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The Impact of Analysis in the Investigation of LBA Glass Production, Transport and Exchange and the Role of Women in this System.

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ABSTRACT

The study of Late Bronze Age (LBA) glasses has developed significantly over the last few decades. The advance of analytical methods capable of the sensitive detection of major, minor and trace elements have enabled researchers in this field to gain a greater understanding of LBA glass compositions in addition to being able to distinguish between glasses manufactured in Egypt and Mesopotamia, the two regions believed to have been the original innovator of glass. This thesis examines a series of LBA glasses excavated from historically significant sites in Egypt, Sinai and the Levant using Laser Ablation Inductively Coupled Mass Spectrometry (LA-ICP-MS). The analysis of unanalysed material from an undisturbed tomb in Gurob, the only confirmed harem palace in Egypt, the temple of Hathor, in Serabit, Sinai and the strategically important site of Tall Zirā'a in the Levant are discussed in this thesis. Early glasses from KV35, the tomb of Amenhotep II (1427-1400 BCE) are examined as part of this thesis: these glasses were previously analysed using scanning electron microscopy; however, this research re-examines the material using LA-ICP-MS, thereby providing trace element data of several colours to determine the provenance of these early royal glasses in addition to presenting trace element data for some of the earliest Egyptian glass colouring strategies. By assessing the strategic importance of the sites in conjunction with the elemental analyses, colouring strategies and provenance of the glasses connected with the sites, this research answers questions about where the first glasses were made and what information the context tells us about the first glasses ever produced. This thesis also readdresses the importance that women played in the transportation and distribution of glass in the LBA. This research also examines the compositional changes in LBA glasses to identify key markers which can be used to date glasses by providing a production era, and consequently indicate the workshops which produced them. Finally, this thesis discusses the control and the volumes of glass moved in the LBA and proposes a model for the LBA glass system.

Keywords: Glass, Egypt, Mesopotamia, Provenance, Composition, LA-ICP-MS, LBA, New Kingdom

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Abbreviations

BCE	Before common era
CE	Common era
c.	Circa
FIG	Figure
HMHK	High magnesia, high potash glass
HMG	High magnesia glass
IA	Iron Age
kV	Kilovolt
LA-ICP-MS	Laser ablation inductively coupled mass spectrometry
LBA	Late Bronze Age
LIA	Lead isotope analysis
LMG	Low magnesia glass
LMLK	Low magnesia, low potash glass
SEM-EDS	Scanning electron microscopy with energy dispersive spectroscopy
SEM-WDS	Scanning electron microscopy with wave dispersive X-ray spectroscopy
PPM	Parts per million
µm	Micron
WT%	Weight percent
XRF	X-ray Fluorescence

1 Introduction

1.1 Background

Archaeometric research of ancient glasses has significantly enhanced the quantity of elemental and isotopic data that can be acquired from Late Bronze Age (LBA) glasses (Shortland, Rogers and Eremin, 2007; Shortland, Freestone and Rehren, 2009; Gratuze, 2013; Degryse *et al.*, 2020; Lankton, Pulak and Gratuze, 2022). Isotopic analysis, developed for dating and other applications in geological studies, has been adapted for the use in archaeological science including applications within glass production, providing further information about raw material sources and possible trade connections (Shortland, 2006; Degryse *et al.*, 2010, 2015, 2020). The application of Laser Ablation Inductively Coupled Mass Spectrometry (LA-ICP-MS) has made it possible for researchers to detect geologically relevant trace elements which enable the distinction between glasses manufactured in Egypt and Mesopotamia, the two regions where the first glassmaking innovation is presumed to have taken place (Shortland, Rogers and Eremin, 2007). This is significant as research examining the earliest glasses has long sought to establish the originators of glass and how this innovative technology was distributed as one of the most high-status items in the LBA (see section 1.7). The regular manufacture of glass appeared in the archaeological records of Mesopotamia and Egypt around 1500 BCE, but the exact geographical source of glassmaking is unconfirmed (Lilyquist *et al.*, 1993, p23; Tite and Shortland, 2008, p209; Shortland *et al.*, 2017). It was proposed by Petrie that glass was first produced in Mesopotamia and was subsequently introduced to Egypt in the mid-15th century BCE, an idea which has been fostered by Oppenheim and other researchers discussed in chapter 8 (Petrie, 1924; Oppenheim, 1973). Iconographic sources discussed in section 1.5.4.1.1 depicts this first apparent import of glass to Egypt as tributes from the Levant and Syria (Wreszinski, 1923, p40), as such this is a discussion that will be addressed in this thesis.

Because of its distinctive status in LBA society and as a man-made material, glass is uniquely placed in archaeology to provide key information about the connections between LBA Egyptian society to luxury goods, LBA trade networks and distribution. Luxury goods in the LBA included gold, silver, semi-precious stones, ivory and jewellery as seen in royal grave goods, iconographic sources (see section 1.5.4.1.1) and detailed in correspondence between Egypt and other rulers in Mesopotamia and the Levant (see section 1.5.4.1.2). Materials such

as gold, silver and stones are challenging to provenance, however, glass is man made and incorporates a number of raw materials which can be identified using analytical techniques that can be categorised using a chemical "fingerprint".

It has been proposed that production and distribution of glass was controlled by the Egyptian Royal Court and therefore was restricted and administered as one of the most prominent luxury items, only bestowed upon society's elite (Moorey, 2001, p4; Shortland, Nicholson and Jackson, 2001, p157). LBA glasses found in Egypt are usually linked to high-status tombs and temples and because of the advantageous preservation conditions of Egypt, glass is relatively easy to identify and recovered from these archaeological contexts. Combined with the well-established Egyptian chronology, analytical research on glasses from secure contexts have the capability of providing crucial supporting evidence for this critical period in which craftsmen become proficient in glass production.

Compositional analysis to determine the provenance of the very earliest glasses is relatively sparce, partly due to the semi destructive nature of LA-ICP-MS analysis and the ethical requirement to preserve historically important objects. Therefore, glasses which are excavated or associated with a confirmed early context presents a valuable opportunity for analysis which will provide deeper insights into the initial technology of composition, the raw materials used, colouring strategies and the provenance. In addition, to date it is rare that Mesopotamian glasses are discovered in Egypt and vice versa (Walton *et al.*, 2009), however it is likely that with the increasing number of analyses more transported foreign glasses are likely to be discovered; especially from legacy collections which contain smaller glass items such as jewellery, vessel fragments or damaged pieces which can be made available for analysis. Items fulfilling these criteria that are attributed to the same significant context may therefore present a viable sample for provenance analysis.

