13th c. AD
BAH36	Al-Khamis	Colourless	Bottle Neck	13th to 14th c. AD

Table 2. Summary of Bahraini Glasses from the 2001 Excavation of the Al-Khamis Mosque area, if date is not given it is undetermined.

The Bahraini glasses excavated by Timothy Insoll are summarised in the above table, with most of them being given an approximate date based on typology. There are 30 samples in total, with 40% being from the excavation site designated as the Police Mosque and the remaining 60% being from the site of al-Khamis itself. Of the glasses from al-Khamis 12 have no approximate date, with all but one of the Police Mosque samples have been given a date range. In terms of colour 50% of the al-Khamis glasses are colourless and most of these have been attributed to dates from the 11th century onwards (of those which have been attributed a date), with most of the colourless samples in the assemblage having been recovered from the al-Khamis site, and only 2 from the Police Mosque. After this the colour most represented are blues ranging from strongly coloured cobalt blue to pale blue and translucent and opaque turquoise which accounts for a third of the al-Khamis samples which are more common here in the earlier 8th-9th centuries AD. The remaining glasses are represented by one brown fragment and one pale purple (BAH 4 and 32 respectively). Of the glasses from the Police Mosque, the majority of 9th-10th century AD samples are accounted for here, with rim glass fragments being the most common find here in the 10th-11th centuries, with the al-Khamis samples also seeming to be vessel fragments, mostly rims and bases and one armlet. At the Police Mosque, green is the most common colour accounting for 42% of samples, followed by blues at 25% and two purple samples, BAH 33 and a dark BAH 34.

4.1.3. Sample Handling and Preparation:

As electron probe microanalysis (EPMA) provides characterisation of the homogeneity of a sample on a micron scale, the glass samples must first be mounted in epoxy resin for their placement on the stage for analysis. It is also recommended that resin stability tests are done due to the potential damage to the surface of the sample by high electron beam energies (Wilson, 2017). After this the sample surface is cleaned using distilled water in an ultrasonic cleaner to avoid contamination from lapping plates or fluids before being polished mechanically (to eliminate shadow effect during analysis), using diamond paste (Wilson, 2017). It is then that the samples are coated with carbon under a vacuum and mounted on the stage, with the application of conductive carbon being done to prevent excessive static charge build-up (Wilson, 2017) (Lankton et al., 2016).

4.2. Methods:

4.2.1. Background of Conducted Analysis:

The analysis of these glasses was undertaken at the archaeological laboratories of the Department of Humanities at the University Park campus of the University of Nottingham. The analysis was done via EPMA-WDS (electron probe microanalysis with wavelength dispersive spectroscopy) by an instrument featuring 4 WDX spectrometers featuring secondary and backscattered electron imaging. The model of EPMA used is a JEOL JXA-8200 Electron Microprobe, which can detect wavelengths from 0.087-9.3nm and has an analysable area of 80x80mm and a magnification range of x40-x300000. The specimen stage is suitable for 25mm polished epoxy resin blocks and the EPMA has a detectable element range of barium to uranium. The results used here were from previous analysis done under the supervision of Dr. Julian Henderson as sampling and analysis of these glasses was prevented due to restrictions placed on access to necessary facilities as a result of the ongoing COVID-19 pandemic, however all processing, formatting and interpretation in this work is the authors' own.

4.2.2. EPMA – Principles of Analysis and Instrument Design:

EPMA is a non-destructive but invasive microanalytical technique based on standards which enable the full quantitative analysis of solid inorganic material on a micron scale with accuracy and precision in the 1-2% range and detection limits as low as ppm (parts per million). The technique was developed by Raymond Castaing in the publication of his 1951 PhD thesis and there are now two main types: EDS (energy dispersive spectrometry) and WDS (wavelength dispersive spectrometry) (Walshaw, 2018). Whereas EDS tends to produce qualitative results, WDS produces quantitative results, with the former based on sorting incident rays by counts, plots and x-ray energies, which

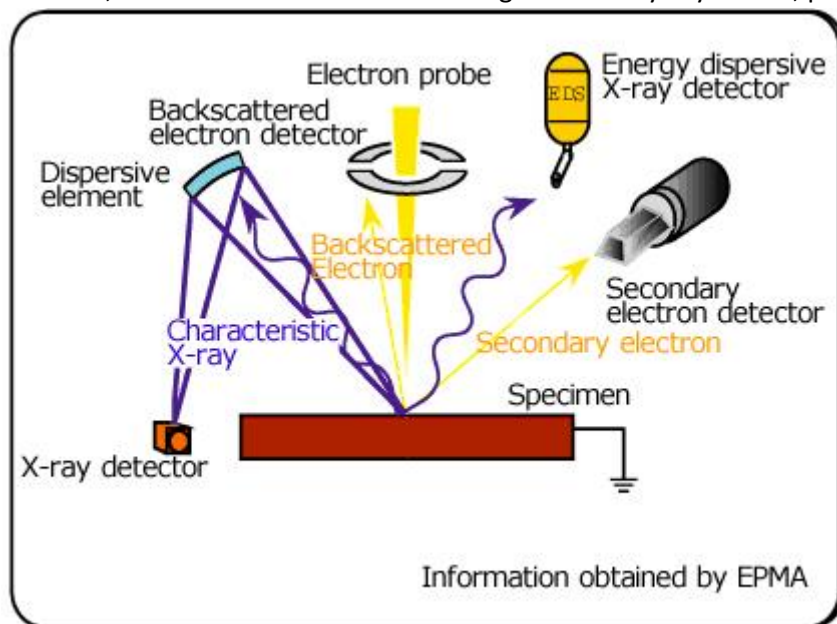


Figure 6. A diagram illustrating the different information received from EPMA and how it is received and detected (Image from www.jeol.co.jp/en/science/epma.html, accessed 08/07/2020).

makes it more suited to looking at major elements with atomic numbers from sodium upwards (Ionescu, Hoeck and Hunt, 2017, 288-292) (Walshaw, 2018). In contrast, WDS uses diffracting crystals with variable d-spacing allowing for the selection of x-rays by preference of wavelength over the suppression of others. These differences mean that WDS gives a better peak vs background ratio in its results and the lower detection limits from this

make it better suited to lower concentrations and lighter elements, however EDS does not have the disadvantage of problematic absorption of low wavelength x-rays in a given sample (Walshaw, 2018).

In terms of elemental characterisation in archaeological materials this technique has been available commercially for the last 50 years, mainly being used for provenance studies and investigations into ancient technologies. The basis on which the technique works is that the beam of electrons focussed on the sample interacts in various ways and produces several different signals, most notably backscattered and secondary electrons as well as x-rays which range in nature from characteristic to continuous spectrum (Ionescu, Hoeck and Hunt, 2017, 288-292). Scattering of electrons from interaction with the sample leads to reflection and deflection in many directions and where there are many deflections at a small angle or very high angle reflections a small portion of the electrons leave the sample, these being backscattered electrons. These come from a small volume of the sample and the resultant energy distribution depends on the atomic number of the atom stimulated (Ionescu, Hoeck and Hunt, 2017, 288-292). Secondary electrons come from ejection of beam electrons from the sample or backscattered electrons leaving the sample surface, they have lower energy and tend to provide sample topographical information, but due to their relationship with backscattered electrons this means they provide some information as to sample composition (Ionescu, Hoeck and Hunt, 2017, 288-292). The continuous x-ray spectrum is generated by the interaction of incident electrons and the atomic nuclei of the sample, due to the fact that an electron in a sample atom may be hit by a beam electron, leaving a vacancy in the outer-most electron shell of the nuclei, emitting a characteristic x-ray and energy wavelength specific to atomic

number (Ionescu, Hoeck and Hunt, 2017, 288-292). This is how the technique can give quantitative determination of a sample of small volume, with secondary electrons and backscattered electrons providing information for imaging as seen in Figure 7 below.

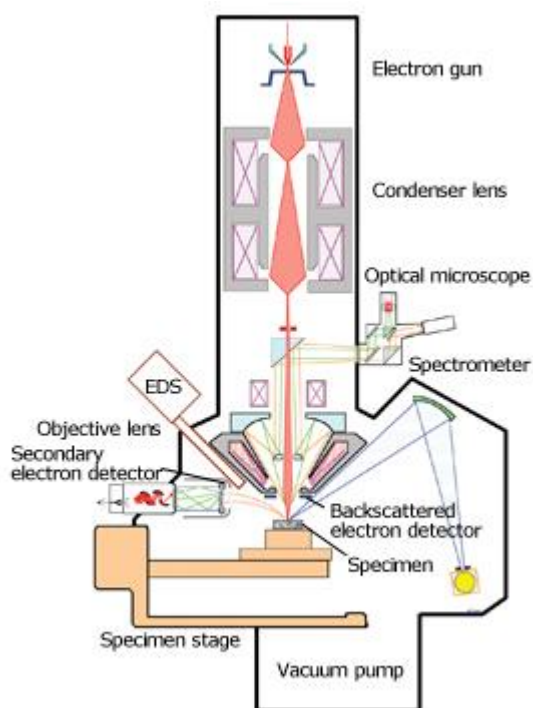


Figure 7 Diagram showing the instrumental design of the electron microprobe for internal working, Image from www.jeol.co.jp/en/science/epma.html, accessed 08/07/2020.

The instrumental design of an electron microprobe as seen in Figure 7 begins with the generation of an electron beam by the heating of a filament, usually made from tungsten which is held as a cathode and held at negative voltage (e.g. 15-30kV) towards the anode. Through an aperture in this anode the electrons are accelerated to form the beam, with the current being monitored by a swing-in Faraday Cage made of a semi-conductive material (Ionescu, Hoeck and Hunt, 2017, 288-292). The diffracted x-rays then move to the gas-filled proportional counter and are plotted sequentially as the diffracting crystal moves to different positions. The most commonly used crystals are TAP, PET, quartz and muscovite amongst others and the function of the electron microprobe requires the distance between the crystal and the counter, as well as the sample and the crystal to be equal sitting on what is known as a Rowland Circle (to fulfil the requirements for Bragg's equation) (Walshaw, 2018) (Ionescu, Hoeck and Hunt, 2017, 288-292). The subsequent ionisation of the gas by interaction with incoming x-rays generates an electric pulse which is then counted to determine

the intensity of the x-ray in EDS of which there is usually one attached to the microprobe. This features a solid-state detector, pulse height analyser and a multi-channel analyser, as well as a detector in the form of a semi-conductive crystal. This enables the view of all characteristic x-rays in the range of energies of interest with the amplified electric charge giving a higher count rate and range of display. This is against the better resolution and peak/count rate produced by the WDS, of which there are usually 4-5 attached to the electron microprobe (Ionescu, Hoeck and Hunt, 2017, 288-292). The complexity in the technique can arise from electron backscattering and inter-elemental absorption with fluorescence x-ray effects are called matrix effects and the output of these is usually reduced via iterative calculations known as matrix corrections (e.g. ZAF) depending on the sample matrix (Walshaw, 2018).

4.2.3. Experimental Design:

The pre-experimental handling and preparation of the samples, as stated above, is a precursor to the experimental design of chemical characterisation of solid materials by electron microprobe, to prepare the surface for the most accurate and precise analysis possible. This method is dependent on the use of appropriate and well-characterised reference materials with a matrix as close to the sample as possible, with primary standard materials being used for standardisation and calibration of results and secondary standards for quality control (Kuehn, 2016). The most common ones used here for the characterisation of glasses from the period and region of our focus would be the

Corning A, B and C glasses, the first two of which are designed to resemble natron and plant ash glasses from the Egyptian, Byzantine, Roman, Mesopotamian and Islamic worlds, while the last is designed to compare to Eastern Asian glasses with high Ba and Pb (Adlington, 2017) (Carpenter et al., 2002). Also, of common use as primary reference materials in the characterisation of ancient glasses are the National Institute of Standards and Technology Standard Reference Materials glasses (NIST SRM) 610-617 (Carpenter et al., 2002). An additional problem with the analysis of ancient glasses is the tendency for alkali elements to migrate in the sample, the effect of which can be minimised by analysing elements Na, K, Ca and Al first and for as limited a time as possible, as well as using a defocussed beam and EDS and WDS simultaneously. Also, the use of secondary reference materials can be eliminated by using 4 primary standards at the beginning and end of each run, with offline blank correction to enhance accuracy and offline adjustment of matrix matching to maximise reproducibility (Kuehn, 2016).

4.2.4. Data Summarisation and Analysis:

All data was processed using Microsoft Excel, where they were summarised and totals to 100% were checked using averages of repeat analyses to give the most robust results. Comparison of results have been made on averages and the observation of graphical representations of data showing discrete groups based on % oxide weight of samples. Additionally, processing of the entire cohort of data for each site has shown clusters based on certain elements and the determination of some by others, indicating the ingredient with which this oxide entered the glass melt.

Chapter 5. Results:

5.1. EPMA analyses of glasses from Mantai, Sri Lanka:

5.1.1 Major compositional groups and raw materials:

From first looking at the MgO and K₂O contents of the Mantai glasses (Figure 8), two main groups were distinguished within the assemblage – one with glasses containing low magnesia (<1.5% weight) and variable potash (0.44-2.92%wt) and another featuring high magnesia (>3% wt) and low potash (<2% wt) as seen in Figure 8. An additional major observation made through analysis of the data set was the two distinct groups formed when comparing the amounts of lime and alumina in these samples, as seen in Figure 9.

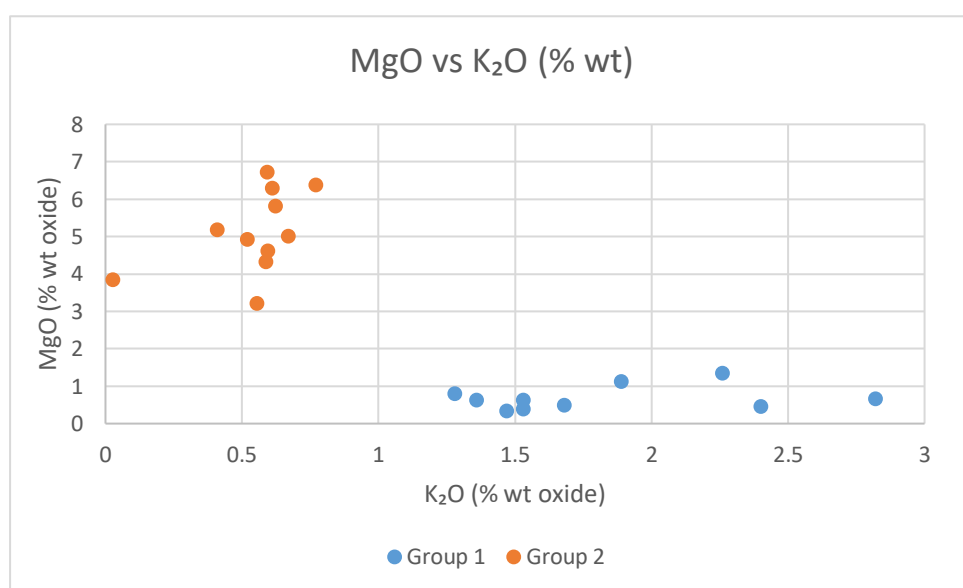


Figure 8. Scatter graph displaying K₂O vs MgO % wt and the two distinct groups formed in terms of their content in these glasses.

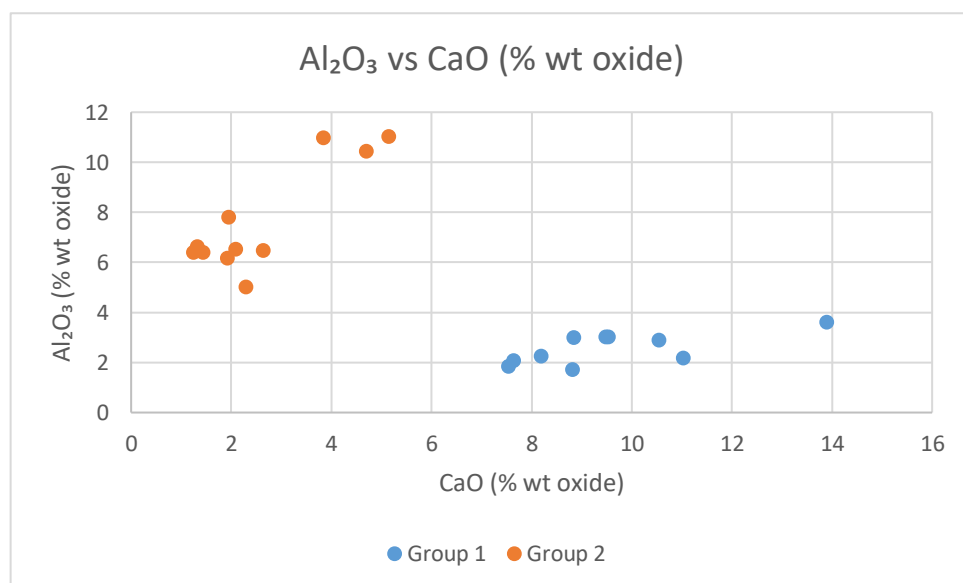


Figure 9. A scatter graph showing the comparison of the content in % wt of alumina and lime in the Mantai glasses, forming two distinct groups.

As seen in figure 9 one of these groups is characterised by high lime contents (>4% wt) and low alumina (<6% wt), while the other contrastingly features low lime contents (<4% wt) and high alumina (>7% wt). Figure 10 shows how the group of glasses containing high magnesia and variable, but mostly low potash, corresponds very well with the high lime and low alumina group, while the same is true of the low magnesia/high potash and low lime and high alumina groups. It is from this that we can say that within this assemblage there are two main glass compositions here, which all but 3 samples fit into, here called Mantai Group 1 and Mantai Group 2. As well as high MgO and lower K₂O and low CaO with high Al₂O₃, Group 1 is characterised by its higher soda contents (17.7% wt compared to the assemblage average of 16.15% wt) and lower silica (61.36% wt compared to the assemblage average of 63.91% wt).

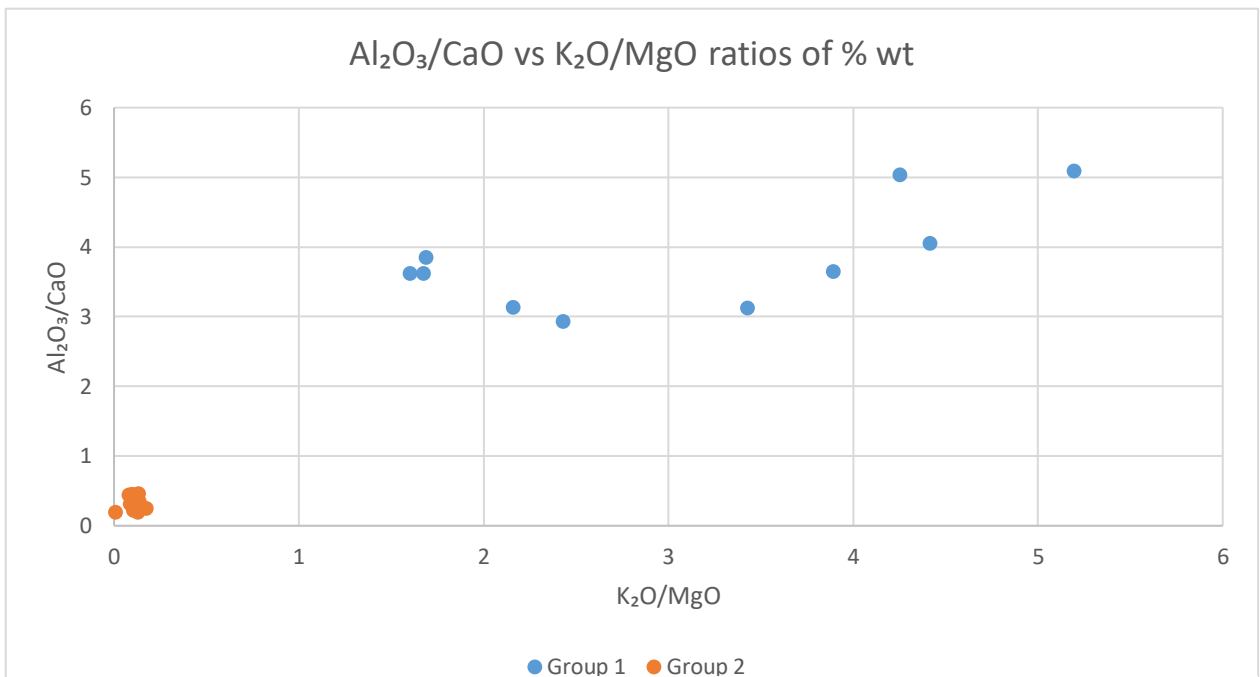


Figure 10. A scatter plot showing the difference in K₂O/MgO and Al₂O₃/CaO ratios of the Mantai glasses, defining Group 1 and 2 distinctly

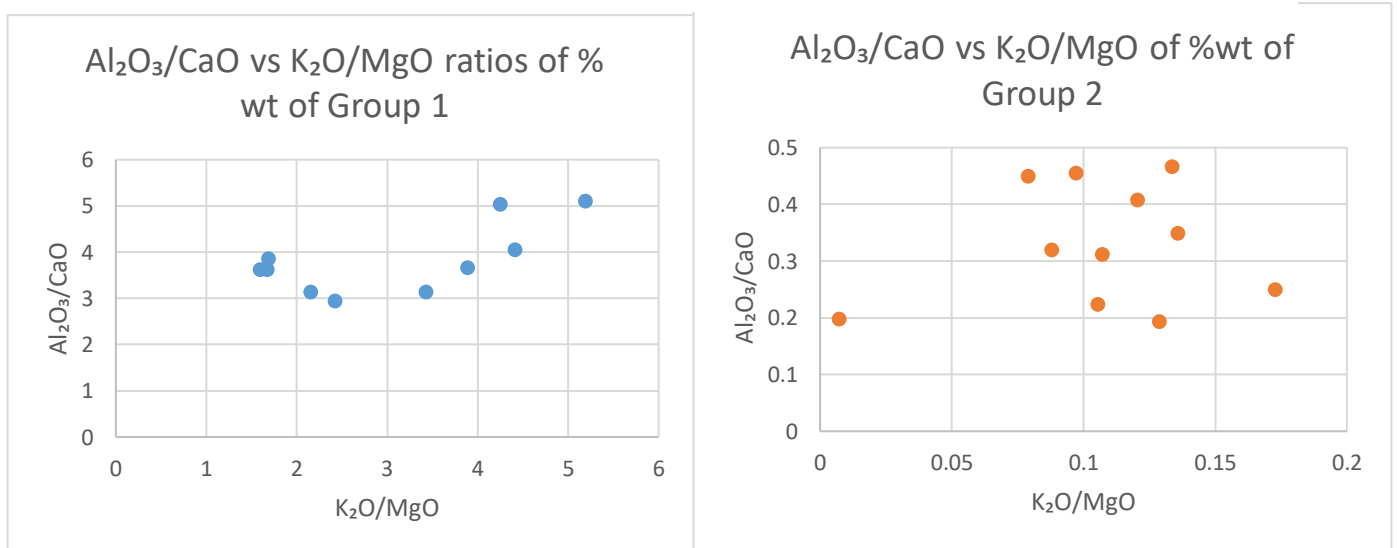


Figure 11. Graphs showing Al₂O₃/CaO vs K₂O/MgO of Groups 1 and 2 individually to show better resolution of results for Group 2 due to the difference in ratio as seen in Figure 10

Figure 8. Graphs showing $\text{Al}_2\text{O}_3/\text{CaO}$ vs $\text{K}_2\text{O}/\text{MgO}$ of Groups 1 and 2 individually to show better resolution of results for Group 2 due to the difference in ratio as seen in Figure 10

The two groups differ on their major element content, with group 1 being a soda-silica-alumina glass and group 2 being a soda-lime-silica type as after soda and silica alumina is the most abundant constituent of group 1 acting as a stabiliser in contrast to the lime, which normally fulfils this but is lacking in these samples. The assemblage can therefore be viewed as two distinct groups characterised by their K_2O , MgO , Al_2O_3 and CaO contents and three outliers which do not fit into either of these groups on the basis of these elements. Magnesia and lime appear to be highly correlated to each other across the dataset, indicating they are both coming in as part of one of the main constituents which indicates a purer mineral source of soda in Group 1 as opposed to Group 2 which likely has a vegetal soda source. From the major elemental differences it is most likely that Group 1 was made using a mineral soda source, and sand rich in impurities, as opposed to Group 2 which was likely made with alkali rich plant ashes and a purer silica source (As seen in group averages vs each other and assemblage averages – Table 5). Additionally, as seen in Table 5, Group 1 exhibits more compositional variation than Group 2, evidenced by the difference in the standard deviations. From this and their averages we can see that some samples within Group 1, as well as the group in general is richer in FeO , TiO_2 and ZrO_2 . This, coupled with the fact that the group is characterised by its high magnesia and alumina, and comparatively lower silica content solidifies the idea that the silica source for Group 1 was likely an impurity rich sand, as seen in Figure 13.

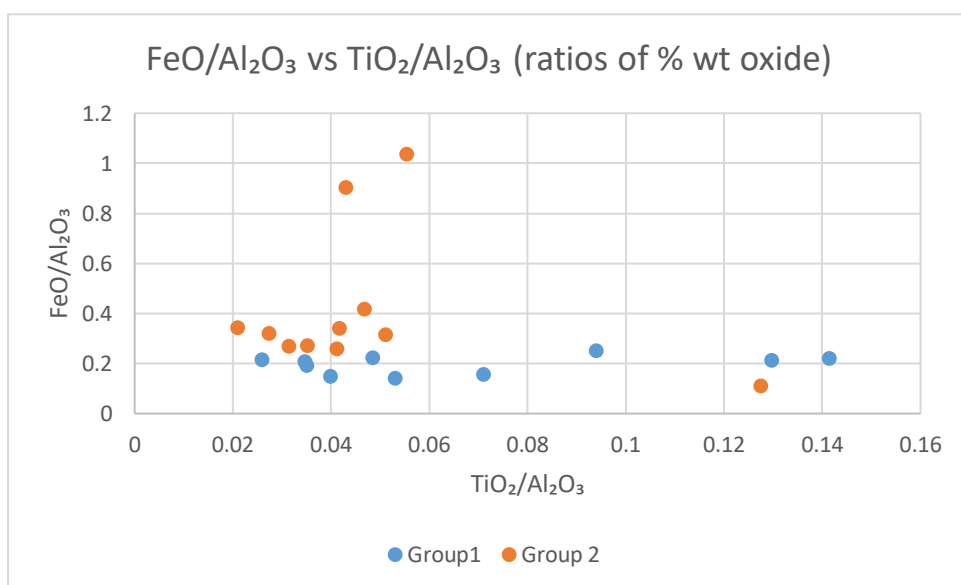


Figure 9. Plot comparing the ratios of % wt oxide of $\text{FeO}/\text{Al}_2\text{O}_3$ vs $\text{TiO}_2/\text{Al}_2\text{O}_3$ for the disparity of Groups 1 and 2.

From these characterisations of major element contents, it is thus apparent that the two main groups of glasses from the Mantai assemblage are Group 1- a m-Na-Al type and Group 2 – a v-Na-Ca type, with only three outliers, the types of which I will now discuss.

5.1.2. Outliers:

The three samples which do not fit with the above groupings are MANT 1, 20 and 24, whose full compositional characterisation can be seen in Tables 3 and 4. MANT 1 is a piece of cobalt blue raw glass with fairly high silica contents (67.4% wt) and low potash and magnesia and being of a soda-lime-silica type. The soda contents of this sample is also comparatively high (19.34% wt) suggesting it may be compositionally similar to the al-Raqqa Type three glass – an Early Islamic LMG with moderate alumina. MANT 20 is also a sample of raw glass, this time coloured opaque red with high magnesia and potash, and a soda-lime-silica composition. The low silica and soda contents suggest

poorer raw material use with a vegetal alkali and impurity rich sands. In terms of colour this sample is high in both CuO and FeO as well as containing small but notable amounts of Sb₂O₅ and PbO which are likely responsible for the red colour and its opacity under the appropriate furnace conditions. MANT 24 is a pale green (likely a natural colour) flask fragment of soda-lime-silica glass with very low magnesia and alumina (0.002% wt and 0.058% wt respectively) and very high potash (7.18% wt) as well as a high silica content of 78.3%wt. This suggests the use of a very pure silica source (perhaps quartz) and an impure alkali source, perhaps low-alumina sands.

5.1.3. Colourants, Decolourants and Opacifiers:

5.1.3.1. Decolourants:

All 3 colourless samples are in Group 2 and are MANT 13, 21 and 25 and are in the form of a piece of plate glass, a tesserae and a bowl fragment respectively. All three samples are seen to have higher silica contents than is the average for the assemblage and Group 2 but vary in their manganese, lead and antimony contents. MANT 13 exhibits very low concentrations of MnO, FeO and Sb₂O₅, but has higher PbO than average at 0.015% wt, as well as very low % wt of common impurities causing colour and colourant constituents. MANT 21 and 25 both contain above average amounts of MnO and Sb₂O₅ - both decolourants known to be used at this time, as well as very low amounts of FeO, thought to contribute to natural glass colour in small amounts and colouration in larger amounts and under certain redox conditions. MANT 21 also has a higher than average quantity of PbO at 0.016% wt, and thus the decolouration of these samples can be attributed to these qualities.

5.1.3.2. Opacifiers:

There are four opaque samples present in the assemblage, two in Group 1, one in Group 2 and one as an outlier, being samples MANT 4 (orange), MANT 6 (red), MANT 23 (red) and MANT 20 (red) respectively, with three of the samples being raw glass (4, 20 and 23) and 6 being a piece of disc glass. The opaque orange sample, MANT 4, shows very high levels of CuO (7.3% wt) as well as higher than average Sb₂O₅ (0.17% wt), PbO (3.35% wt), BaO (0.15% wt) and SnO₂ (0.25% wt). The high copper is likely the source of the orange colour as well as a contributing factor to opacity of the sample, but the high lead content is most likely responsible for this attribute in the form of lead antimonate or stannate). The other three opaque samples are all red, with MANT 6 and 20 showing a high CuO content (2.36% wt and 1.55% wt respectively) and moderate amounts of FeO which were likely determinant of the colour. The opacity of these two samples appear to be due to elevated PbO (with the average for Group 1 being skewed due to the high content of MANT 4) and Sb₂O₅, with neither containing detectable amounts of SnO₂, making lead antimonate the most likely opacifier used here, which is consistent with glassmaking technology of the time. The remaining sample MANT 23 contains higher than average CuO and Sb₂O₅ as well as FeO and Ag₂O, but no detectable PbO or SnO₂ - meaning that the opacifying agent of this glass is unclear from this analysis.

5.1.3.3. 'Intense' Colours:

Three samples, all in Group 1, are described as having an 'intense dark' colour being the brown MANT 8 – a raw glass sample and the dark green 'black' appearing MANT 22 (also raw glass) and MANT 30 (an armlet fragment). They all exhibit high alumina as well as high titania and vanadium content and high FeO contents (1.37-2.04% wt) which are likely the cause of the colour, as well as possibly the redox conditions affecting the FeO in the furnace. The brown MANT 8 appears to have higher As₂O₅ and both the dark green samples contain high Sb₂O₅ contents, both metalloid compounds, however their effect on colour here is undetermined. It is more likely a combination of

alumina, iron and redox furnace conditions was conducive to producing these colours and their intensity.

5.1.3.4. Colourants:

Colour in Group 1 is variable, and excluding those samples already discussed the composition of each sample must be considered to try and explain its colour. MANT 10 is a translucent purple sample, containing high manganese (0.49% wt) which is known to produce a purple colour, as well as high FeO and BaO, which may explain the samples translucency (Abd-Allah, 2009). MANT 12a is a transparent red, the colour of which can be attributed to the high CuO contents (2.57% wt), and its transparency perhaps to its PbO and BaO contents. MANT 12b is turquoise which could be a naturally occurring colour but is more likely due to the combination of CuO (2.6% wt) and FeO (1.96% wt) as well as small amounts of BaO and PbO. MANT 15 is blue and contains high titania levels (1.43% wt) and high FeO (2.33% wt) which could be impurities leading to this colour or one of the highly variable colours produced by the redox states of iron. MANT 19 is a piece of raw crucible glass, and is also turquoise, which is more likely natural and may be partially due to the levels of ZrO₂ and other impurities from the crucible.

Colour is far less variable in Group 2, containing the 3 colourless and 1 opaque sample already discussed and the rest being blues and greens, most of which, such as MANT 5, 9, 17 and 18 are likely naturally coloured, being pale greens and aqua. There are two samples which are cobalt blue in colour – MANT 14 and 26 – both of which have above average CoO contents as expected, but only slightly due to the potency of this colourant meaning its use is necessary only in very small amounts. The last sample from Group 2 to discuss is the emerald green MANT 27, the colour of which is likely due to the high P₂O₅ and TiO₂ as well as increased FeO, known to cause this rare but known colour in Islamic glass (Henderson, 1999).

The colour of the outlying glasses is fairly clear also, apart from the opaque red MANT 20 discussed above, there is the pale green MANT 24, likely a natural colour and the cobalt blue MANT 1 with an expected slight increase in CoO content.

Group 1	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3
MANT4	13.29	1.12	13.9	54.21	0.17	0.18	0.51	1.89	3.61	0.36	0	0
MANT6	20.64	1.35	10.54	59.97	0.24	0.18	1.23	2.26	2.91	0.42	0	0.03
MANT8	18.5	0.8	8.19	67.66	0.07	0.55	1.61	1.28	2.26	0.77	0.05	0.05
MANT10	20.45	0.49	9.49	60.45	0.07	0.18	1.24	1.68	3.03	0.46	0	0
MANT12a	19.74	0.63	8.84	59.15	0.05	0.39	1.3	1.53	3.01	0.31	0	0
MANT12b	14.54	0.63	9.53	59.5	0.1	0.39	1.38	1.36	3.04	0.33	0	0
MANT15	15.73	0.663	11.03	64.04	0.052	0.394	0.936	2.82	2.19	1.431	0.015	0.008
MANT22	18.7	0.393	7.64	65.88	0.049	0.475	1.29	1.53	2.09	1.081	0.015	0.011
MANT30	18.29	0.462	8.82	65.76	0.055	0.339	0.704	2.4	1.73	0.626	0.019	0
MANT19	21.06	0.333	7.54	65.37	0.055	0.252	0.656	1.47	1.86	0.4	0.039	0
Average	18.094	0.6871	9.552	62.199	0.0911	0.333	1.0856	1.822	2.573	0.6188	0.0138	0.0099
St.Dev	2.695833	0.32456585	1.90530721	4.18900797	0.06408579	0.1309351	0.36178176	0.51081199	0.623948894	0.373357678	0.018035767	0.01701274
Group 2	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3
MANT5	15.93	6.38	2.64	61.97	0.22	0.27	0.77	4.21	6.48	0.11	0	0
MANT9	14.74	5.19	4.7	57.45	0.43	0.39	0.41	2.58	10.44	0.22	0	0.03
MANT13	14.9	3.84	1.318	72.37	0.018	0.294	0.028	0.101	6.64	0.168	0.002	0.002
MANT14	16.18	5.81	1.93	63.04	0.104	0.323	0.623	2.79	6.19	0.083	0.047	0
MANT17	16.2	6.72	2.09	62.51	0.153	0.327	0.592	3.97	6.53	0.086	0.021	0.004
MANT21	13.09	4.92	1.432	68.52	0.094	0.259	0.519	2.6	6.4	0.045	0.014	0.002
MANT23	16.11	6.3	2.29	65.01	0.092	0.281	0.612	2.85	5.03	0.048	0	0.002
MANT25	11.78	4.62	1.242	71.71	0.07	0.224	0.595	1.96	6.41	0.034	0.017	0.012
MANT26	15.85	3.21	1.95	64.28	0.211	0.227	0.555	2.26	7.81	0.108	0	0.021
MANT27	14.3	5.01	5.15	58.78	0.382	0.199	0.67	2.33	11.03	0.263	0	0.02
MANT28	15.43	4.33	3.84	58.7	0.231	0.326	0.588	2.44	10.98	0.135	0	0.013
Average	14.9554545	5.12090909	2.59836364	64.0309091	0.18227273	0.28363636	0.542	2.55372727	7.630909091	0.118181818	0.009181818	0.009636364
St.Dev	1.42825322	1.10606017	1.36129286	5.06480889	0.12976833	0.0560112	0.19224256	1.06832337	2.146124202	0.073427268	0.014871571	0.010298279
Outliers	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3
MANT1	19.34	1.16	3.06	67.4	0.05	0.21	1.24	0.44	5.51	0.33	0	0.03
MANT20	15.34	4.44	2.51	61.91	0.222	0.311	0.587	2.92	7.24	0.146	0.001	0.017
MANT24	7.53	0.002	0.058	78.3	0.063	0.123	0.182	7.18	4.85	0	0.019	0.004

Table 3. The chemical analyses of the Mantai glasses with values representing % wt oxide, 0 representing element not detected. Averages and Standard Deviations for both groups are included. Table 3 shows % wt oxide for oxides Na₂O to Cr₂O₃.