It is vital to understand the significance of these research papers within the context of glass as a material (section 1.2.1). The previous work on LBA glasses (section 1.2.5), and the archaeology of the period (section 1.5). Therefore, this chapter provides a comprehensive background and literature review of the most relevant research to this thesis. This chapter then summarises the structure of the thesis, giving details of each of the papers, and then progresses to discuss the aims and objectives which flow through the papers.

1.2 Literature review

A number of subject areas are covered within this thesis therefore the structure of the literature review is clearly defined to introduce the relevant information to the reader. The review starts by defining glass as a material, its composition, and then specifying these subjects within the context of the LBA, specifically focusing on the raw materials and colourants that were used in early manufacture. The discussion continues with an overview of how raw glass was made and defines the two distinct stages of early glassmaking in sections 1.4.1 and 1.4.2. While the evidence for the production of glass from raw materials is scant, glassmaking in the LBA has been extensively studied and the key sites are introduced and discussed, along with the key evidence for glassmaking and glassworking.

The background to the social impact of glass is then discussed, including how glass was controlled, distributed, and used within LBA Egypt and neighbouring societies. Sections 1.4.3 and 1.4.4 present the early uses vessels, the objects that were made out of glass, the perceived value of glass and the patterns of distribution. These topics are placed within a reference guide which facilitates the information for the reader.

1.2.1 What is glass?

Kinetic theory defines the three material states as being solid, liquid and gaseous (Brill, 1962). Glass by definition is an amorphous solid (Paul, 1990, p1,9), lacking the long-range order of other crystalline materials, but instead having a specific internal atomic arrangement which is highly complex and therefore difficult to define (Zachariasen, 1932; Shelby, 2005, p3). When observed at a molecular level, the characteristics of glass fall between the regular rigid form of solid-state bodies and the random, disordered structure observed in liquids (Newton and Davison, 1989). The structure of glass more closely resembles malleable materials such as rubber or plastic (Dyre, 2006). This disordered structure consists of entangled long chains of molecules which provide the material with some small fluidity while providing the rigidity to maintain form (Le Bourhis, 2014, p57). Therefore, glass is considered to be a distinct form of "polymerised state" which maintains a high level of rigidity at standard temperatures due to the elevated quantity of cross-linking between the long molecular chains (Le Bourhis, 2014, p65).

The term “glass” specifically describes the structure, rather than the composition (Newton *et al.*1989, p4), therefore all glasses have similar atomic arrangements which gives this group comparable structures and properties. The structure of ancient glass is necessary for understanding how particular compositions were worked and used (Rehren, 2000b, 2000a), in addition to providing insight into how LBA glasses maintained the levels of preservation observed today (Hench and Clark, 1978). The actual number of glass compositions can be infinite and are classified according to the elements they contain (Shortland, 2012, p20), however the composition itself fundamentally affects the respective physical properties (Henderson, 2013, p5).

1.2.2 The analysis of glass

For this thesis, the collection of major, minor and trace elements are fundamental for answering the research questions described in section 1.10. Laser Ablation with Inductively Coupled Mass Spectrometry (LA-ICP-MS) is a highly sensitive analytical technique which is widely used for the detection of major, minor and trace elements in LBA glasses. Sensitive detection is essential for accurate composition determination and the provenancing of glass, in addition to identifying relevant elements at low levels which provide critical information about raw materials, specifically colourants (Gratuze, Blet-Lemarquand and Barrandon, 2001; Shortland, Rogers and Eremin, 2007; Walton *et al.*, 2009; Lankton *et al.*, 2016; Lankton, Pulak and Gratuze, 2022; Jackson and Nicholson, 2023). Furthermore, LA-ICP-MS has many advantages including the low limit of detection, accurate determination of a wide range of elements, and the ability to analyse relatively small samples of approximately 2mm or less. The technique is also virtually non-destructive, ablating a small sample size approximately 8µm in diameter. Samples can be secured and loaded directly into the sampling chamber or be mounted in resin prior to the analysis, for example small fragments of glass.

The LA-ICP-MS protocol including the standard reference materials used for each research project in this thesis is described in each chapter under the methodology section.

1.2.3 Network formers and network modifiers

The physical properties of the glass are directly influenced by the elemental composition; these elements are classified as “network formers”, “network modifiers”, colorants and opacifiers (Zachariasen, 1932; Newton and Davison, 1989, p5). Elements defined as network formers are

the prime contributors to the three-dimensional structure of the glass, providing the stability. The primary network forming oxide in ancient glasses is silica. Crystalline silica, such as quartz, forms tetrahedrons with the silicon atoms at the centre with oxygen atoms at each corner (Doremus, 1994, p25). The tetrahedra form a lattice that repeats regularly, creating a "long range order" which is stable and resistant to high temperatures and chemical influence. Molten silica which is cooled extremely quickly does not have the time to form the regular order, and instead the glass forms an irregular, non-crystalline structure (Le Bourhis, 2014, p56-57).

Oxygen atoms that form bonds with two silica tetrahedra are termed "bridging oxygens", whereas oxygen atoms that form bonds with only one silicon atom are "non-bridging oxygens" (Rao, 2002, p25). Crystalline silica contains only bridging oxygens whereas in the non-crystalline structure, spaces between the silica chains can incorporate cations, specifically alkali components which are called "network modifiers" (Zachariasen, 1932), positively charged ions which are attracted by the negatively charged non-bridging oxygens (Brill, 1962). Network modifiers in ancient glasses are the monovalent alkali metals sodium (Na^+) and potassium (K^+) and divalent calcium (Ca^{2+}) and magnesium (Mg^{2+}). The presence, absence and relevant percentages of network modifiers fundamentally affect the physical properties of the glass (Kurkjian and Prindle, 1998; Dériano, 2002).

Monovalent ions Na^+ and K^+, derived from fluxes, can only bond with one non-bridging oxygen each, therefore forming a comparatively weak connection within the network and resulting in the melting point of the structure being significantly reduced (Le Bourhis, 2014, p57). The loose bonds between the monovalent alkali metals and the oxygen atoms can result in the glass dissolving or in extreme cases, being fully soluble in water as the monovalent ions move into the water and are replaced with the incumbent H+ ions (Newton and Davison, 1989, p6).

The divalent ions Ca^{2+} and Mg^{2+} typically derived from limestone or lime containing materials, in comparison, form new bridges and therefore stronger bonds within the structure by bonding across two non-bridging oxygen atoms (Le Bourhis, 2014, p8). These atoms are more stationary thereby providing increased stability within the glass (Shelby, 2020, p90).

1.2.4 Fluxes

The melting temperature of pure quartz is 1713℃ which was impossible to achieve using ancient technology, therefore another compound referred to as “flux” was used to lower the melting temperature of the glass (Wedepohl, 2003). Several fluxes have been used in history to lower the melting temperature of a glass batch, making it possible for ancient glassmakers to melt silica. Fluxes were used in the production of vitreous materials including glazed stones, faience, and glass. The fluxes used specifically in the LBA and IA discussed in this thesis are plant ash and natron fluxes.

Plant ash has been widely used as a flux in the LBA, the medieval period, East of the Roman Empire and throughout the Islamic world. It was also used later in Europe and has also been employed up until relatively recently (Turner, 1956a, 1956c; Freestone, 1991). Plant ash was established as the source of the alkali by Brill in 1970 and further work by Henderson confirmed the high MgO content, characteristic of plant ash Egyptian glass (Brill, 1970; Henderson, 1988). Since its proposition, it has been accepted that the main type of plant ash flux used in the LBA was derived from “halophytic plants”: plants that thrived in, or were at least resistant to, the relatively high salt content in the soil (Turner, 1956c). Soda-rich plants such as *Salicornia* and *Salsola kali* (Freestone, 1991; Nicholson, 1993; Henderson, 2000) could be sourced from the edges of the desert, coastal margins and dunes and contain a relatively high concentration of magnesia and potassium oxide which is detected in the final composition of the glass (Nicholson and Henderson, 2000, p25). Sayre and Smith classified glasses as high magnesia glass (HMG), which describe the plant ash glasses, and low magnesia glass (LMG) which can be used to describe natron glasses. Glasses which contain between 2-4% potash and above 2% magnesia indicate that a plant ash flux has been used (see Figure 1)

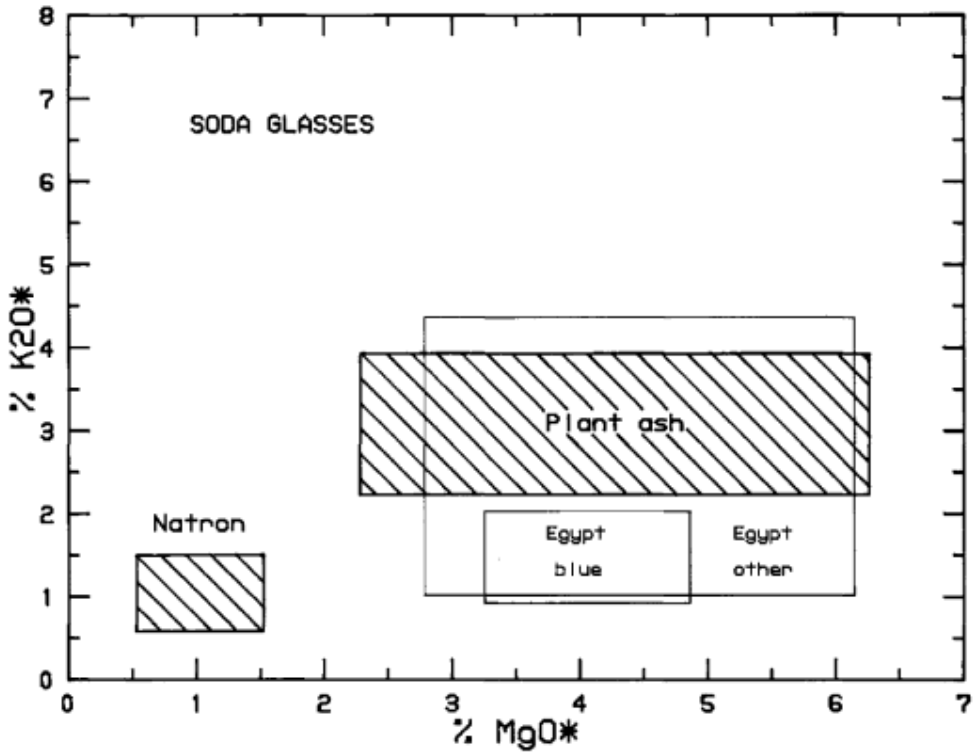


Figure 1: Ranges of normalised potassium and magnesium oxides for soda-lime glasses of natron and plant-ash types, with Egyptian cobalt and noncobalt glasses superimposed (Lilyquist *et al.*, 1993, p53, fig 51).

The second relevant source of flux came from soda-rich compounds derived from large, evaporitic lakes such as the Wadi Natrun in Lower Egypt, approximately 100km northwest of Cairo (Shortland, 2004). These mineral deposits are often referred to as "natron", especially within archaeological contexts, however natron refers to sodium carbonate 10-hydrate, whereas the primary compound in these deposits is sodium carbonate bicarbonate 2-hydrate ($NA_2CO_3.NaHCO_3.2H_2O$), also known as trona (Shortland *et al.*, 2006a). As mentioned, natron glasses contain relatively low concentrations between 0.5-1.5% of both magnesia and potash, therefore are compositionally distinct from plant ash LBA glasses. In addition to the use of a flux for vitreous materials, natron was widely used for other applications including for medicine and for mummification (Henderson, 1985).

1.2.5 Raw materials and composition of LBA glass

The usual composition of unweathered Egyptian HMG LBA glass is typically 60-63% silica, 16-18% soda, 6-9% lime, 2-6% magnesia, and 2-3% potash and between 1-4% alumina (Sayre and Smith, 1961a; Brill, 1963, 1999b; Lilyquist *et al.*, 1993, p41; Tite and Shortland, 2003; Shortland and Eremin, 2006). Current consensus accepts that silica was likely sourced from

either quartz pebbles or sand for ancient LBA glassmaking. Excavations at Amarna by Petrie identified quartz pebbles lining the base of glass kilns, leading him to the conclusion that the heating and cooling of pebbles would facilitate easier pulverisation for eventual glassmaking (W. M. F. Petrie, 1894, p26). Analysis by Rehren and Pusch on both semi-finished glass and archaeological finds of vessels containing pure white quartz dust at Qantir has confirmed that crushed quartz was the main source of silica, thereby supporting Petrie's original theory (Rehren and Pusch, 2008, p30). Crushed white quartz pebbles are one of the purest sources of silica, however, impurities such as aluminium, titanium and iron were potentially introduced as a result of the grinding tools used in the crushing process (Pusch and T Rehren, 2007). However, the use of sand as a raw material is still a possibility, with Nicholson proposing that a low-impurity quartz sand was used at Amarna, based on the lack of evidence for associated grinding tools during his excavations of site O45.1 (Jackson and Nicholson, 2007a). Sand as a raw material contributes a number of impurities such as iron oxides, lime and alumina depending on the source; Egyptian sands can contribute between 1-4% alumina and up to 18% lime (Tite and Shortland, 2003, p290), notably Amarna sands can contain up to 20% lime (Nicholson and Henderson, 2000, p197). Research by Stoch *et al*. confirmed that shape, texture and defects in sand grain shape affected how quickly a batch of glass could be melted, therefore grinding materials was a necessary step to reduce excessive fuel and time consumption (Stoch, Pakulska and Stoch, 1978).