Group 1	MnO	FeO	CoO	NiO	CuO	ZnO	As2O5	SrO	ZrO2	Ag2O	SnO2	Sb2O5	BaO	PbO
MANT4	0.03	2.99	0	0	7.3	0	0	0	0	0	0.25	0.02	0.15	3.35
MANT6	0.11	1.57	0	0.04	2.36	0	0.17	0	0	0	0	0	0.12	0.18
MANT8	0.03	2.04	0	0	0	0	0.19	0	0	0	0	0	0.15	0
MANT10	0.49	2.1	0	0	0	0	0	0	0	0	0	0	0.24	0
MANT12a	0	1.7	0	0.07	2.57	0	0	0	0	0	0	0	0.13	0.11
MANT12b	0	1.96	0	0.04	2.6	0	0	0	0	0	0	0	0.12	0.1
MANT15	0.057	2.33	0	0	0.014	0.008	0	0	0.026	0	0	0.169	0.106	0.01
MANT22	0.035	1.68	0.004	0.003	0	0	0	0	0.089	0	0	0.06	0.023	0
MANT30	0.046	1.37	0	0.005	0.003	0.002	0	0	0.122	0.005	0	0.087	0.05	0
MANT19	0.061	1.066	0	0.002	1.247	0.019	0	0	0.054	0	0	0.056	0	0
Average	0.0859	1.8806	0.0004	0.016	1.6094	0.0029	0.036	0	0.0291	0.0005	0.025	0.0392	0.1089	0.375
St. Dev.	0.145496	0.538124	0.001265	0.024895	2.306465	0.00619	0.076041	0	0.044633	0.001581	0.079057	0.055677	0.069899	1.047264
Group 2	MnO	FeO	CoO	NiO	CuO	ZnO	As2O5	SrO	ZrO2	Ag2O	SnO2	Sb2O5	BaO	PbO
MANT5	0.05	0.9	0	0	0	0	0.05	0	0	0	0	0	0.05	0
MANT9	0.05	1.96	0	0	0	0.05	0	0	0	0	0	0	0.05	0
MANT13	0.006	0.144	0	0.005	0.015	0.009	0.023	0	0.02	0	0	0.007	0	0.015
MANT14	0.045	1.74	0.229	0.004	0.259	1.204	0.024	0	0.018	0.003	0	0.145	0	0
MANT17	0.039	0.54	0.004	0.001	0	0.004	0.069	0	0.019	0.002	0	0.224	0	0
MANT21	1.04	0.383	0	0.01	0.01	0.002	0.067	0	0.009	0	0	0.173	0	0.016
MANT23	0.195	0.783	0.034	0.013	0.142	0.03	0	0	0	0.007	0	0.176	0	0
MANT25	0.47	0.398	0	0	0	0	0.033	0	0.007	0	0	0.108	0	0
MANT26	0.909	2.02	0.227	0.052	0.406	0.055	0.01	0	0.004	0	0	0.139	0	0
MANT27	0.054	1.62	0.005	0.009	0.003	0.006	0.021	0	0.01	0	0	0.136	0	0
MANT28	1.188	1.038	0.006	0	0.002	0.014	0.034	0	0.006	0.012	0	0.187	0	0.003
Average	0.367818	1.047818	0.045909	0.008545	0.076091	0.124909	0.030091	0	0.008455	0.002182	0	0.117727	0.009091	0.003091
St. Dev.	0.458416	0.679324	0.090564	0.015142	0.137379	0.358434	0.023835	0	0.007621	0.00392	0	0.080093	0.020226	0.006204
Outliers	MnO	FeO	CoO	NiO	CuO	ZnO	As2O5	SrO	ZrO2	Ag2O	SnO2	Sb2O5	BaO	PbO
MANT1	0.05	1.97	0.12	0	0.18	0	0	0	0	0	0	0	0.06	0.15
MANT20	0.962	1.86	0.021	0.01	1.55	0.047	0.03	0	0	0.004	0	0.132	0	0.216
MANT24	0.61	0.135	0.01	0.002	0	0	0.073	0	0.006	0	0	0.419	0	0

Table 4. Table 4 shows % wt oxide for oxides MnO to PbO for the same samples as table 3.

		Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	K ₂ O	CaO	TiO ₂	MnO	FeO	CuO	PbO	Sb ₂ O ₅
Mantai	Average	16.1525	2.86679167	5.40541667	63.9141667	0.13545833	2.36879167	5.30291667	0.331833333	0.271958333	1.429041667	0.777541667	0.172916667	0.09325
	St. Dev.	3.05798715	2.32897499	3.83133338	5.27233654	0.1059064	1.35860415	2.7965909	0.340266154	0.375218323	0.736308386	1.606721921	0.665492982	0.100863
Group 1	Average	18.094	0.6871	9.552	62.199	0.0911	1.822	2.573	0.6188	0.0859	1.8806	1.6094	0.375	0.0392
	St. Dev.	2.55749174	0.3079102	1.80753313	3.9740419	0.06079712	0.4845988	0.59192989	0.354198193	0.138030033	0.510508805	2.188104897	0.993521515	0.055677
Group 2	Average	14.9554545	5.12090909	2.59836364	64.0309091	0.18227273	2.55372727	7.63090909	0.118181818	0.367818182	1.047818182	0.076090909	0.003090909	0.117727
	St. Dev.	1.36178602	1.05458699	1.29794182	4.8291058	0.12372924	1.01860636	2.04624914	0.070010153	0.437082854	0.647709926	0.130986088	0.005915381	0.080093

Table 5. Summary of the averages in % weight of oxide for the major and minor elements of importance to explained results analysed for the entire assemblage and the two discerned groups, as well as standard deviations for each.

5.2. EPMA analyses of glasses from Bilad al-Qadim, Bahrain:

5.2.1. Major Compositions and Raw Materials:

Unlike the Mantai glasses, there is no clear division of composition based on the consideration of MgO vs K₂O (see Figure 14), but what can be seen from this comparison is that all of the samples are soda-lime-silica glasses, with high contents (between 2-6% K₂O, and 2-5% MgO) of both magnesia and potash, reflecting a likely vegetal source of soda for these glasses. Notable exceptions are samples BAH 1 and BAH 24 which both have low contents of each of these oxides (BAH 1 has 1.15% wt MgO and 0.14% wt K₂O, and BAH 24 has 0.58% wt MgO and 0.31% wt K₂O), and BAH 3, which has a potash content slightly above 2% wt, but a very low magnesia content of 0.2% wt. This could be attributed to a mineral soda source and purer silica source for BAH 1 and 24, and a possible vegetal soda source and more impure silica source for BAH 3. Another anomalous sample with regards to MgO vs K₂O is BAH 11, with very high contents of both (6.595% wt MgO and 7.84% wt K₂O) which could be due to a number of factors – impure raw materials, recycling, deliberate addition or an accident with the glass melt.

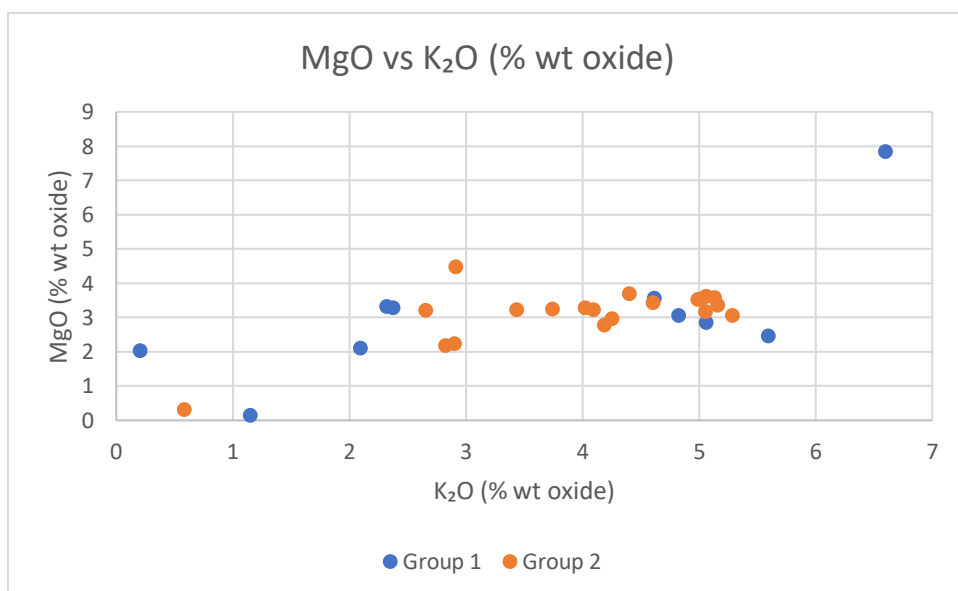


Figure 10. A graph showing the comparison in contents of MgO vs K₂O of the Bahrain glasses grouped in groups attributed to their Al₂O₃ and CaO contents in % wt oxide.

The clearest division of the samples is based on Al₂O₃ content, as seen in Figure 15, with all the samples having CaO contents in the range of 4-10% wt, with the average being around 6-7% wt, but there being a divide of the alumina content into those with more or less than 2% wt contents. Here Group 1 will be the reference for the lower content group (0.5-1.7% wt) and Group 2 the designation for the higher content group (1.99-3.5% wt). A more focussed picture produced by comparing the ratios of MgO/K₂O and Al₂O₃/CaO as seen in Figure 16 (excluding the anomalously high BAH 1, to give a clearer picture of the data. Here we see Group 1 to have a greater range, as well as higher ratios, which is very distinct from the larger but much more compositionally tight Group 2. The range of Group 1 is MgO/K₂O between 0-2.5 and Al₂O₃/CaO between 0.8-1.6, in comparison to Group 2 having MgO/K₂O ranging from 0.0675-0.2552 and Al₂O₃/CaO from 0.33-0.58.

Figure 11. A comparison of the Al_2O_3 and CaO contents of the Bahrain glasses, split into two groups based on Al_2O_3 content.

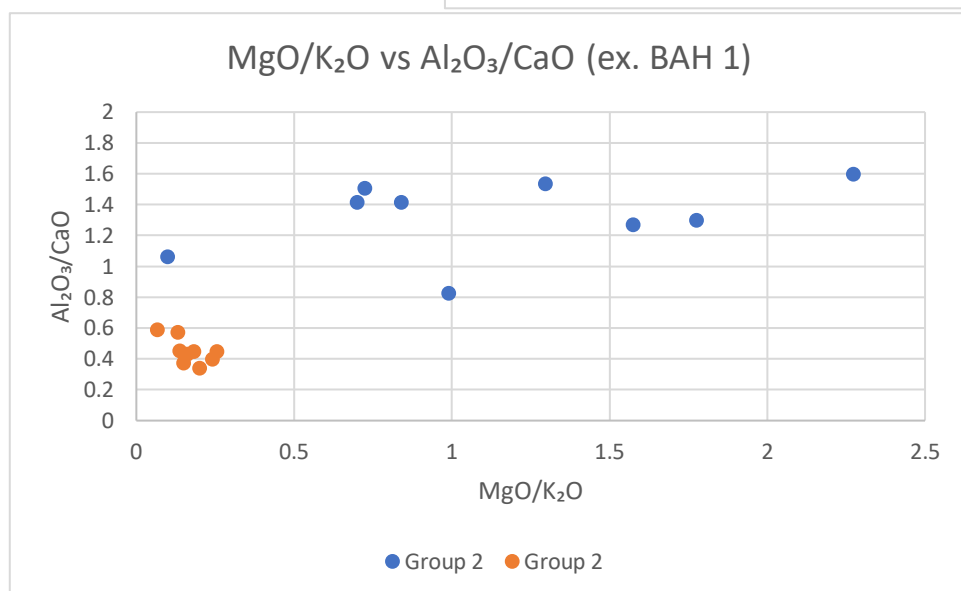
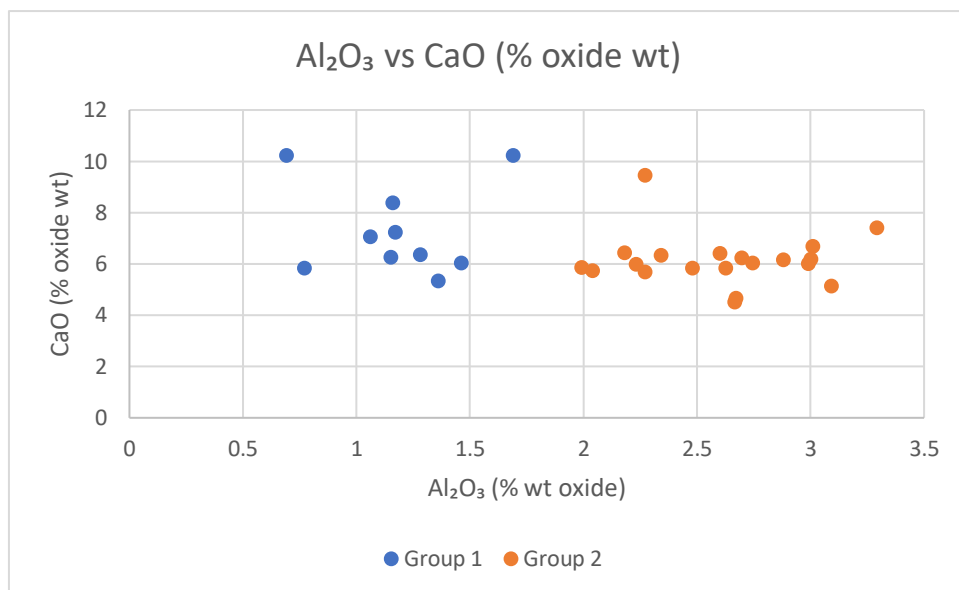


Figure 12. A comparison of the ratios of $\text{MgO}/\text{K}_2\text{O}$ and $\text{Al}_2\text{O}_3/\text{CaO}$ for groups 1 and 2, excluding BAH 1.

Overall, the average content of Al_2O_3 for Group 1 is 1.18% wt, where Group 2 has an average of 2.60% wt and the CaO average contents for the groups are 7.298% wt and 6.13% wt respectively. Although contents of iron oxide and titania for the groups are broadly comparable, with Group 1 having slightly higher TiO_2 contents and Group 2 having a marginally higher average Fe_2O_3 content, a comparison of their ratios with Al_2O_3 , as seen in Figure 17 shows further distinction. Again Group 1 has a much broader range of ratios, as well as them being generally slightly higher also, where Group 2 is comparatively more tightly grouped and lower. Most of the glasses found here are soda-lime-silica and likely made from a plant ash soda and a relatively impure sand as a silica source with a marine lime element. The full set of results as well as averages for all detected elements and their standard deviations are shown in Tables 6,7 and 8.

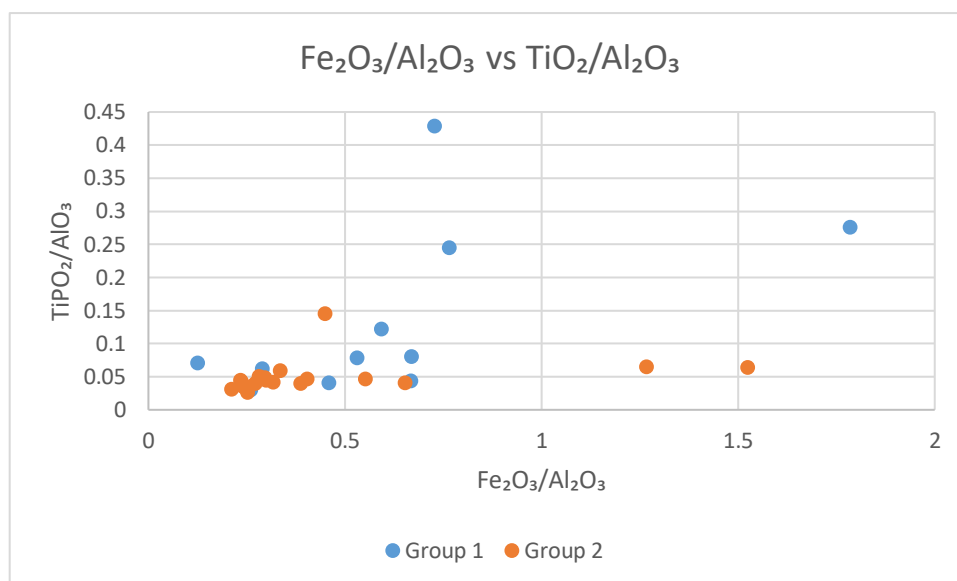


Figure 13. A comparison of the ratios of $\text{Fe}_2\text{O}_3/\text{Al}_2\text{O}_3$ and $\text{TiO}_2/\text{Al}_2\text{O}_3$ showing the distinction between Groups 1 and 2

5.2.2. Colourants, Decolourants and Opacifiers:

5.2.2.1. Anomalous Results:

Only one sample is of indeterminate colour - BAH 1 a sample of glaze from a kiln with no significant levels of impurities, a high silica content, high $\text{Al}_2\text{O}_3/\text{CaO}$ contents and very high lead contents. This may indicate reheating of glasses, but no other evidence for glass working can be seen in this assemblage. Contamination from adherence to the kiln surface may distort the true contents of the glass here and it will not be discussed further.

5.2.2.2. Decolourants:

A large proportion of the glasses of this assemblage are colourless, representing 30% of Group 1, 40% of Group 2 and 37% of the whole assemblage. These glasses are not distinct from the remaining samples based on MgO , K_2O , Al_2O_3 or CaO contents, and Sb_2O_5 is also close to the average for the cohort. The average MnO_2 content is elevated, with the mean content for colourless glasses being 1.77% wt compared to 1.17% wt and the content of transition metals and impurities responsible for colouring glass (Fe_2O_3 , CoO , CuO and NiO) are diminished when compared with the remainder of the assemblage. This is to be expected as it is known that colourless glasses were made in the Islamic World at this time using relatively small amounts of manganese (Duckworth et al., 2015). All but one of the colourless glasses recovered were excavated from the al-Khamis site, which may be indicative of the status or function of colourless glasses within the mosque.

5.2.2.3. Opacifiers:

Only one sample here is described as opaque – BAH 11 which is an opaque turquoise colour, referenced earlier due to its notably high MgO and K_2O contents, likely from impure soda and silica sources. It has higher lead contents than average (0.65% wt) and elevated tin contents which may indicate the use of a lead-tin oxide as an opacifier for this glass, a technique known to have been used in the Islamic World and previously since the 1st Millennium BC (Matin, 2019). The turquoise colour is likely from the high CuO contents 1.425% wt compared to the assemblage average of 0.467% wt, known to produce this colour in Islamic glasses.