The source of soda from LBA glasses is widely accepted to come from plant ash, contributing significant amounts of soda and being a minor source of potash, lime, and magnesia. The use of plant ash as an alkali source was identified by Brill in 1970 from ancient Mesopotamian texts, with supporting analytical evidence by Henderson, who determined the high magnesia content of both plant ash and Egyptian glass (Brill, 1970; Henderson, 1989). In the IA, natron was widely used as the source of the soda flux in glass production (Shortland *et al.*, 2006a). This mineral source is relatively low in magnesia and potash compared with LBA plant ash glasses, enabling distinction between the two glassmaking periods first proposed by Sayre and Smith in 1961 (Sayre and Smith, 1961b). The source of LBA and IA fluxes are discussed in further detail in 1.8.4.

Lime is an essential component and acts as a stabiliser, thereby increasing the preservation properties of the glass and making it resistant to water (Nicholson and Henderson, 2000; Stern, 2017). Lime is introduced to the glass with the raw materials as a component of calcareous

sand, the plant ash, or introduced into the glass through the lime-rich parting layer of the crucible lining which served as an anti-contamination measure and to aid the separation of the glass ingot from the ceramic (Turner, 1956c; Henderson, 1985; Rehren, 2008). There is also the potential for the deliberate addition of lime by glassmakers.

For compositions of glass containing 73.1% silica, 21.9% soda and 5% lime modelled in phase diagrams, there is a theoretical minimum melting temperature of 725°C (Cox, Bell and Pankhurst, 1979, p42). However, LBA soda-lime-silica glass compositions differ from modern compositions due to the relatively high concentrations of impurities due to unrefined raw materials (Turner, 1956b, 1956c). Therefore, while the primary oxide components in ancient compositions are soda, silica and lime, there are typically seven elements that are detected in concentrations over 0.5% such as Si, Na, Ca, Mg, K, Al, and Fe (plus Cl). Other elements such as cobalt and copper act as colourants as discussed in section 1.2.6, and antimony is often used as an opacifying agent. As analytical techniques become more sensitive, the number of elements that can be accurately detected at low concentrations increases.

1.2.6 Colourants

Almost all LBA glass is coloured, therefore colourants are an important part of the glassmaking process and provide key information about the provenance and technology of LBA glasses. Glass is coloured by the addition of transition metals to the base mixture at some stage in the process. These agents also provide some opacity to the glass: copper, cobalt, lead, iron, manganese, and antimony are added to the glass alone or combined to produce red, white, yellow, green, purple, brown, black, amber and hues of blue including sky blues, turquoises, and dark blues.

Egypt produced the largest range of coloured glasses in the LBA; therefore, the focus of the colourant sections is on this region. The main differences in LBA colouring strategies between Egypt and Mesopotamia are listed in Table 1 below:

Colouring strategy	Egypt	Mesopotamia
Colourless	x	o
Co blue	xxx	x
Cu blue	xxx	xxx
Co+Cu blue	xxx	o
Cu + Sb Turquoise	xxx	xxx
Co + Cu + Sb opacified blue	xx	o
Co + Sb opacified blue	xxx	o
Sb white	xx	[xx]*
Pb + Sb yellow	xx	?[x]*
Mn black	x	o
Other blacks	x	xx
Cu + Pb + Sb green	xx	o
Fe green	x	x
Mn purple	xx	o
Cu red	x	o

Table 1: The prevalence of colouring technologies in Egypt and Mesopotamia the LBA. Adapted from Shortland *et al*., 2017 and updated with data from Walton *et al*., 2012, Varberg *et al*., 2016 and Reade 2021 (Von Saldern, 1970; Walton *et al.*, 2012; Varberg *et al.*, 2016; Shortland *et al.*, 2017; Reade, 2021). Key = xxx common, xx present, x rare, o not observed, *Due to poor preservation, the colour may be weathered blue beads (Starr, 1939).

1.2.6.1 Colourless, amber, and brown glasses

Colourless, amber, and brown glasses are glasses which appear to contain no deliberately added colourant, therefore it is by comparing the composition of colourless glasses to coloured glasses that the strategy for coloured glasses and the associated elements of specific colourants are determined. There is a significant portion of glasses which are technically “colourless” and exhibit as optically colourless to amber and even deeper shades of brown due to the oxidation conditions of iron present in the glass.

This is observed from the analysis of brown and amber glasses from Malkata and Amarna that appear to be manufactured with no deliberate colourant added (Shortland and Eremin, 2006). Brown and amber glasses are relatively rare and are usually dated to between the reigns of Tutankhamun (1336-1327 BCE) and Pinudjem II (959–945 BCE) (Nolte, 1968).

1.2.6.2 Blue to dark blue

The deeper hues of blue and dark blue were usually created by the addition of cobalt. Cobalt was used alone, or used in addition with copper which is discussed in section 1.2.6.3. Cobalt ores are relatively rare and virtually never appear as a native element, occurring more frequently in complex ore bodies (Andrews, 1962). Cobalt ores usually contain other associated transition metals such as manganese, iron, zinc, nickel, copper, arsenic and aluminium which are unchanged as they become incorporated into a glass batch; these associated elements are detected during the analysis of glasses thereby provide provenancing information about the source of the ore used (Shortland and Tite, 2000). Cobalt is one of the strongest transition metal colourants which can colour glass a distinct blue hue with concentrations as low as 0.05% CoO (Weyl, 1951; Shortland and Eremin, 2006; Lankton, Pulak and Gratuze, 2022). An excess of cobalt can also achieve a very dark blue colour which appears black, however most Egyptian LBA glasses coloured exclusively by cobalt do not contain in excess 0.3% (Shortland and Eremin, 2006; Lankton, Pulak and Gratuze, 2022).

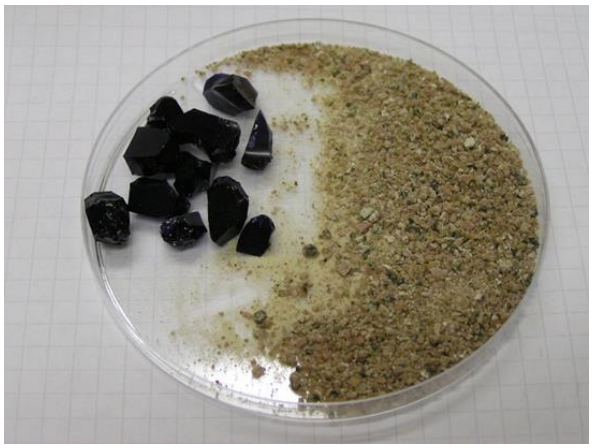


Figure 2: (left) Unprocessed cobalt alum from the Western Oases, Egypt.

Figure 3: (right) Processed cobalt ore with the resulting dark blue cobalt coloured glass.

The first identified use of cobalt colourants in glass date to the mid-18th Dynasty during the reign of Tuthmosis III (1479-1425 BCE). This cobalt source is a cobaltiferous alum, likely

sourced from the Dakhla and Kharga Oases in the Egyptian Western Desert and contain characteristic elevated concentrations of Ni, Mn and Zn (Kaczmarczyk, 1986) (see Figure 2 and 3), which make this ore discernible from other cobalt sources, which in turn has been used to document the trading of Egyptian glass to Mycenaean Greece and Tell Brak in northern Mesopotamia (Henderson, 1998; Walton *et al.*, 2009). In addition, 18th Dynasty cobalt glasses have characteristic low concentrations of potash averaging 1% with elevated concentrations of up to 5.8% alumina compared with non-cobalt coloured glasses (Shortland and Eremin, 2006; Lankton, Pulak and Gratuze, 2022). The use of cobalt as a colourant in glass occurs almost exclusively in Egypt but very rare examples have been identified in the Near East (Walton *et al.*, 2012).

Source of glass	Source of cobalt/ Type	Period used	Al	Ni	Zn	Mn	Fe
Egypt	Dakhla and Kharga Oases/Western desert Type "A"	1550-1295 BCE 18th Dynasty					
Egypt	Unknown Type "R"	1295-1069 BCE Ramesside period					
Egypt	Unknown Type "N1"	664-300 BCE Late Period/ Ptolemaic period					
Egypt	Likely Qamsar, Iran Type "N2"	664-300 BCE Late Period/ Ptolemaic period					

High | Greatly elevated | Somewhat elevated | Compares with colourless glass | Not detected

Table 2: The general characteristics of different cobalt types and source (Kaczmarczyk, 1986; Abe *et al.*, 2012).

The cobaltiferous alum from the Dakhla and Kharga oases was used until the 20th Dynasty, however analyses on glasses securely dated to the 19th-20th Dynasties from Dahshur North and Northwest Saqqara show that a different cobalt source, likely from a cobaltiferous siliceous ore, was primarily used to colour Ramesside co-blue glasses (Abe *et al.*, 2012). The use of the new cobalt source appears to coincide with the Asian campaign undertaken by Ramesses II and the research by Abe *et al*. shows contemporaneous use of both cobalt sources, therefore, the

introduction of the new cobalt source was not due to the depletion of the Western Desert source. It has been theorised that the use of a new cobalt source may have been due to the geographical separation caused by the relocation of the Egyptian capital from Thebes to Memphis, which was more than twice the distance from the Western desert oases compared with the New Kingdom glass centres of Malkata and Amarna (Shortland and Eremin, 2006; Abe *et al.*, 2012).

The Ramesside cobalt source exhibits low concentrations of Zn with elevated Ni and although the origin of the Ramesside cobalt is not known at this time, it has been concluded that it is not derived from the Iranian cobalt sources (Abe *et al.*, 2012). The same study by Abe *et al*. (2012) also confirms that a third source of cobalt appeared after the Late Period, designated as "Type N" (Abe *et al.*, 2012). This ore appears in two forms which is distinguished by the Mn content: type N1 is characterised by a depletion of Mn and lack of Ni, and type N2 is characterized by high Mn and a depletion of Zn (Abe *et al.*, 2012). The origin of type N2 is likely from asbolane from Qamsar, Iran (Allan, 1973), which is a manganese rich cobalt ore. The source of type N1 is currently unknown. Therefore, the distinct cobalt sources provide key supporting evidence for indicating the production era of cobalt coloured glass (see Table 2).

1.2.6.3 Light blue to turquoise blues

Copper was widely used in the LBA to create light to turquoise blue hues in glasses. Egyptian glasses containing copper often contain elevated levels of tin indicating that a bronze source was used (Kaczmarczyk and Hedges, 1983), whereas copper glasses from the Near East are characteristically low in tin indicating that a purer source was used (Brill, 1999a; Shortland and Eremin, 2006; Shortland, Rogers and Eremin, 2007).

1.2.6.4 Blue Cobalt-copper (Co+Cu) glasses

Co+Cu glasses are common in Egypt and fall into a distinct colour category as the elevated concentrations of cobalt and copper suggest that both were deliberately added to achieve the required blue colour. The cobalt content in Co+Cu glasses can exceed 0.4% which could indicate that a satisfactory blue was not achieved and copper was added to the glass for the desired effect (Shortland, 2012, p107). Co+Cu glasses are defined as being glasses which have more than 0.05% CoO and more than 0.1% CuO respectively or of 300 ppm Co and 850 ppm Cu, respectively (Shortland and Eremin, 2006; Smirniou and Rehren, 2013).

1.2.6.5 Opacified glasses - White

Antimony, used to create glasses which are "white" in appearance, is commonly found in lead and silver ores (Mass, Wypyski and Stone, 2002), the major ore being stibnite (Sb_2S_3) which is found in Iran, Anatolia and Caucasia but it is also found in its raw metallic state (Shortland, 2002). There are no known sources in Egypt, therefore antimony was an imported material.

The addition of up to 2% of antimony to a colourless batch achieves a white glass (Shortland and Eremin, 2006) which was primarily used to decorate vessels, creating the feather, garland, arcade marvered patterns and the polychromatic twisted rim and feet seen in the iconic Egyptian vessels (Nolte, 1968). Vessels with bodies (also known as ground colour) made of white glass are known, however they are rare with approximately 16 white bodied vessels from Ancient Egypt in existence, which equates to 5% of the total number of relatively intact vessels from Ancient Egypt (Nolte, 1968). It should also be noted that white glasses are rarely found in the Near East (Kirk, 2009; Shortland *et al.*, 2017; Reade, 2021).

In addition to creating white glasses, antimony was also commonly used in the LBA as an opacification agent. Combining antimony with calcium produced calcium antimonate, another LBA opacification agent. Understanding of the opacification process has advanced as a result of several focused studies in the past 10 years, but interpretation of the evidence is challenging. Studies have focused on specifically when the opacification agent was prepared and when it was added to the glass batch, in addition to the implications of the lime and antimony content in translucent and opacified glasses. Shortland observed that the method of opacification differed between Egyptian and Near Eastern glassmakers; Egyptian glasses contain the same concentrations of lime in both translucent and opacified glasses, suggesting that antimony is used as the sole agent for opacification (Shortland, 2002; Shortland and Eremin, 2006). By comparison, glasses produced in Nuzi show an increased concentration of lime in opacified glasses of 9.0% compared with translucent glasses containing 6.0% (Shortland *et al.*, 2017). It has been proposed by Shortland *et al*. in the same study that this may have been due to factors in the raw materials i.e., a higher lime content plant ash used by workshops producing opacified glasses, or that lime was methodically added in addition to antimony to opacify the glasses in the Near East. Another proposal is that glasses in Nuzi were created using a higher temperature and that the parting layer of the crucibles contribute to the lime content.