5.2.2.4. Colourants:

Cobalt Blues:

Four samples are described as having this colour – BAH 3, 8, 20 and 26 with 20 being called ‘translucent cobalt blue’ and 26 as ‘pale cobalt blue’. As expected, all four samples exhibit elevated cobalt levels averaging 0.085% wt compared to the assemblage mean of 0.028% wt, needing only a small amount of cobalt to produce a vivid colour. The translucent and pale samples also exhibit elevated MnO_2 and Sb_2O_5 , both known to act as decolourants, which may explain their different shades. Fe_2O_3 is additionally elevated, especially in BAH 20 (2.52% wt) and BAH 26 (1.65% wt) which can also produce a blue colour under the right furnace redox conditions, and may have contributed to the colour of these glasses but it is unclear from just these analyses.

Other Blues:

Samples BAH 29 and 22 are described as ‘pale blue’ which may be a natural colour for the glass as produced by their moderate Fe_2O_3 contents. However, the samples contain 0.09% wt and 0.08% wt of CoO respectively (vs average 0.02% wt) as well as moderate to high MnO_2 and high Sb_2O_5 levels (0.15% wt and 0.12% wt respectively compared to the average 0.08% wt). Again, this could theoretically be a blue colour from the elevated cobalt with the decolourant effect of the manganese and antimony giving a paler hue.

Greens:

Four samples, all from the Police Mosque site, are green, with BAH 25 and 27 being described as ‘pale green’ and BAH 21 and 35 as ‘transparent green’. Compared to the assemblage average there is little deviation, except for the elevated Fe_2O_3 levels in BAH 21 and 25 where there is a moderate amount in the other two samples. The average content of all impurities indicates this colour is natural and most likely the result of the presence of iron oxide and the appropriate redox conditions in the furnace.

Aqua and Turquoise:

BAH 11, an opaque turquoise sample has already been discussed under section 6.2.2.3 and thus will not be further discussed here. BAH 28 is ‘translucent turquoise’ and BAH 24 is ‘aqua’. The first of these has notably low alumina, but elevated CuO contents and thus is likely naturally coloured as a product of this. BAH 24 is also likely naturally coloured based on Fe_2O_3 and impurity contents and is more likely to have a mineral soda source based on MgO contents compared to the rest of the assemblage.

Purples:

Three samples, all from Group 2, are purple namely BAH 32 (‘pale purple’), BAH 33 (‘translucent purple’) and BAH 34 (‘dark purple’). All these samples contain moderate to high MnO_2 contents – 1.63% wt, 1.44% wt and 1.03% wt respectively, and thus showing a lighter colour with increased contents. The inverse is evident in regards to Sb_2O_5 content which means it may play a role in the darkening of the colour, possibly through its potential role as an opacifier, however the production of different shades could be due to dilution of the glass in different melts or the oxidation state of manganese determining the colours from furnace redox conditions.

Brown:

Only one sample, BAH 4, is brown, which is likely a result of the iron and manganese oxidation in the furnace producing this brown colour. This is from the MnO_2 and Fe_2O_3 elevation and the effect this combination can have on the colour of glass in an oxidising furnace atmosphere (Abd-Allah, 2009).

	Na2O	SiO2	MgO	As2O3	K2O	P2O5	Al2O3	Cl	SO3	PbO	CaO	TiO2
Group 1												
BAH1	14.06	71.84	1.15	0	0.14	0.2	1.69	0.02	0.28	0.07	10.24	0.12
BAH3	12.095	67.735	0.2	0.035	2.03	0.18	0.69	0.095	0.33	3.28	10.22	0.03
BAH9	14.7	63.355	4.615	0	3.56	0.35	1.46	0.6	0.23	0.07	6.04	0.06
BAH11	14.215	57.775	6.595	0	7.84	0.28	1.17	0.395	0.455	0.65	7.23	0.035
BAH23	13.34	69.6	2.37	0	3.27	0.32	0.77	0.27	0.31	0.08	5.83	0.33
BAH25	14.81	64.79	2.32	0	3.31	0.45	1.16	0.48	0.19	0.01	8.38	0.32
BAH28	14.66	66.5	4.82	0	3.06	0.26	1.15	0.67	0.27	0.13	6.27	0.09
BAH29	15.57	66.27	5.59	0	2.46	0.19	1.36	0.53	0.26	0	5.33	0.11
BAH30	14.47	67.25	2.09	0	2.11	0.36	1.06	0.69	0.14	0.1	7.07	0.26
BAH31	13.84	68.18	5.06	0	2.85	0.25	1.28	0.37	0.33	0	6.37	0.08
Average	14.176	66.3295	3.481	0.0035	3.063	0.284	1.179	0.412	0.2795	0.439	7.298	0.1435
St. Dev.	0.899877	3.629582	2.010787	0.0105	1.846586	0.082122	0.283706	0.217741	0.081989	0.964204	1.671806	0.109409
Group 2												
BAH4	17	58.995	5.285	0	3.045	0.29	3.29	0.43	0.395	0.01	7.42	0.1
BAH5	13.205	69.71	3.43	0	3.225	0.34	2.665	0.58	0.085	0	4.52	0.095
BAH6	15.115	63.85	5.155	0	3.36	0.23	2.27	0.505	0.255	0	5.68	0.095
BAH7	17.415	59.245	5.015	0	3.545	0.355	2.695	0.605	0.29	0	6.24	0.13
BAH8	13.305	68.81	4.185	0	2.775	0.18	2.67	0.485	0.27	0.06	4.665	0.11
BAH10	17.51	59.585	4.985	0	3.52	0.375	2.745	0.565	0.28	0	6.035	0.115
BAH12	14.595	63.65	4.09	0	3.215	0.275	2.625	0.445	0.25	0.045	5.835	0.105
BAH13	18.73	56.835	5.055	0	3.16	0.285	3.01	0.525	0.44	0	6.695	0.1
BAH14	14.415	67.52	2.655	0	3.21	0.235	2.23	0.56	0.235	0.02	5.975	0.1
BAH20	14.05	67.45	2.9	0	2.23	0.24	1.99	0.62	0.12	0.01	5.87	0.13
BAH21	14.23	66.98	2.82	0	2.18	0.18	2.04	0.65	0.13	0	5.74	0.13
BAH22	14.28	64.14	3.74	0	3.24	0.33	3	0.58	0.19	0.3	6.18	0.12
BAH24	16.04	67.35	0.58	0	0.31	0.24	2.27	0.89	0.06	0.03	9.46	0.33
BAH26	14.22	64.05	4.02	0	3.28	0.3	2.99	0.45	0.28	0.17	6.01	0.14
BAH27	13	66.93	2.91	0	4.47	0.35	3.09	0.53	0.12	0	5.14	0.08
BAH32	16.51	62.52	4.6	0	3.43	0.38	2.48	0.57	0.17	0.05	5.84	0.11
BAH33	14.96	63.9	4.4	0	3.69	0.31	2.6	0.42	0.32	0	6.4	0.13
BAH34	17.71	59.67	5.13	0	3.58	0.34	2.88	0.6	0.26	0.07	6.17	0.09
BAH35	15.1	64.65	4.25	0	2.96	0.29	2.18	0.52	0.2	0	6.43	0.13
BAH36	16.59	62.2	5.06	0	3.62	0.22	2.34	0.48	0.21	0.02	6.34	0.08
Average	15.399	63.902	4.01325	0	3.10225	0.28725	2.603	0.5505	0.228	0.03925	6.13225	0.121
St. Dev.	1.633148	3.548219	1.157786	0	0.802771	0.059613	0.361471	0.100981	0.095425	0.071768	0.991325	0.05098

Table 6. Chemical analyses of the Bilad al-Qadim glasses with values representing % wt oxide, 0 representing element not detected. Table 6 shows % wt oxide for oxides Na₂O to TiO₂.

	SnO	BaO	Sb2O5	Cr2O3	MnO2	Fe2O3	CoO	NiO	CuO	ZnO	Total
Group 1											
BAH1	0	0	0	0.01	0.02	0.21	0.01	0.03	0.04	0.17	100.28
BAH3	0.015	0.05	0.04	0	0.51	0.46	0.1	0.015	0.04	0.02	98.18
BAH9	0.005	0.005	0.04	0.025	0.03	0.67	0.025	0.025	1.735	0.22	97.82
BAH11	0.09	0.02	0.155	0	0.01	0.305	0	0	1.425	0	98.65
BAH23	0	0	0.14	0	1.53	0.56	0	0.01	0.02	0.09	98.84
BAH25	0.02	0.01	0.13	0	0.32	2.07	0	0	0.14	0	98.91
BAH28	0.03	0.07	0.08	0.02	0.02	0.61	0.02	0	1.23	0.15	100.1
BAH29	0	0.01	0.15	0	0.97	0.91	0.09	0	0.04	0.06	99.88
BAH30	0.1	0.02	0.03	0.03	2.86	0.81	0.01	0	0	0.07	99.53
BAH31	0.02	0.04	0.14	0.02	0.56	0.37	0	0.05	0	0.02	99.84
Average	0.028	0.0225	0.0905	0.0105	0.683	0.6975	0.0255	0.013	0.467	0.08	99.203
St. Dev.	0.034943	0.022277	0.055877	0.0115	0.864547	0.50242	0.035809	0.01631	0.663149	0.072938	0.801137
Group 2											
BAH4	0.015	0.02	0.055	0.01	1.175	0.83	0	0.01	0.035	0.02	98.435
BAH5	0	0.015	0.065	0	0.975	0.635	0.02	0.025	0.07	0	99.66
BAH6	0	0.015	0.08	0.015	1.03	0.54	0	0.025	0	0.04	98.255
BAH7	0	0.04	0.05	0.01	2.51	0.795	0.01	0	0.035	0.01	98.99
BAH8	0.005	0.015	0.05	0.01	0.07	1.74	0.03	0.035	0.155	0.005	99.63
BAH10	0	0.045	0.14	0.02	2.485	0.87	0.015	0.01	0.015	0.065	99.365
BAH12	0	0.04	0.045	0.01	1.585	0.71	0.01	0.005	0.045	0.005	97.59
BAH13	0.04	0.055	0.06	0	3.045	0.765	0.005	0.01	0.03	0.05	98.895
BAH14	0	0.05	0.045	0.015	1.445	0.665	0	0	0.055	0	99.425
BAH20	0.02	0.02	0.11	0	0.67	2.52	0.09	0.05	0.57	0.25	99.89
BAH21	0	0.05	0.06	0.03	0.33	3.11	0.14	0.15	0.58	0.21	99.73
BAH22	0	0.01	0.12	0	1.67	1.16	0.08	0	0.09	0	99.22
BAH24	0	0.02	0.07	0	0	1.02	0	0	0	0	98.63
BAH26	0.03	0	0.14	0	1.67	1.65	0.12	0.03	0.3	0.17	99.99
BAH27	0	0.04	0.07	0.02	2.14	0.78	0.01	0.02	0	0.03	99.72
BAH32	0	0.03	0	0	1.63	0.58	0.02	0.02	0.06	0.14	99.11
BAH33	0	0	0.07	0	1.44	0.73	0	0.03	0	0.12	99.53
BAH34	0.02	0.01	0.11	0	1.04	0.61	0.04	0	0	0	98.3
BAH35	0.01	0.02	0.14	0	1.76	0.73	0.01	0.03	0	0.17	99.57
BAH36	0.04	0	0.1	0	1.45	0.57	0.01	0	0.02	0.06	99.4
Average	0.009	0.02475	0.079	0.007	1.406	1.0505	0.0305	0.0225	0.103	0.06725	99.16675
St. Dev.	0.013472	0.017283	0.036865	0.00886	0.772507	0.674514	0.041198	0.032538	0.171577	0.077886	0.62211

Table 7.% wt oxide for oxides SnO to ZrO for the same samples as Table 6. These samples are split into groups reflecting their major element contents and the ratios thereof.

		Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	K ₂ O	CaO	TiO ₂	MnO ₂	Fe ₂ O ₃	CuO	PbO	Sb ₂ O ₃
Bahrain	Average:	14.99133	3.835833	2.128333	64.71117	0.286167	3.089167	6.520833	0.1285	1.165	0.932833	0.224333	0.1725	0.082833
	St. Dev.	2.931895	1.305896	0.790706	11.4546	0.072401	1.130311	1.276115	0.073107	0.81764	0.628917	0.354709	0.213923	0.040352
Group 1	Average:	14.176	3.481	1.179	66.3295	0.284	3.063	7.298	0.1435	0.683	0.6975	0.467	0.439	0.0905
	St. Dev.	0.899877	2.010787	0.283706	3.629582	0.082122	1.846586	1.671806	0.109409	0.864547	0.50242	0.663149	0.964204	0.055877
Group 2	Average:	15.399	4.01325	2.603	63.902	0.28725	3.10225	6.13225	0.121	1.406	1.0505	0.103	0.03925	0.079
	St. Dev.	1.633148	1.157786	0.361471	3.548219	0.059613	0.802771	0.991325	0.05098	0.772507	0.674514	0.171577	0.071768	0.036865

Table 8. Summary of the averages in % weight of oxide for the major and minor elements of importance to explained results analysed for the entire assemblage and the two discerned groups, as well as standard deviations for each.

Chapter 6. Discussion:

To form this discussion as to what types of glass are present in these assemblages the data from each of the four main identified groups was graphically and numerically compared to 11 datasets of contemporary glasses from the Middle East, Islamic World and Indian Ocean regions namely Byzantine Pergammon in Turkey (Schibille, 2011), Sir Bani Yas in the UAE (Phelps, Simpson and Freestone, 2018), Siraf in Iran (Swan et al., 2017), a mixture of Middle Eastern sites (Samarra, Nishapur, Khirbat al-Minya, Cairo, Ctesiphon, Beirut and Damascus) (Henderson et al., 2016), Kenya and India (Dussubieux et al., 2008), Zanzibar (Wood et al., 2017), al-Raqqa in Syria (Henderson, McLoughlin and McPhail, 2004) (Henderson, 1999), Sumatra (Dussubieux and Soedewo, 2018), Abbasid Samarra in Iraq (Schibille et al., 2018) and Cambodia (Carter et al., 2019). The comparisons were made based on percentage weight oxide of major and minor elements including MgO, K₂O, CaO, Al₂O₃, SiO₂, Na₂O, P₂O₅, TiO₂, MnO, Fe₂O₃, PbO, and Sb₂O₅ and ratios of these. These sites were chosen due to the range of well characterised glass types found at them and the importance of the sites in glassmaking of this region and period, as well as to give a range across the entire area of study. Some samples have been excluded from certain graphs due to their anomalous values skewing the results and graphically distorting the presentation of data, where this has been done it is noted in the chart title which samples have been excluded.

6.1. Discussion of the Mantai glasses:

6.1.1. Mantai Group 1:

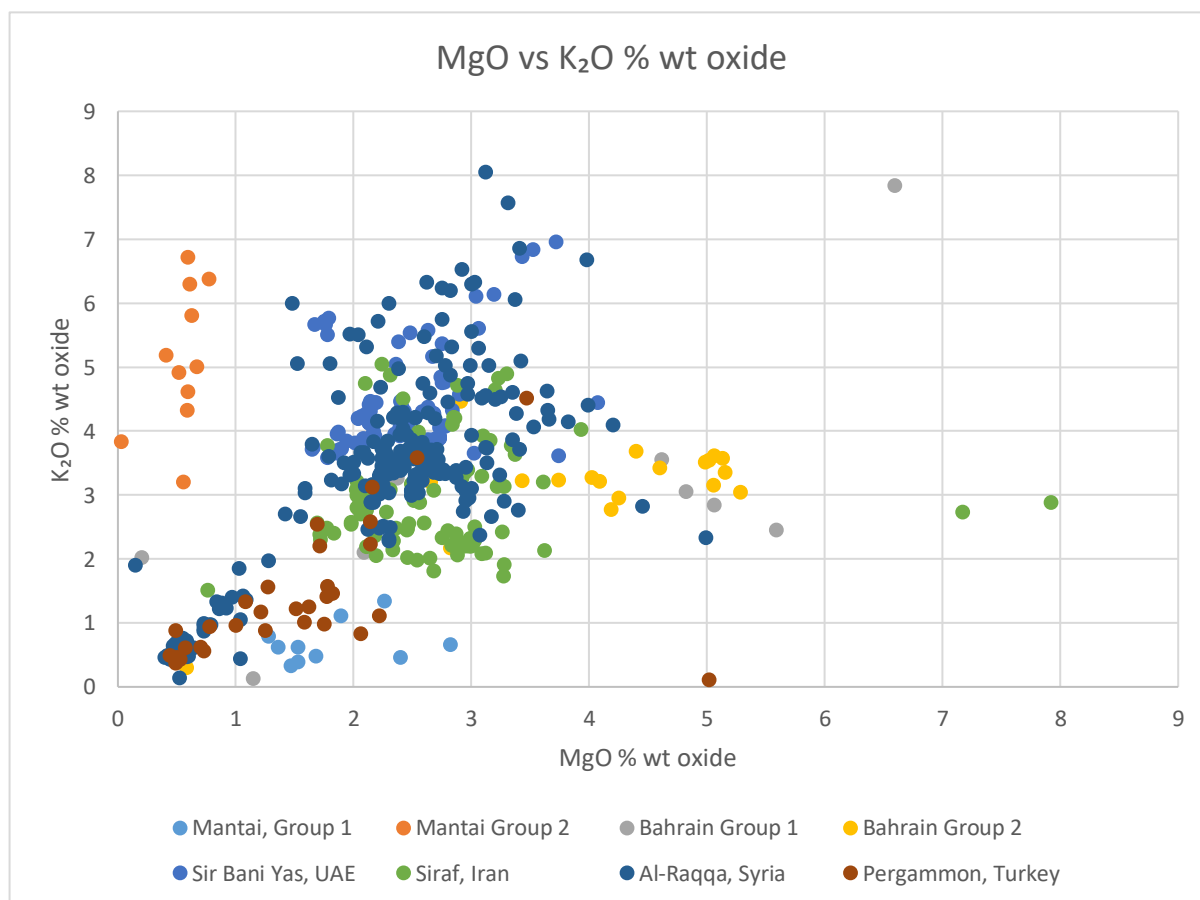


Figure 14. A comparison of MgO and K₂O contents in glasses from the Islamic world and a set of Byzantine glasses.

As seen in the results section, Mantai Group 1 is characterised by its low contents of magnesia (<1.5% wt) and low potash (all samples <3% wt, majority <1.5% wt) as well as low lime contents (<4% wt) but with high levels of alumina (>7.5% wt) and soda (average 18.09% wt). This is indicative of a mineral source of soda being used as flux with an alumina rich sand as a silica source. In comparison to the other data sets on its magnesia and potash content, this group plots within the boundaries of a mineral soda glass, and is comparable to the natron glasses from Byzantine Pergamon as well as subsets of glasses from Mtwapa, Kenya, Angkor Thom, Cambodia and Zanzibar as seen here in figures 18 and 19.