1.2.6.6 Opacified glasses - Yellow

Lead antimonate was used in Dynastic Egypt to produce opaque yellow glasses which were largely utilised, like white glasses, for the decorative pattern element which was applied to vessels in the 18th Dynasty. Lead antimonate is rare, the main lead compound responsible for the yellow colour being $Pb_2Sb_2O_7$ (Molina *et al.*, 2014), however the main ores of lead and antimony; galena (PbS) or a lead-zinc ore such as sphalerite (ZnS) and stibnite (Sb_2S_3) are reasonably common. Therefore, it is likely that lead antimonate was produced by roasting galena and stibnite with an excess of lead to achieve the five to one ratio observed in analytical studies (Molina *et al.*, 2014). Subsequent mixing, grinding and roasting steps would result in the lead antimonate forming a lead rich matrix (Shortland, 2002). Lead isotope analysis of lead antimonate glasses from the sites of Malkata and Amarna indicate that the ore is galena (lead sulphide) and the source is likely from Gebel Zeit situated on the Red Sea Coast, Egypt (Castel, Pouit and Soukiassian, 1988; Shortland, Nicholson and Jackson, 2000; Shortland, 2002; Shortland, 2006). The source of stibnite is likely from the Caucasus, where antimony mines known to be active in the LBA were discovered (Chernykh, 1992; Shortland, 2002).

Yellow glass vessels are rare, with only nine mostly intact vessels from Ancient Egypt remaining (Nolte, 1968). These vessels are challenging to date using elemental compositional information only, however, yellow bodied vessels been broadly dated to the Ramesside period (1295-1069 BCE)(Nolte, 1968).

1.2.6.7 Black

Black glasses are frequently used for both decorative twisted rims and feet on vessels in addition to being the second most common body colour in Ancient Egypt after the blue hues (Nolte, 1968). Analyses of early black glasses from ancient Egypt and Mesopotamia dated between the reigns of Tuthmosis III and Tuthmosis IV (1400-1390 BCE) show that an optically black hue was achieved in glass by adding an excess of one or a combination of transition metals including copper, cobalt, manganese, and iron (sometimes with the addition of the metalloid antimony), therefore creating glasses which were very dark blue or purple (Lilyquist *et al.*, 1993; Shortland and Eremin, 2006; Jackson and Nicholson, 2007a).

Analyses of later LBA black glasses dated between 1348-1069 BCE from the Egyptian sites of Amarna, Gurob, Timna, and Badari and from the Iranian and Syrian sites of Choga Zanbil and

Tell Brak respectively, and Pella in Jordan show that copper, cobalt, and manganese were detected in trace concentrations, i.e., significantly lower than the levels required to impart a deep hue resembling black. Instead, these black glasses do not appear to have any colourants deliberately added but exhibit relatively elevated concentrations of Fe_2O_3, known to create black glasses in addition to pale green or amber/brown hues (Shortland and Eremin, 2006; Reade, 2021, p80; Lankton, Pulak and Gratuze, 2022). This indicates that ancient glassmakers adopted a new strategy for creating black glasses sometime after the reign of Tuthmosis IV. Iron was introduced as an impurity into glass batches via the silica source, and other raw materials with a large proportion of iron impurities (Rehren, 2008).

1.2.6.8 Green, opacified and not opacified

Green glasses were used in jewellery (see Figure 4) and inlays; green glass vessels are rarely found in the New Kingdom but appear to become more popular after the 18th Dynasty (Nolte, 1968).. Analysis has shown that Egyptian New Kingdom green glass was achieved in mainly two ways: 1.) opacified green was created by combining lead antimonate and copper or 2.) a translucent green was created by the presence of iron. Studies undertaken using SEM-EDS (Scanning electron microscopy with energy dispersive spectroscopy) and LA-ICP-MS analysed 30 samples of green glasses from Malkata and Amarna; interestingly all 30 samples were coloured using the former strategy of combining copper and the opacifying agent lead antimonate (Shortland and Eremin, 2006; Lankton, Pulak and Gratuze, 2022). Mass also reported that seven green glasses from Malkata were coloured using copper and lead antimonate, however one green glass had no copper detected. This may have been a detection limit issue as lead and antimony were detected in comparable levels to the other green glasses (Mass, Wypyski and Stone, 2002).

The latter iron-based strategy appears to have been largely adopted by craftsmen at Amarna which was then continued into the Ramesside period. The analysis of green glass rods excavated from Amarna by Varberg *et al*. in 2016 established that of the four green glass rods examined in the study, two were identified as Mesopotamian in origin and one as Egyptian in origin; all three rods contained copper and lead antimonate. A further rod, found to of Egyptian provenance, contained trace levels of copper, lead and antimony with elevated levels of Fe_2O_3 compared with the other three rods. This confirms not only the exchange of glass between the

two regions, but also that the two colouring strategies were worked contemporaneously at Amarna (Varberg *et al.*, 2016).

1.2.6.9 Purple

The primary colourant responsible for purple glasses is manganese oxide. Purple glasses can contain up to 2.62% magnesia, however a purple glass from Amarna (198) analysed in research by Lankton (2022) shows that the sample contains both 2.56% MnO and 1.67% CuO. Purple glasses are relatively rare in Egypt and rarer in the Near East and were likely produced at specialist workshops.

The main ore of manganese is pyrolusite (MnO_2), which is a relatively pure source of manganese, therefore the lack of associated elements means that the exact source of manganese still remains unknown. Other manganese oxides include psilomelane ((Ba, Mn) Mn_4O_8 (OH)), both ores being common in Egypt (Lucas and Harris, 1962; Kaczmarczyk and Hedges, 1983, p34-5). The minerals can be differentiated by the barium content which indicates that psilomelane or another hydrated manganese ore was used (Kaczmarczyk and Hedges, 1983, p106-110). LBA glasses show no significant barium, usually 0.04% or less, therefore pyrolusite is the likely source (Shortland, 2012, p117).

1.2.6.10 Red

The primary colouring agent for red glass is copper, but in the reduced Cu^{+} state rather than the oxidised Cu^{2+} used to create blue glasses (Weyl, 1951). The production of red glass requires a greater degree of control over the raw materials, the colourants, and the firing conditions. To maintain the Cu^{+} state require for the red colour, the glass must be maintained in a reducing atmosphere so that the copper separates from the melt in the form of cuprous oxide crystals (Cu_2O, cuprite) or as metal microparticles which create the red colour (Bandiera *et al.*, 2020). Antimony was also used to control the redox reaction in the creation of red glasses in addition to charcoal and sometimes iron (Cable and Smedley, 1987; Freestone *et al.*, 2003).