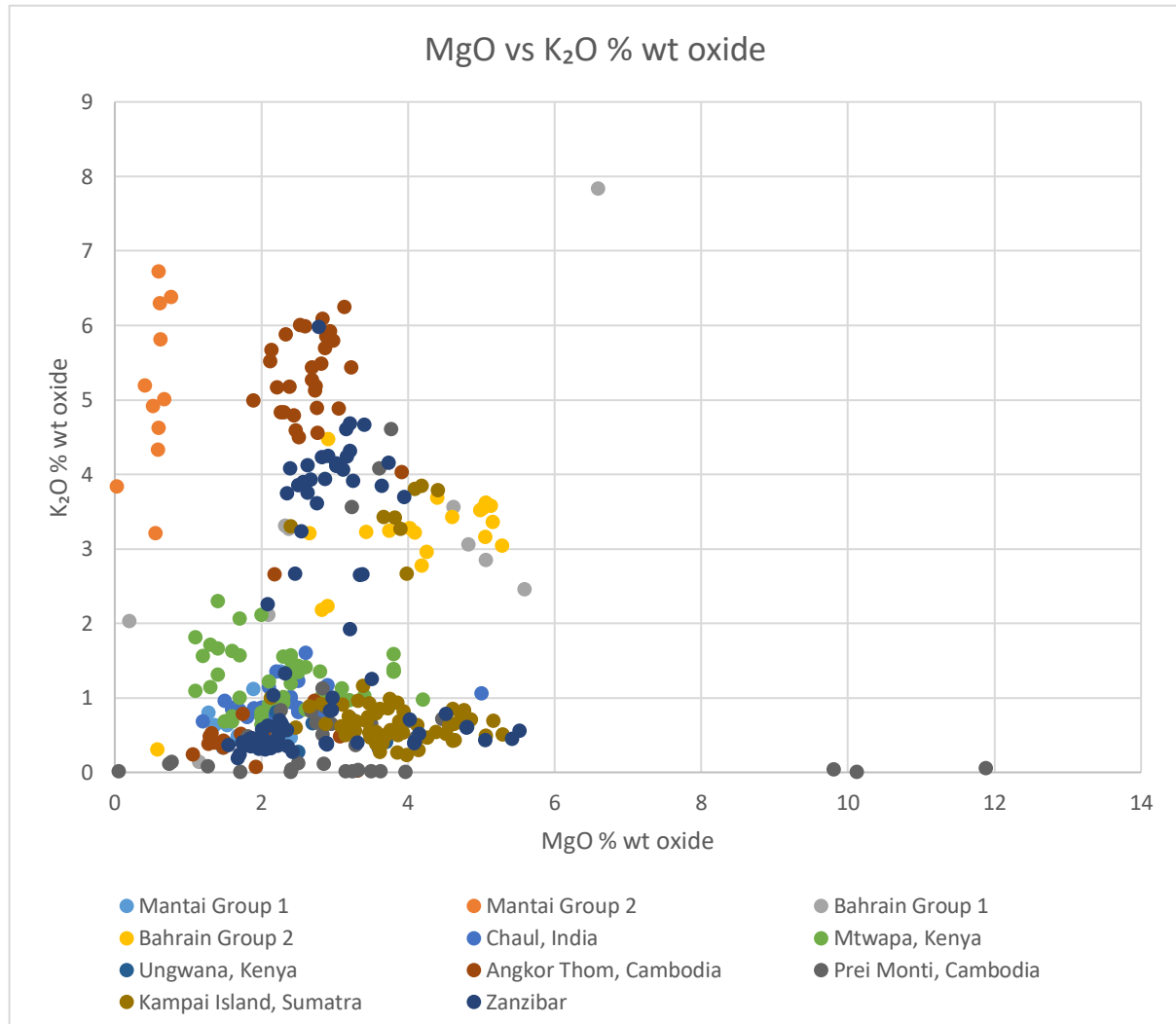


Figure 15. A comparison of MgO and K₂O contents of glasses from Eastern Africa and the Indian Ocean.

In addition to comparable MgO/K₂O contents with many glasses from the Indian Ocean trade region, Mantai Group 1 plots well with these glasses in terms of its Al₂O₃ and CaO contents, as seen in Figure 19. Additional comparisons of Al₂O₃ vs Fe₂O₃, MgO vs CaO, K₂O vs CaO and MgO/K₂O vs Al₂O₃/CaO confirm the similarity in major elements with these data sets, or sub groups therein, making an Indian Ocean or South Asian origin for these glasses more probable. When compared to the slightly later set of glasses from Mtwapa, Kenya which is a coastal urban settlement connecting the East African hinterland to the wider Indian Ocean exchange network, where the pre-colonisation glass likely came from India, we see major similarities with the type identified as m-Na-Al (Dussubieux et al., 2008). The subgroup of glasses from Zanzibar also form a cluster with the glasses from Mtwapa, Chaul and Mantai Group 1, all of which have been identified as this type as well as this subset of

glasses from Sumatra and Angkor Thom. The Zanzibar glasses are mostly m-Na-Al type 1, from Sri Lanka itself, with Mantai being suggested as a centre of glassmaking or South India but to determine where the Mantai Group 1 glasses fall in terms of which subtype of m-Na-Al this is not able to be determined from the EPMA results due to the discrepancy being based on trace elements content, most notably uranium and barium (Wood et al., 2017).

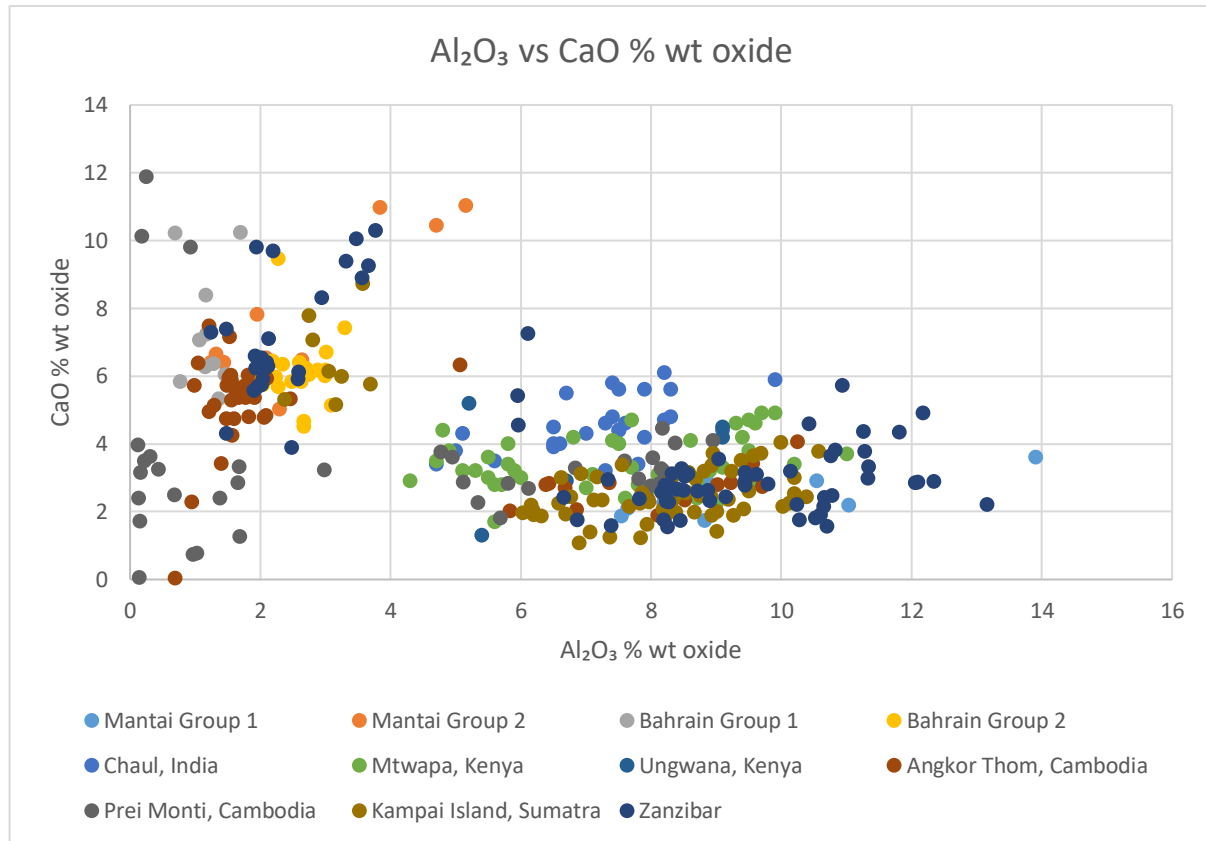


Figure 16. A comparison of CaO and Al₂O₃ contents with glasses from the Indian Ocean and East Africa

m-Na-Al stands for mineral soda high alumina glass, common in Asia and East Africa from the 5th century BC until just before the 20th century when colonisation happened and craftworking methods underwent major change (Axinte, 2011) (Dussubieux et al., 2008). Generally type 1 is more common from the 5th century BC to the 10th century AD at sites in South and South East Asia and is higher in uranium but lower in barium, whereas type 2 is found more at sites in Eastern and Southern Africa as well as India (where they are thought to originate) from the 10th to the 19th century AD and inversely contains high barium contents and low uranium while type 3 is similar but with elevated caesium although at least five subtypes have been identified to date (Wood et al., 2017) (Dussubieux and Soedewo, 2018). This type of glass is believed to have been made locally to South Asia and accounts for a large portion of all glass recovered from sites of this period and region. The most likely materials used to make this are a mineral soda from India called *reh*, a mineral efflorescence widely available in India generally containing less than 1.5% wt MgO and low CaO, which is a mixture of compounds including sodium carbonate (Na₂CO₃), sodium chloride (NaCl) and sodium sulphate (Na₂SO₄) (Dussubieux, Gratuze and Blet-Lemarquand, 2010). The elevated alumina contents shown in this type of glass is a product of this *reh* or similar mineral soda flux being fused with poor quality sands high in impurities or granite rich sands, also from the local area (Dussubieux and Soedewo, 2018). It may be possible to propose one sample as being from a certain subtype, based on the colourant contents it has been shown to have, namely the opaque orange MANT 4 which contains 7.3% wt CuO as well as elevated lead and slightly elevated tin contents. m-Na-Al type 3 often is red

or orange, opaque and coloured with similarly high levels of copper as well as elevated iron contents (MANT 4 contains 2.99% wt oxide Fe_2O_3 compared to the group average of 1.06% wt oxide) and the opacifier of usual choice is lead stannate, the most likely opacifier used for this sample (Carter et al., 2019). It is however not possible to accurately attribute any of these samples to a particular subtype of m-Na-Al glass without further trace element analysis, but we can definitively say they are part of this group and likely locally made, potentially in Mantai, where MANT 1 is a fragment of glaze from a kiln, but doesn't conclusively indicate the site to be a glassmaking centre. These results do seem to support the idea of local production in South East Asia and this being a way through which there was contact with East Africa and their hinterlands, through which connections to the Islamic world could be forged.

6.1.2. Mantai Group 2:

In contrast to the m-Na-Al Mantai Group 1, Group 2 is characterised by its higher potash and contrastingly higher magnesia contents ($\text{MgO} > 3\%$ wt oxide and majority of samples $> 2\%$ K_2O wt oxide) which indicate them to have a vegetal soda source, most likely plant ash. All the glasses in this group are of the soda-lime-silica type with high lime (exceeding 5% wt oxide), low alumina ($< 5\%$ wt

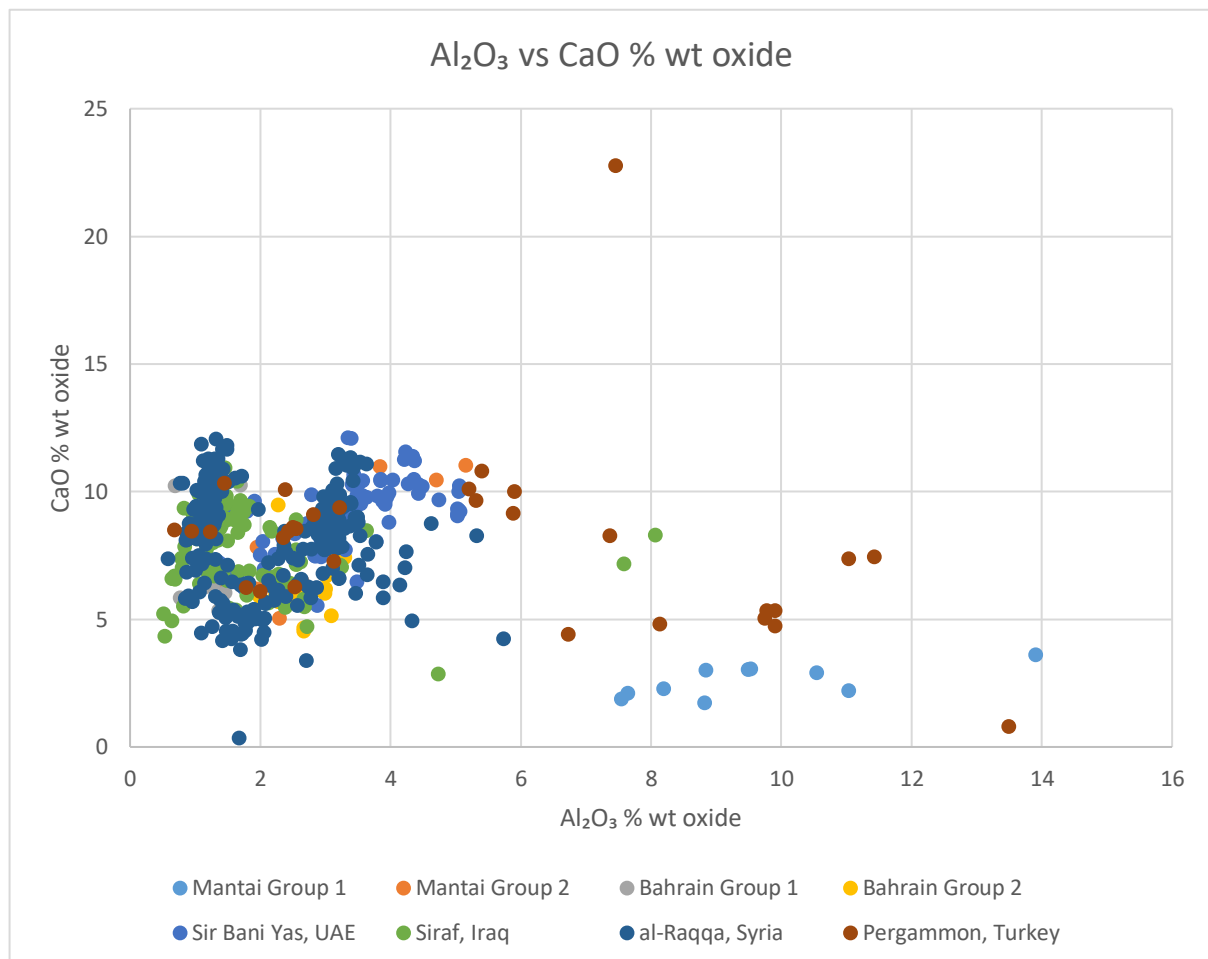


Figure 17. A comparison of Al_2O_3 and CaO contents with glasses from the Islamic World and a dataset from the Byzantine Empire.

oxide) and lower soda (average 15.37% wt oxide) consistent with a plant ash soda use. In terms of the MgO vs K_2O contents of this group of glasses this group plots closest to the Bahrain glasses, having a very high MgO content, much more so than the Islamic and Middle Eastern glasses as well

as the Indian Ocean glasses. Looking at the Al_2O_3 vs CaO contents, these glasses plot best with the results from the Sir Bani Yas glasses and the higher lime-bearing samples from al-Raqqa (see Figure 21).

When considering MgO and CaO contents, as well as $\text{MgO}/\text{K}_2\text{O}$ vs $\text{Al}_2\text{O}_3/\text{CaO}$ ratios of Mantai Group 2 with the other datasets, the likely relation to Islamic glasses from al-Raqqa, Siraf, Sir Bani Yas and the Middle East becomes more apparent, as shown in Figures 22 and 23. In the latter figure a definite cluster can be seen with these values and those obtained from samples at these locations, with Mantai Group 2 exhibiting high $\text{MgO}/\text{K}_2\text{O}$ ratios in contrast to lower $\text{Al}_2\text{O}_3/\text{CaO}$ as well as all glasses from Samarra except those made with natron as a soda source (Figure 22).

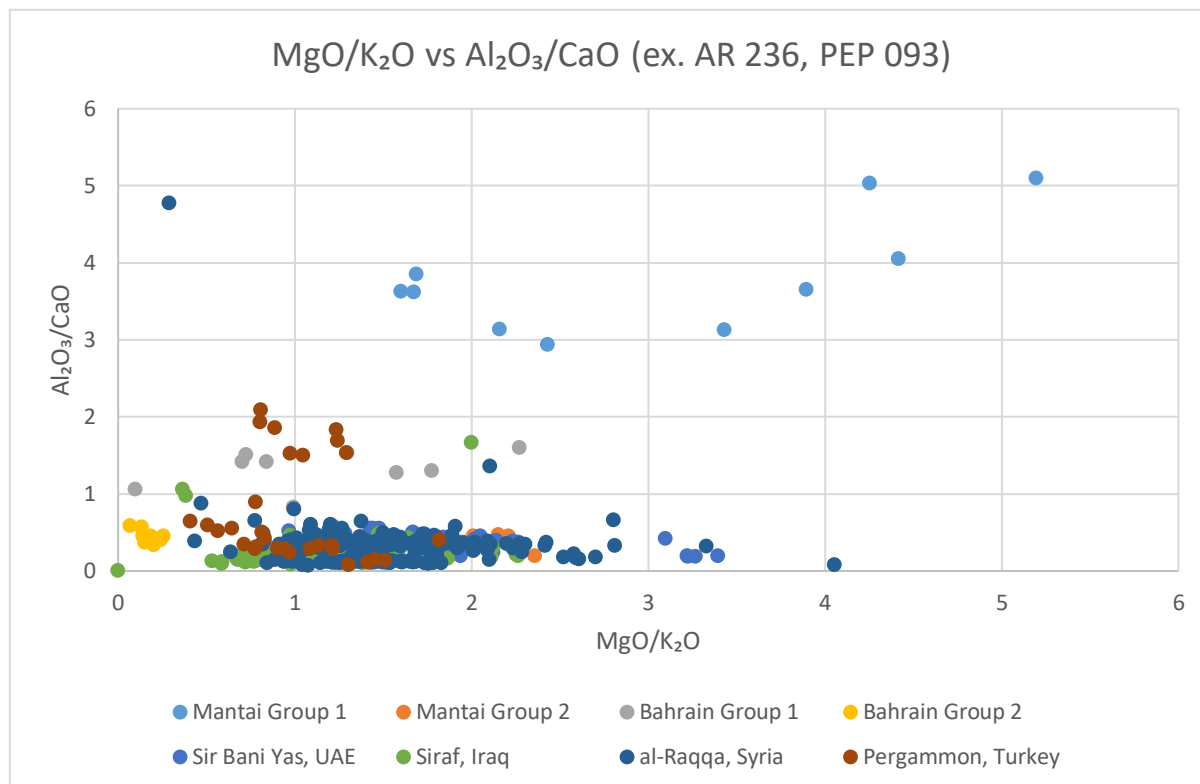


Figure 18. A comparison of $\text{MgO}/\text{K}_2\text{O}$ vs $\text{Al}_2\text{O}_3/\text{CaO}$ ratios with glasses from the Islamic world and a dataset from the Byzantine Empire.