Red glass vessels are also rare with few examples found in Egypt although it was frequently used during the reigns of Tuthmosis III and Amenhotep II (1427-1400 BCE) for mosaic style glasses and later for inlays and other decorative purposes like jewellery (Nolte, 1968; Aldred, 1971; Lilyquist *et al.*, 1993, p34). Analyses by Lankton *et al*. (2022) on eleven red glasses show that ten of the samples, excavated from Amarna and dated to 1348-1320 BCE, are Egyptian in

origin and only one is from Mesopotamia dating to c. 1275 BCE (Lankton, Pulak and Gratuze, 2022). The analysis to date shows that red glass composition appears to be the most variable of all the glasses, with several strategies using copper alone, or in combination with antimony, tin, lead and zinc; regardless, copper is present in significant quantities of up to 14.9% (Lilyquist *et al.*, 1993; Shortland and Tite, 2000; Shortland and Eremin, 2006; Jackson and Nicholson, 2007a).

Qantir is identified as a Ramesside production site for red glass on an industrial scale and also as a copper smelting site (see section 1.5.1.3).

1.3 Glassmaking procedure

The previous section defined the raw materials which have been identified in LBA glasses primarily from the interpretation of analyses. This section discusses how raw materials were combined to create glass and then worked into finished objects.

It is recognised that LBA glass*making* and glass*working* are two separate industries and should not be confused; glassmaking refers to the manufacture of glass from the raw materials, whereas glassworking refers to the practice of working the raw glass to form objects such as vessels. The raw materials, usually including a colourant and an opacifier, are combined to create a "batch" which is then heated in a kiln or furnace. The melting temperatures required to make the glass will be significantly higher than those required to "work" the glass, depending on the composition. Rehren *et al*. have proposed that some primary glassmaking workshops in Egypt and Mesopotamia specialised in specific colours, whereas others produced several different colours (Rehren, Pusch and Herold, 2001, p233-4; Pusch and Rehren, 2007, p161-3).

Experiments to recreate the LBA glassmaking process by researchers working at different sites, such as Nicholson *et al*. and Hodgkinson at Amarna and Rehren at Qantir, may propose alternative procedures using their interpretation from site-specific archaeological evidence and the analysis of the glass finds (Jackson and Nicholson, 2007a; Merkel and Rehren, 2007; Pusch and Rehren, 2007; Schoer and Rehren, 2007; Hodgkinson, 2015). However, the theories generally follow the same principles: white quartz pebbles would be ground to a fine, flour-like quartz powder and combined with the other raw materials and mixed in a reaction vessel lined with a lime parting layer to enable removal of the raw glass from the vessel. The parting layer also served as a contamination barrier to avoid the glass mix encountering the ceramic.

The vessel containing the raw materials was then fired at approximately 900°C to produce a batch of semi-finished glass. This stage would melt the non-reactive salts which would form a separate liquid for absorption by the ceramic. The semi-finished glass would then be crushed and mixed with the colourants in a cylindrical crucible. The crucible would also be lined with lime-based parting layer and more flux would be added if required. Finally, the crucible was then fired to temperatures exceeding 1000°C to produce the glass ingot.

This reconstruction is based on evidence from established workshops, however the discussion of processes undertaken at an early Egyptian workshop, and the potential location of a glassmaking factory from the reign of Tuthmosis III has not been discussed. There are several sources of textual evidence to confirm that envoys, women and specialists including craftsmen travelled between Egypt and Mesopotamia at this time, therefore it is likely that the technology transfer of glass could be made relatively rapidly (Zaccagnini, 1983, 2000; Moorey, 2001).

As discussed, there may have been variations in the colours of glass produced at specific sites, therefore glassmakers and glassworkers were likely linked through an LBA network which facilitated the exchange of such exclusive services and goods (Sherratt and Sherratt, 1991). Such networks also likely included supplying glassworking sites with the required colours, perhaps in ingot form, to make vessels and objects (Smirniou and Rehren, 2011).

1.4 Early glasses

In this section, the very earliest glass finds are discussed. Early glass finds, defined by Peltenburg as "Stage 1", are rare, sporadic, and debated (see section 1.4.1). This section then goes on to discuss the later uses of glass, particularly the most important and 'iconic' core formed vessels, the key object type produced using glass in this period (see section 1.4.4.1).

1.4.1 "Peltenburg Stage 1" - the earliest man-made glass

Small "glass" items are known dating to between the 5th and 11th Dynasties, however these are sporadic and are likely accidental by-products from other vitreous or pyrotechnic manufacturers, such as faience (Beck, 1934; Peltenburg, 1987; Moorey, 1999, p190-2). Peltenburg (1987) has described between 25-30 instances of early glass finds and has explained the issues relating to these early finds of glass. Specifically, archaeological methods did not always follow rigorous methodology which would lead to unreliable or inaccurate recording of

both stratigraphy and finds. Consequently, the dating of items would be lost in the process. In addition, items believed to be glass were found to be glazed objects on later examination or lack reliable provenance.

Peltenburg has defined two distinct stages to describe glass production which are pertinent to this thesis: Stage 1 is defined as a "pre-adaptive stage characterised by the very infrequent and irregular use of glass" (Peltenburg, 1987, p18), thus glass which has been created as an unintentional by-product. It has been proposed that faience was the precursor to glass, however there is no evidence which demonstrates a credible progression from this industry towards the regular glass production observed in Stage 2 (Peltenburg, 1987, p16). The proposition that contemporary metalworking provided the trigger for the first glasses has been discussed by several researchers as both groups shared similar working conditions and practiced the skill of manipulating molten product under controlled temperatures, specifically vessels (Brill, 1963; Peltenburg, 1987; Mass, Wypyski and Stone, 2002) in addition to the proposition that the colourants were metallurgical in origin (Brill, 1963; Peltenburg, 1987, p20; Swann, McGovern and Fleming, 1990). Hence, products classified according to the definition of Stage 1 are not discussed further as this thesis is exclusively concerned with the intentional manufacture of glass production as described by Stage 2.

Early glass artefacts, such as beads, have been identified in several tombs before the reign of Tuthmosis III. These examples were historically cited as the first examples of glass in royal burials, specifically those seen from the burial of Queen Ahhotep, the mother of Ahmose (1550-1525 BCE), the first king of the 18th Dynasty (Lilyquist *et al.*, 1993, p23). However, the circumstances surrounding the original excavation of the burial and the contents of the tomb are contentious due to the lack of contemporaneous record keeping (Miniaci, 2022, p66). It has also been suggested that the burial assemblage was an amalgamation of items from other interments, some indicating that the coffin was reinterred in the Third Intermediate Period (1069-945 BCE) (Lacovara, 2022, p153). Therefore, the early glass finds associated with Ahhotep must be viewed with some reservation, and for the purposes of this research are also not considered.