A comparison of the Al_2O_3 and Fe_2O_3 contents of the Mantai Group 2 samples with the wider dataset also shows these results to cluster with the higher iron containing samples from Sir Bani Yas, Siraf and a subset of the al-Raqqa glasses (see Figure 25), whereas they are considerably lower in both when contrasted with the glasses from the Indian Ocean region. Upon consideration of the major and minor elements, the glasses in Mantai Group 2 seem to be most related to the Sir Bani Yas, Siraf and al-Raqqa glasses, as well as the glasses from the Middle East which were under the control of the Islamic caliphates. Of these sites the Mantai Group 2 glasses tend to plot with the higher MgO samples from each and their link to these glasses and those from the Middle East, notably Damascus and Ctesiphon which can be seen further in their Fe_2O_3 and TiO_2 contents as well as alumina and P_2O_5 . In closer comparison to the al-Raqqa glasses on their MgO and Al_2O_3 contents Mantai Group 2 tends to chart best with the compositionally wide ranging Type 4 and a similar spread is seen when looking at the CaO and P_2O_5 contents of them (Figure 26-29). These similarities indicate the Mantai Group 2 glasses may be from al-Raqqa or made to a similar recipe, as additionally indicated by the very high magnesia levels of this group, which may stem from the plant species used as flux, which may have been fused experimentally with cullet or recycled glass (Henderson, McLoughlin and

McPhail, 2004). In terms of the glasses from Sir Bani Yas, the Mantai Group 2 glasses plot most closely with the first two groups identified here, being more similar to the type 2 due to its lower lime than group 1, which is still moderate to high, as well as the P_2O_5/K_2O vs MgO/CaO ratios and impurity levels, including Al_2O_3 , Fe_2O_3 and TiO_2 . In addition to this, the consistent levels of MnO , although low, are a hallmark of Islamic glassmaking, especially distinct from Sasanian traditions (Phelps, Simpson and Freestone, 2018). The parallel of this group with the glasses from Siraf can also be seen by consideration of these major elements, where the high contents of K_2O and especially MgO indicate the Mantai Group 2 glasses to have an origin in the Islamic Iran or Iraq areas, which is consistent with that which is suggested by comparison with al-Raqqa and Sir Bani Yas. The main group of glasses identified at Siraf also contain elevated levels of the impurities previously mentioned, as well as higher P_2O_5 and lime which are characteristic of this group (Swan et al., 2017). The relation of the compositions of Mantai Group 2 to sites in the Middle East such as Ctesiphon, Damascus and Samarra, which are also seen in comparison to this group can be explained by the exportation of glasses from glassmaking sites such as al-Raqqa and Samarra sending glass across the entire Islamic world from where it travels further, a trade encouraged by the regional specialisations we know to have been present (Henderson et al., 2016). Overall, the glasses here identified as being part of Mantai Group 2 can be attributed to having an origin in the Islamic world, made to a recipe using magnesia rich plant ashes and sands containing impurities, the range of which could be attributed to the difference in sediment content (Phelps, Simpson and Freestone, 2018). It can be said that in many ways this group resembles the al-Raqqa type 4 glasses, but it would not be possible to say this with certainty without looking at the trace element discriminants, which are seen to be the main basis on which the Siraf glasses are divided. This shown relation of the Mantai Group 2 glasses is very important as it provides evidence for the contact between the Islamic trade world and the Indian Ocean circuit at the time, where even though glass was being produced locally, contact and trade was occurring and spreading goods and influence of the Islamic world into South East Asia and Eastern and Southern Africa.

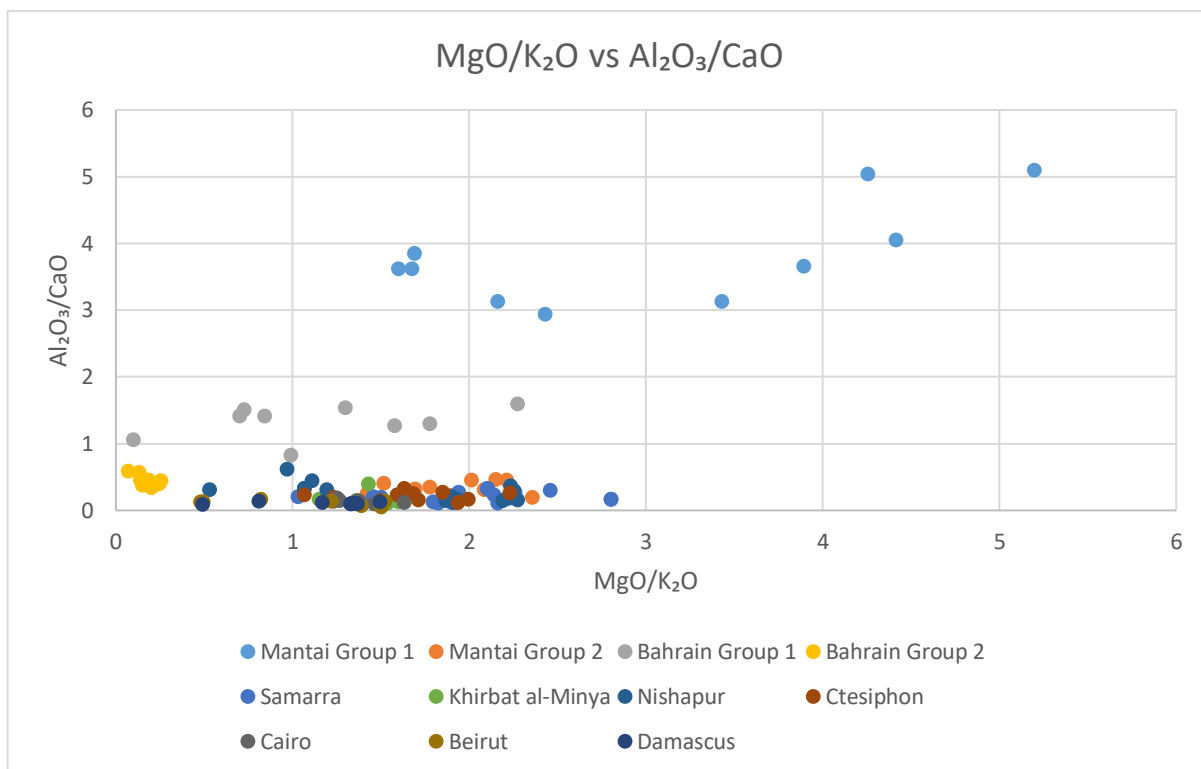


Figure 19. A comparison of MgO/K₂O vs Al₂O₃/CaO ratios with glasses from across the Middle East.

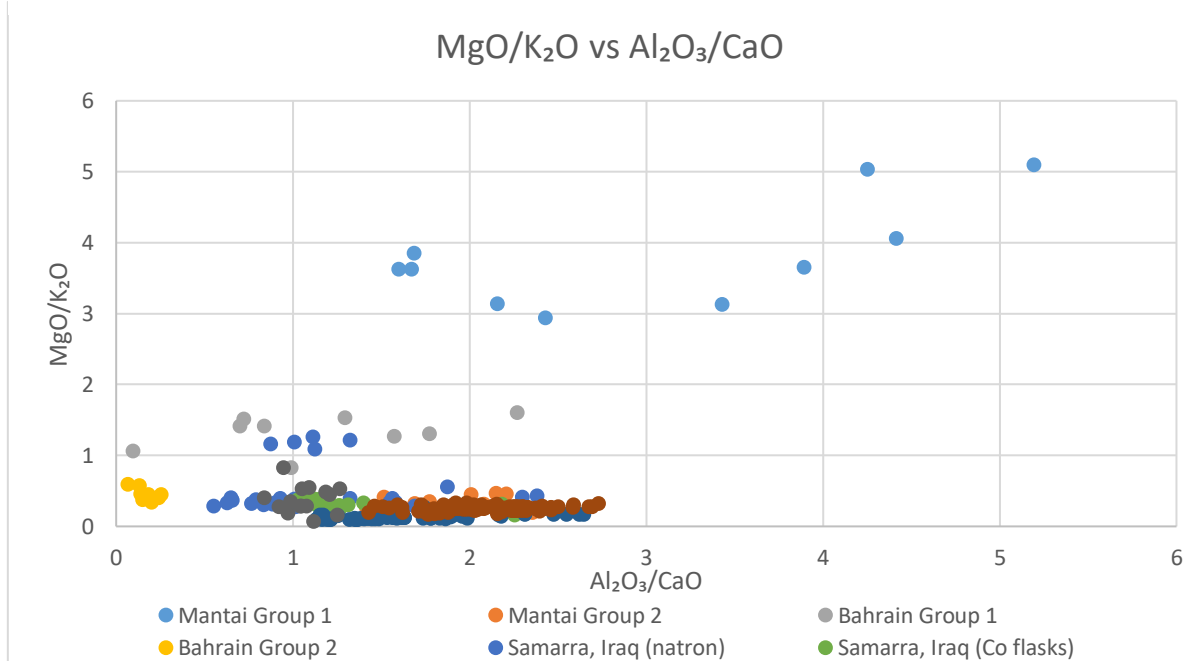


Figure 20. A comparison of MgO/K₂O vs Al₂O₃/CaO ratios with glasses from Samarra, Iraq

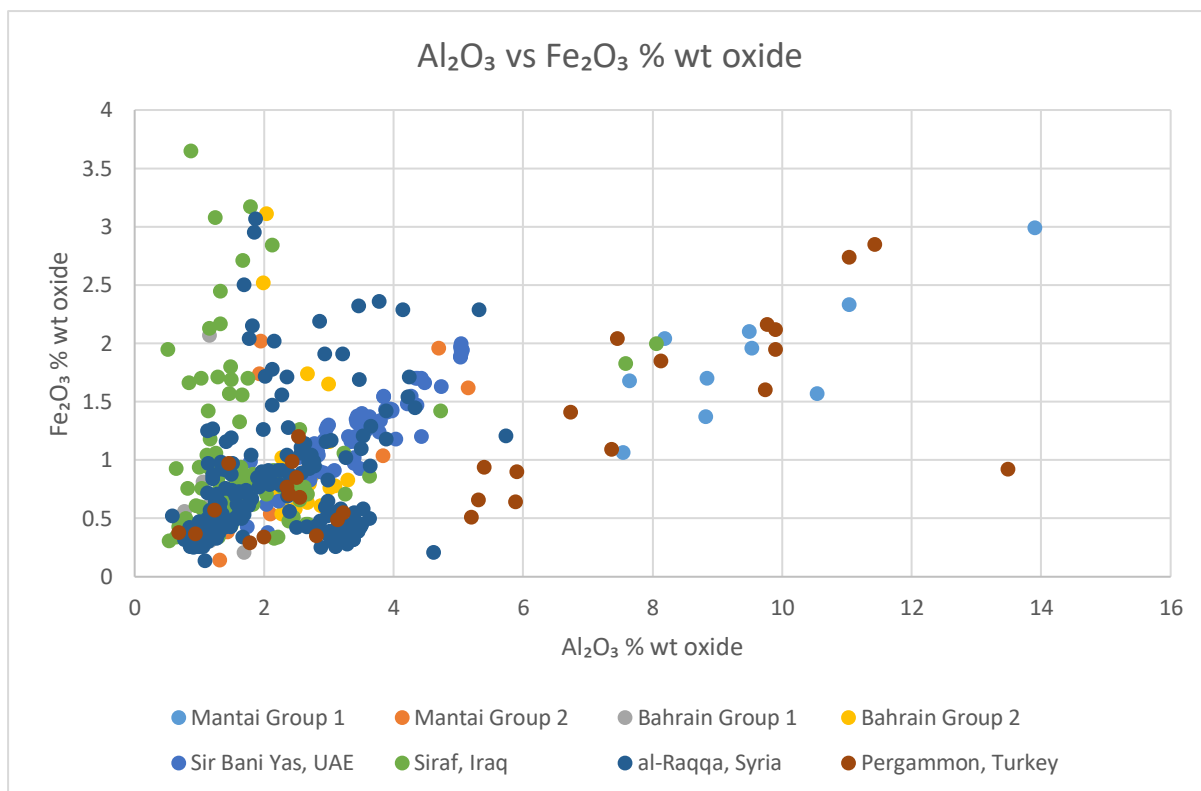


Figure 21. A comparison of Al_2O_3 and Fe_2O_3 contents with glasses from the Islamic world and a dataset from the Byzantine Empire

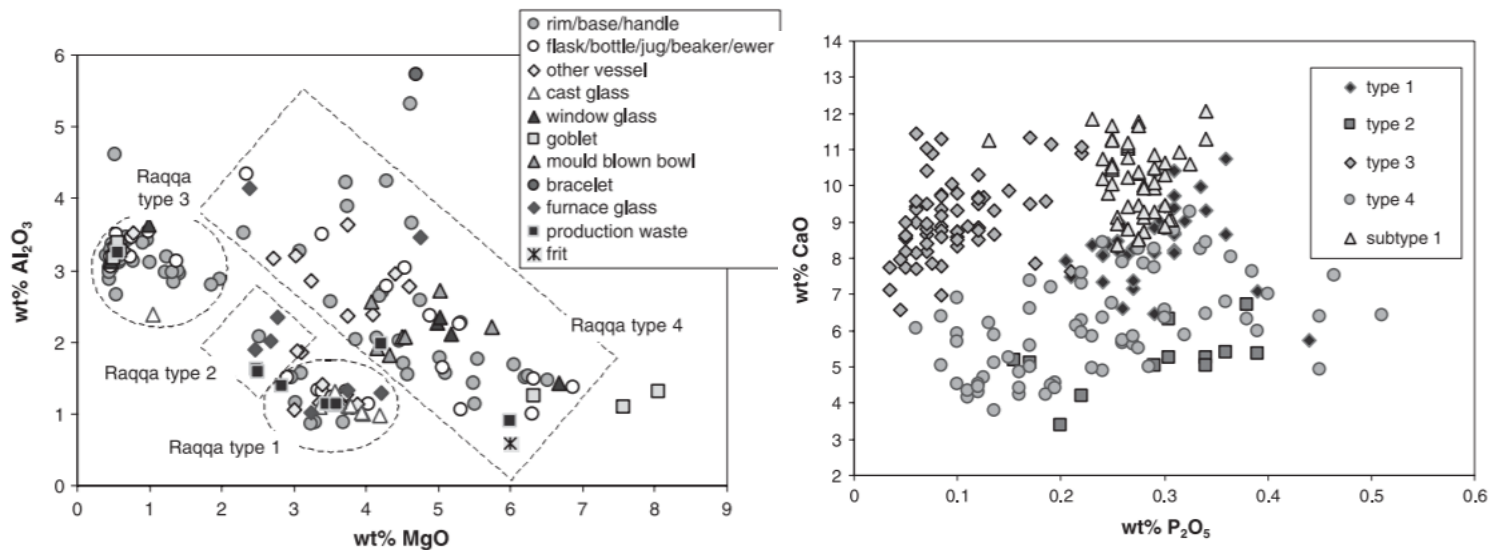


Figure 22. Comparisons of MgO vs Al_2O_3 for the al-Raqqa identified types, images from Henderson, McLoughlin and McPhail, 2004.

Figure 23. Comparisons of CaO vs P_2O_5 for the al-Raqqa identified types, images from Henderson, McLoughlin and McPhail, 2004.

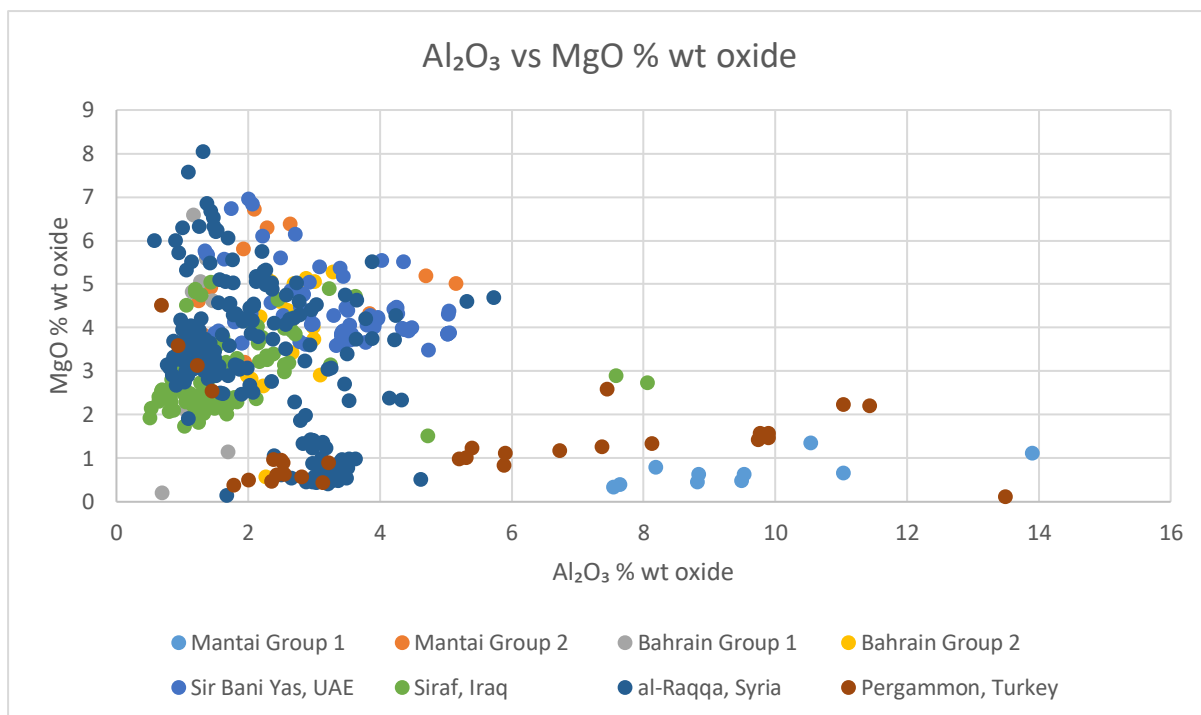


Figure 24. For comparison with Figure 26, comparisons of Al₂O₃ vs MgO.

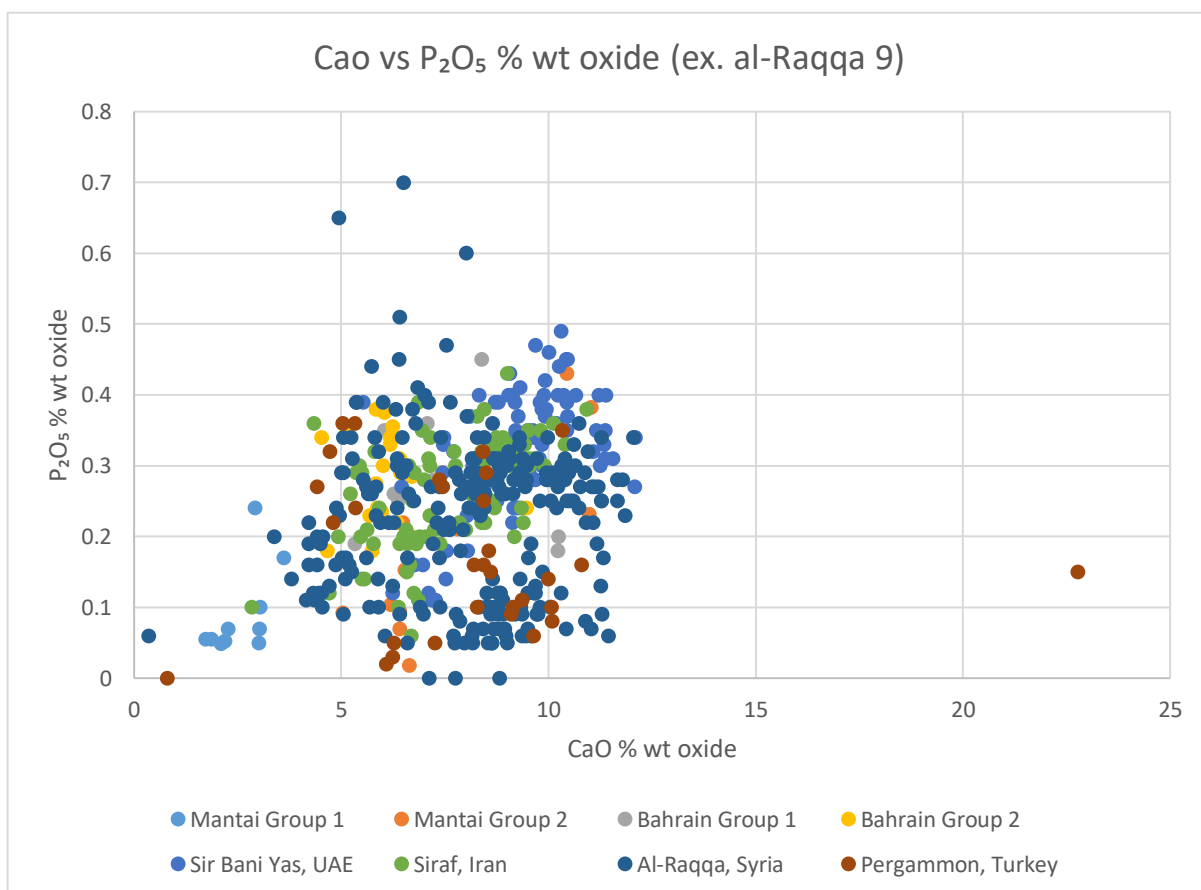


Figure 25. For comparison with Figure 27, comparisons of P₂O₅ vs CaO.

6.2. Discussion of the Bahrain Glasses:

6.2.1. Bahrain Group 1:

All the glasses analysed from the first of the Bahrain groups are of a soda-lime-silica composition, with high magnesia and potash (all >1.5% wt oxide and most >3% wt). Additional characteristics of this group distinguishing them from the other Bahrain glasses are their very low alumina (<2% wt oxide) and slightly elevated lime. This makes it likely that the materials used in the fusion of this glass were a vegetal flux and a purer silica source, as its SiO₂ is also elevated in comparison to Bahrain Group 2, perhaps indicating the use of a refined sand. When compared to the other datasets from across the Islamic world and Indian Ocean trade region, it can be seen that these glasses are compositionally more like those from al-Raqqqa, Siraf and Sir Bani Yas, as well as Ctesiphon, Beirut and Damascus in the Middle East. Some of the contents of the Bahrain Group 1 glasses are also broadly comparable to the Mantai Group 2 samples discussed above. When compared to the al-Raqqqa glasses Bahrain Group 2 plots with the high MgO vs CaO samples (Figure 30), but is closest to type 2 based on potash and magnesia contents, which is similar based on its wide range, low lime and higher P₂O₅ as seen in Figure 31.

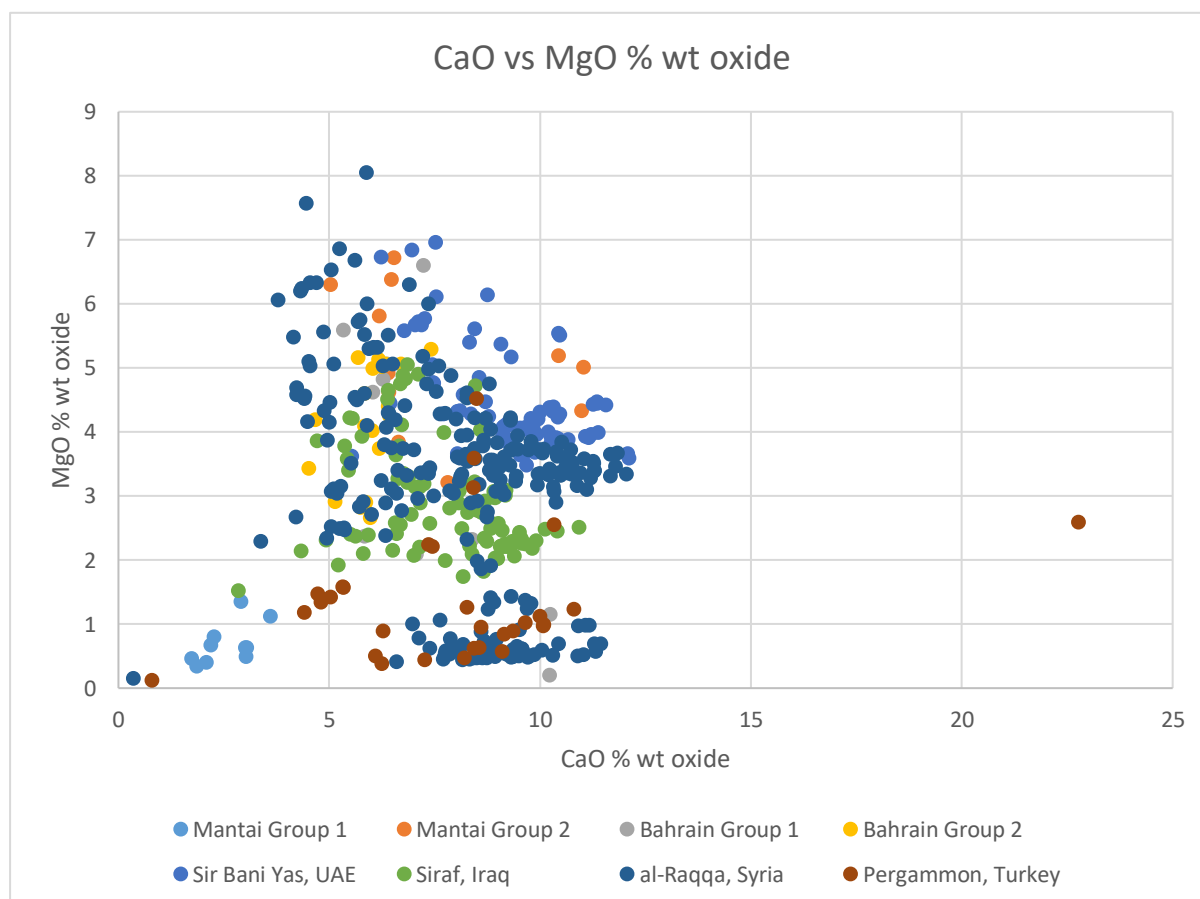


Figure 26. A comparison of CaO and MgO contents compared to glasses from the Islamic world and a dataset from the Byzantine Empire

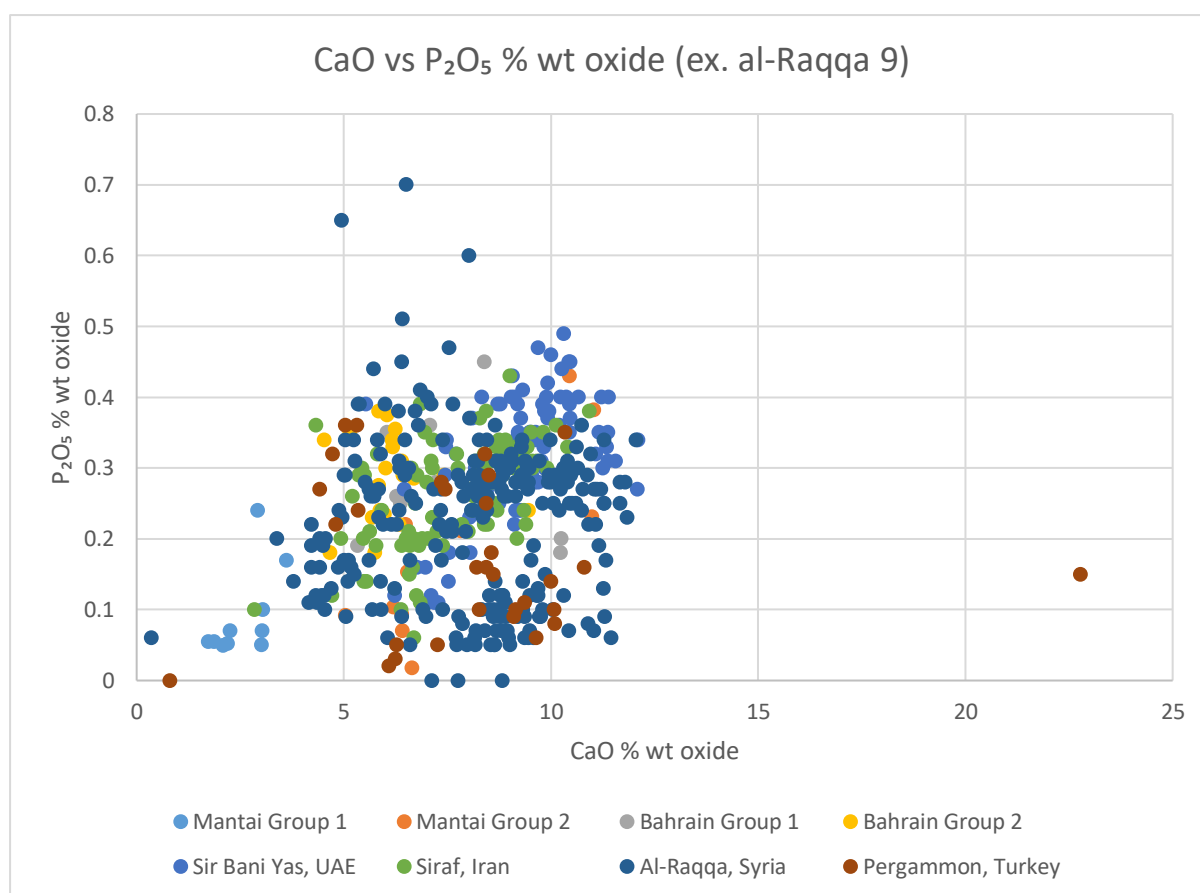


Figure 27. A comparison of CaO and P₂O₅ contents with glasses from the Islamic world and a dataset from the Byzantine Empire.

In further comparison with the al-Raqqa glasses, parallels can be seen with type 2 in regard to the low alumina and impurity contents both groups exhibit, illustrated in Figure 32, where both alumina and iron contents are notably low, again pointing to a purer silica form. Although they bear many compositional similarities it would take trace element analysis to confirm the relation of these glass types due to additional discriminants and the low number of both samples in type 2 and in Bahrain Group 2 (Henderson, McLoughlin and McPhail, 2004). When comparing the Bahrain Group 1 data with that from Siraf, although as aforementioned a sub-group cannot be suggested on this based on the use of trace elements to do this, it can be seen from the MgO vs K₂O contents that this group is more likely to be of Syro-Palestinian origin as the MgO levels are high, but not as much as would be expected from Mesopotamian Islamic glasses (Swan et al., 2017). This would support a hypothesised al-Raqqa origin for these glasses as the type 2 here exhibits a similar range of MgO contents, as Mesopotamian and Persian glasses have generally been seen to have higher MgO contents and MgO/CaO ratios when compared to their Syro-Palestinian and Levantine counterparts, in a trend from west to east (Swan et al., 2017). As with Mantai Group 2, the closest match of the Bahrain Group 1 glasses from Sir Bani Yas would likely be the type 2 here. This is based on the low lime they both exhibit, and the magnesia values already discussed. It is also notable that all three groups are fairly low in impurities such as iron and titania, as well as lower in alumina. Bahrain Group 1 also has a few samples with higher MnO contents, despite the groups generally low content and alumina levels (see Figure 33) of when compared to the whole set of glasses, these being the colourless samples in the group – with manganese being the decolourant of choice in glassmaking in the Islamic world at this time (Phelps, Simpson and Freestone, 2018). It is hard to discern the full nature of the

similarities this group has with the glasses from Ctesiphon, Cairo, Beirut and Damascus due to the data plotting closely for major and minor elements but being divided on Cr/La and Li/K ratios. This could be down to the use of a similar glass recipe in different places or production in one area before dispersal by trade to others, however it is more likely that these glasses were fused in one zone due to their similarities, but at which urban centre this occurred is currently unknown (Henderson et al., 2016). On reflection of the entire dataset, it seems most likely that the Bahrain Group 1 glasses were fused in the Syro-Palestinian zone or using materials from here, which would account for the high MgO and low alumina, a tentative suggestion as to a type would be al-Raqqa type 2 with which it fits best compositionally, however this cannot be definite.

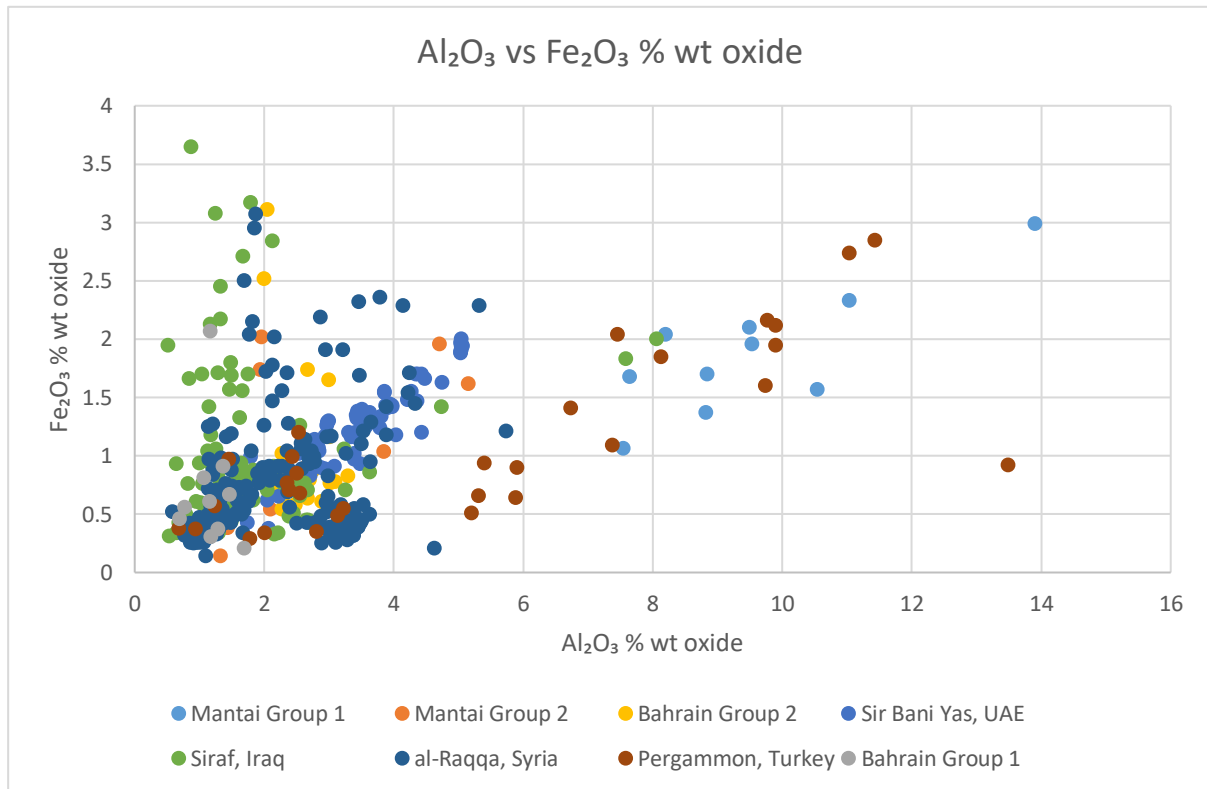


Figure 28. A comparison of Fe_2O_3 and Al_2O_3 contents with glasses from the Islamic world and a dataset from the Byzantine Empire.

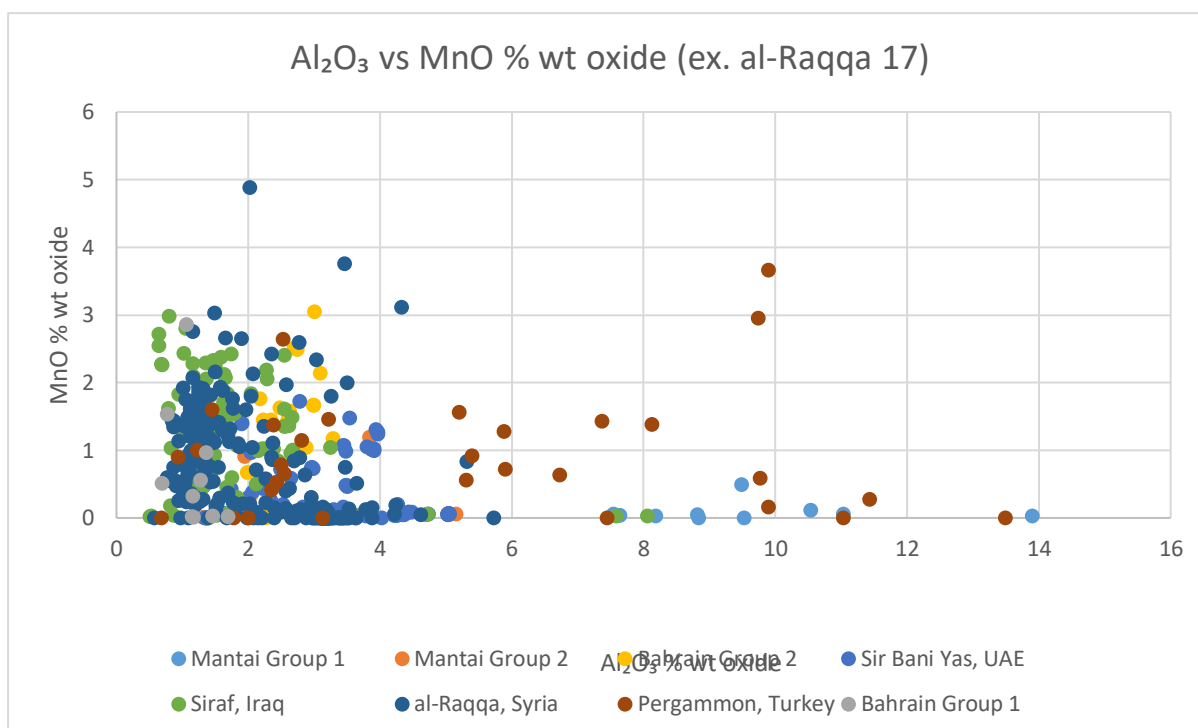


Figure 29. A comparison of MnO and Al₂O₃ contents with glasses from the Islamic world and a dataset from the Byzantine Empire.

6.2.2. Bahrain Group 2:

All the samples in this group are characterised by their high MgO and K₂O (>2% wt), moderate lime (around 6% wt) and low alumina contents (<3.5% wt) as well as their elevated MnO (due to the number of colourless glasses in this cohort) and high P₂O₅ (average 0.29% wt). The glasses of this group form a tighter range of percentage oxide weights in comparison to Bahrain Group 1. In terms of MgO and K₂O contents, these glasses plot most closely with some of the higher MgO Siraf and al-Raqqa glasses (see Figure 19) as well as some of the Middle Eastern glasses based on impurity levels ratios and levels of K₂O vs P₂O₅ (Figure 36). Additionally, based on MgO and K₂O levels, some of the Bahrain Group 2 glasses plot with the higher MgO and K₂O Zanzibar glasses, as well as those with lower alumina and higher lime (see Figures 19 and 20). This is also evident when looking at levels of CaO vs P₂O₅ (Figure 34 and 35) where like in the MgO vs Al₂O₃ contents, there are similarities between the lower lime Siraf and al-Raqqa glasses and the higher lime Zanzibar glasses (Figure 36).

The datasets bearing the most similarities to Bahrain Group 2 are the high MgO/low CaO Siraf glasses, and the lower lime al-Raqqa glasses, as well as some of the Zanzibar glasses and some broader comparisons with those from the Middle East. The main group identified at Siraf has consistently elevated manganese as well as the moderate lime and low alumina values shown in the Bahrain Group 2 samples but they fit better across the major and minor components with a subset of the al-Raqqa glasses (Henderson, McLoughlin and McPhail, 2004) (Swan et al., 2018). The MgO and K₂O contents are undoubtedly indicative of the use of a plant ash flux, and also bear many similarities to the group al-Raqqa type 1, being of a similarly tight compositional range, also having low alumina, higher manganese and phosphorus but lower lime and elevated iron (see Figure 21, 32, 33 and 34). The size, range and homogeneity of this group supports the possibility of it being from al-Raqqa type 1, likely with a deliberate addition of manganese, due to it being a well-known and controlled recipe used repeatedly. However, this type has been posited to have been made with a pure silica source, such as chert or quartz, reflected in the low alumina contents, but has a higher

silica content than shown in Bahrain Group 2 (Henderson, McLoughlin and McPhail, 2004). The similarities the group exhibits with the glasses from Sir Bani Yas seem to be broad and there is no group here which fits with enough similar features to be considered a possible parallel (Phelps et al., 2018). The group of closest composition at Zanzibar is the v-Na-Ca group, which has low alumina and moderate lime (see Figure 21) as well as lower proportions of major oxides (i.e. silica and soda). This group has been shown in some of its characteristics to align with al-Raqqa type 1, with the exception of the lime and alumina contents of type 1 ($>6\%$ wt CaO and $<2\%$ Al_2O_3) which would indicate this group to be the closest to Bahrain Group 2 (Wood et al., 2017). This would additionally explain the similarities in some oxide contents between Bahrain Group 2 and Mantai Group 2, as well as the glasses from the Middle East, as they would have a similar origin and be linked by known routes of glass trade. This would indicate that this part of Bahrain was well-integrated into the trade routes of the Islamic world and major focal points of the caliphates, perhaps having this glass imported specifically for the mosque at al-Khamis, with the colourless glass having a potential cultural or religious significance.

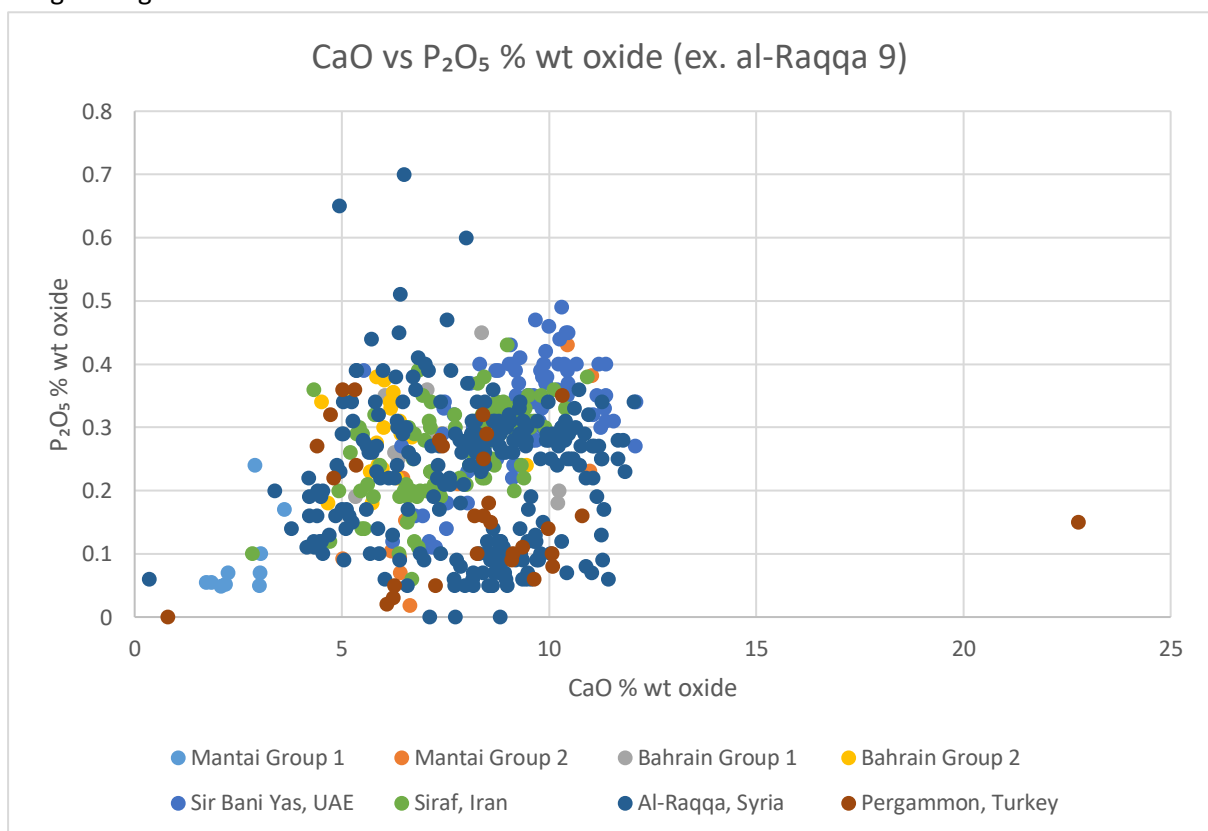


Figure 30. A comparison of CaO and P_2O_5 contents with glasses from across the Middle East.

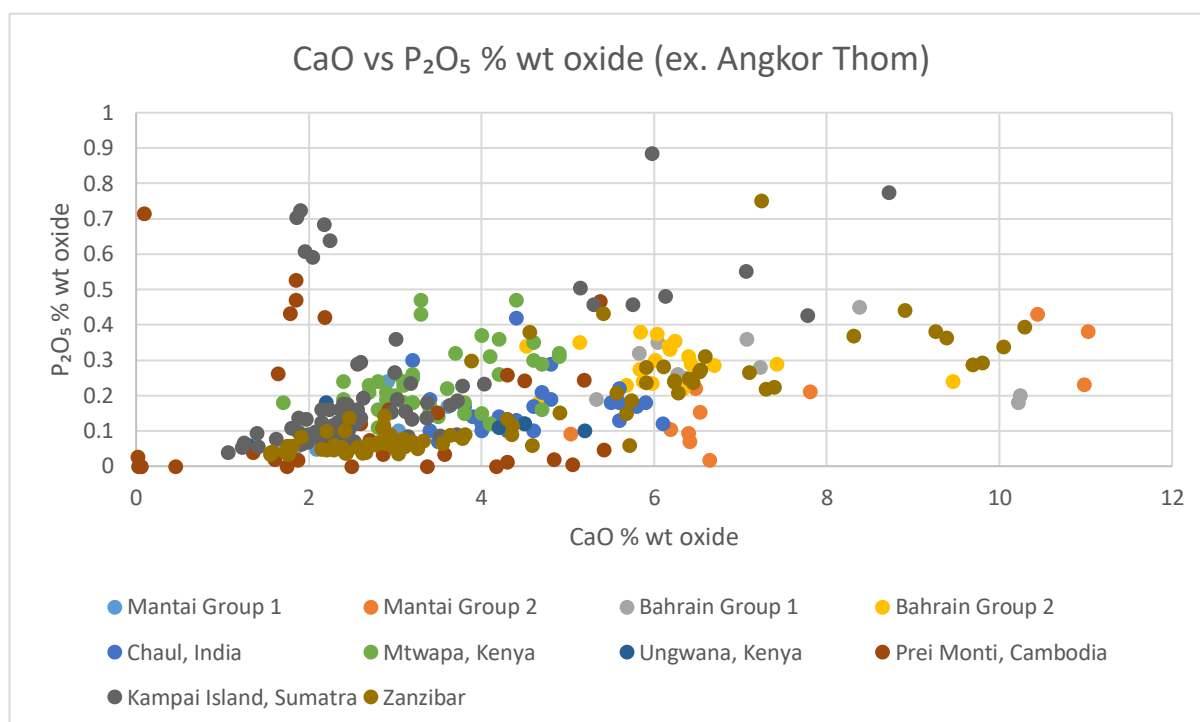


Figure 31. A comparison of CaO and P₂O₅ contents with glasses from the Indian Ocean region.

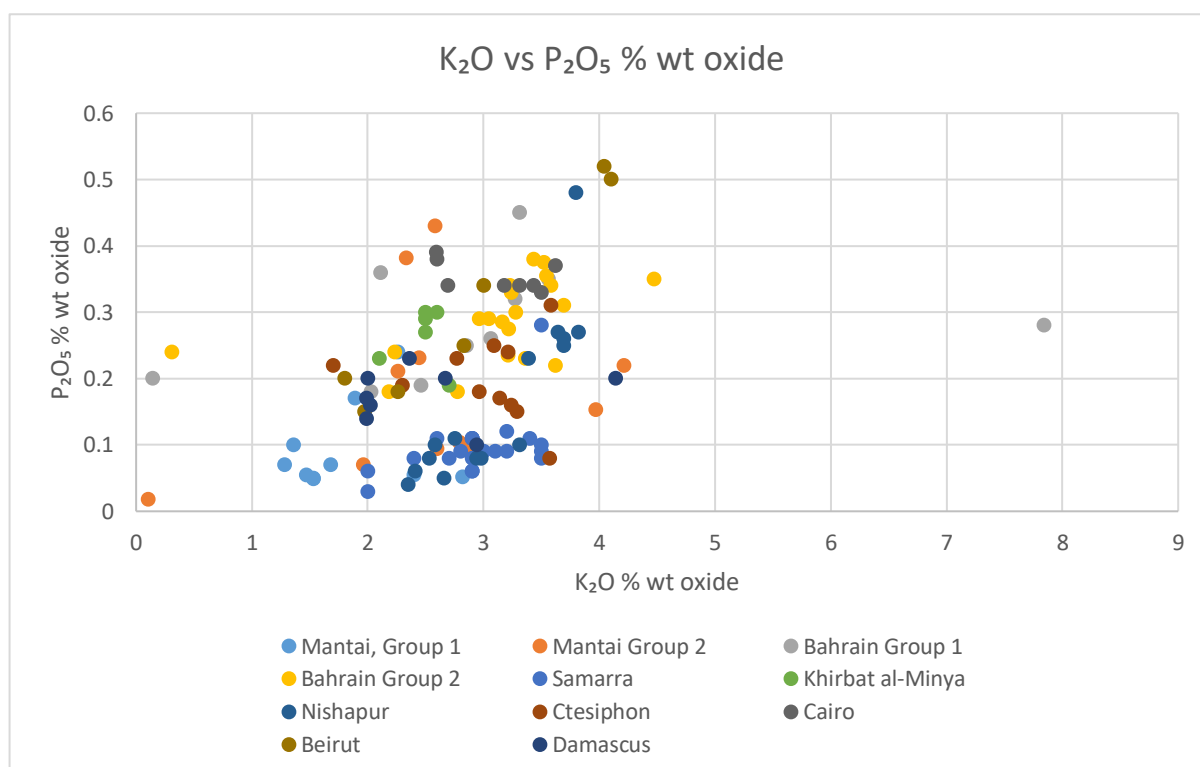


Figure 32. A comparison of CaO and P₂O₅ contents of glasses from the Islamic world and a dataset from the Byzantine Empire.

Chapter 7. Conclusions:

The aims of this work were to provide data of the chemical characterisation of these glasses from Mantai, Sri Lanka and Bilad al-Qadim, Bahrain between the 8th to the 13th centuries AD and to give an indication of what their composition and possible provenance may be and mean for trade in the Indian Ocean and Islamic World regions and their connection to the wider Maritime Silk Road. This here has been done mainly through a review of the relevant literature and comparison of results to contemporary datasets from across the relevant region.

From this review and discussion, it became clear that the glasses from Mantai formed two main groups as well as some outliers whose likely provenance is given in the results section of this work. The first of these groups (Mantai Group 1) was shown to be of the type already known as m-Na-Al based on their high alumina, low lime and low magnesia and potash content and comparison to datasets known to feature this type, perhaps made using the soda rich mineral evaporate *reh*, commonly found in India. This type is known to originate from South East Asia, with Mantai itself as a possible production location, showing clear links via the Indian Ocean trade routes to East Africa and India, further indicating the position of Mantai as an entrepôt and its role in transshipment and distribution of glass. The group here referred to as Mantai Group 2 was shown to likely originate from the Islamic World, made from plant ash and a low alumina silica source, resembling known recipes from the production site of al-Raqqā. The results of this group show Mantai to have been integrated into the wider networks of the Islamic World and wider Silk Road, providing a link between the Indian Ocean region to this, including East Africa.

The Bahrain glasses too formed two groups the first of which being made from plant ashes and a very low alumina silica source, also related to known recipes from al-Raqqā and closely matching samples from sites known to have had glass exported there from this site. This group is very likely fused from materials from the Syro-Palestinian region and most probably were made in this region and exported to Bahrain. The interpretation of Bahrain Group 1 and the further second group from this site – Bahrain Group 2 – provide evidence for the integration of Bahrain into the trade routes of the Islamic world. The high magnesia and potash with low alumina and higher manganese and P₂O₅ contents of these glasses indicate the use of a plant ash flux with a low alumina silica source, possibly chert or refined sand. This group bears similarities to some v-Na-Ca glasses but is again most closely related to glasses from major centres of the Islamic World and Middle East, much like Mantai Group 2, to which it also bears similarities. This is further suggestive of the integration of Bahrain into the wider networks of the Islamic World and Maritime Silk Road encompassing this region and the Indian Ocean trade sphere as well as the possible import of colourless glass for use at the mosque.

As previously mentioned in the discussion section of this work, the interpretation and more exact provenance of these glasses would benefit from further analysis, specifically on the trace element content of these samples. A technique such as laser ablation inductively coupled plasma mass spectrometry would greatly enhance our understanding of the exact sub-groups to which these glasses belong, as although major and minor elemental analysis such as that provided by electron microprobe analysis can give an indication as to which compositional group these glasses belong to, the detail of sub-groups could be informed. Not only would this provide confirmation of which compositional group these samples belong to but it would aid comparison with a greater number of datasets on a wider range of elements, which has been seen to be important in the Cr/La and Li/K ratio distinction of glasses from the Middle East and the discerning of m-Na-Al subgroups by their barium and uranium contents. Additionally, further characterisation even of major and minor elemental composition of another assemblage from Bilad al-Qadim in Bahrain could provide a wider

picture of the types of glass present at this site over the period. This was unfortunately not able to be included in this work as first intended due to the restrictions on access to samples and research facilities as a result of the ongoing COVID-19 pandemic meaning this work had to be based on analyses done prior to these events. However, possible future work on these samples may further illuminate the picture of trade and relations to the wider Islamic World with Bahrain and the status of this site.

Overall, the major contributions of this work lie in the evidence for the position of Mantai as an entrepôt which was a link between the trade circuits of the Islamic World and wider Maritime Silk Road as well as South East Asia to the Indian Ocean region, especially in this period the Eastern coast of Africa and its hinterlands. The compositions of the Bahrain glasses give an indication as to how far reaching these maritime links were as well as the large extent of integration of Bahrain to the Islamic World and how glass was used at religious centres of this faith and culture.

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