1.4.2 "Peltenburg Stage 2" – deliberately manufactured glass

Stage 2 is defined as "That period in the history of glass in which its individual properties have first been realized and the products exhibit characteristics unique to glass-working" ,

(Peltenburg, 1987, p18). Therefore, it is the beginning of Stage 2 relating to the first deliberate innovation of glass, and how this early phase then reflects the continuation of Stage 2, which is discussed in this research.

It has been proposed that the original innovation of glass came from the Near East and was subsequently transported to Egypt following military campaigns undertaken by Tuthmosis III (Petrie, 1924; Lucas and Harris, 1962; Oppenheim, 1973; Peltenburg, 1987; Moorey, 1999; Jackson and Nicholson, 2007a). Researchers have cited several sources as evidence: the Eridu fragment (see section 8.1), the relief scenes from the Hall of Annals which show glass being given as gifts to the temple of Amun; the items have been interpreted as tribute and "booty" from Mesopotamia (see section 1.5.4.1.1) and glassmaking texts believed to show that glassmaking was known to Mesopotamia as early as 2112-2004 BCE (Garner, 1956; A L Oppenheim, 1970; Spalinger, 1977). Archaeological evidence for early Mesopotamian glasses transported to Egypt comes from the tomb of the "Three Foreign Wives of Tuthmosis III" which contained stylistically foreign glass vessels, objects, and jewellery (see section 1.5.4.1.4). However, glassmaking remains in Mesopotamia are rare and definitive physical evidence for glassmaking in Mesopotamia has yet to be discovered (Moorey 1999, p201-202).

Based on the convention that glass was invented in Mesopotamia, it has been proposed that an Egyptian glassmaking industry was established shortly after the introduction of glass to Egypt using foreign glassmakers and workers (Lilyquist *et al.*, 1993; Nicholson and Henderson, 2000, p195; Moorey, 2001). This thesis will discuss this topic and propose that glassmaking was established in Egypt during the reign of Tuthmosis III (see section 8.2.1) (Shortland 2012, p47-49; Walton *et al*. 2012).

1.4.3 Uses of glass

One of the original uses of glass was to imitate precious and semi-precious stones, particularly lapis lazuli and turquoise, simulated by cobalt and copper coloured glass respectively (see Figure 4). The colour blue was significant in the Ancient Egyptian ideology, physically representing a spectrum of spiritual meanings, including the colour of divine truth and justice. Lapis lazuli was the colour of the 'holy sky realms' and turquoise was recognised as the colour of transcendence (Aldred, 1971; Ragai, 1986). Turquoise was relatively rare, thereby making it highly prized in Egypt and therefore used frequently with Egyptian jewellery, (Aston, Harrell and Shaw, 2000, p62). Turquoise could be obtained relatively locally by Egyptian miners at

Wadi Maghâra and at Serabit el-Khâdim in Sinai, however extracting turquoise was a laborious process and mining expeditions were undertaken by private individuals and military forces with ranking officials present to ensure that the venture was successful (Redford, 1992, p79). It should also be noted that periods of turquoise mining appear to run parallel with political stability in Egypt. Despite the lucrative market, the turquoise mines at Serabit were abandoned at the end of the 12th Dynasty following the invasion of the Hyksos and work was only reinitiated when political stability returned in the New Kingdom era after 12 years of stability under Amenhotep I (1525–1504 BCE) (Grimal, 1992, p391; Mumford, 1999, p724).

Figure 4: 18th Dynasty c. 1340-1320 BCE. Findspot: The Valley of the Kings. Description: Complex necklace, formed with two strings of beads, made from gold, glass and semi-precious stones. This necklace demonstrates the use of early glasses in jewellery (as beads) along with other semi-precious stones. British Museum, EA65617 (https://www.britishmuseum.org/collection/object/Y_EA65617).

Lapis lazuli was also favoured by both the Ancient Egyptians and Mesopotamians; the source came from Badakhshan in Afghanistan, therefore was a highly desired item that the Egyptians could not source domestically (Aldred, 1971, p34; Wilkinson, 1971, p7). The king of Babylonia and the king of Mitanni seemingly both had access to rich sources of lapis lazuli, but both rulers

state in correspondence to the king of Egypt (cuneiform tablet ABL 1240) that the combination of the high price of lapis lazuli, the associated difficulties to obtain it in combination with the high volumes demanded by Egypt created civil unrest in their respective countries (Oppenheim, 1970, p12). Given the cultural significance and the relentless demand for blue stones, it seems understandable that an alternative source, even one which was profoundly labour intensive, would serve as a reliable and even more attractive substitute. It is notable that the dark blue glass inlays in the gold funerary mask of Tutankhamun was initially recorded as lapis lazuli by some scholars (Tiradritti, 1998, p235).

In addition to the manufacture of artificial coloured stones, early glasses were used to make beads, small items such as scarabs, inlays for jewellery, figurines, formed and polished disks and plaques for decorative purposes (Figure 4) (Nicholson and Henderson, 2000, p196; Reade, 2021, p1). Glass was also used to create vessels in a variety of shapes; the shapes of these vessels often took the same form as ceramic vessels and were named as such (Nolte, 1968). It has been suggested that core formed vessels appeared later "after the middle of the second millennium" as vessel production required advanced techniques as well as the developed infrastructure and resources (Oppenheim, 1970, p16). However, this has not been confirmed with strong archaeological evidence.

1.4.4 Glass vessels

Early vessels were created by casting glass into a shape and then "cold-working" using lapidary techniques usually employed for creating stone vessels (Broschat and Rehren 2017). For example, a kohl pot dated to the early 18th Dynasty (Figure 5) shows evidence of this technique as the interior appears to have been drilled (Nicholson, 2012).

It has been proposed that glass produced in the LBA would have been too viscous to pour into a mould in the same way that bronze was cast (Brochat and Rehren, 2017), therefore the glass would have been added in powder form to a continually heated mould and gradually melted until the mould was full, a process which has been recreated experimentally (E. M. Stern and Schlick-Nolte, 1994).

Figure 5: 18th Dynasty kohl jar made from opaque turquoise-blue glass and dated to the reign of Tuthmosis III, findspot: Egypt. This kohl jar represents one of the earliest glass vessels discovered in Egypt and is believed to have been cold worked. British Museum, EA24391. https://www.britishmuseum.org/collection/image/515543001 .

1.4.4.1 Core-formed vessels

The technique most associated with vessel production in LBA Egypt is core forming. This process represents a significant advance in glassworking technology and vessel production, although to date there is no substantial evidence to suggest where the practice originated and when (Shortland, 2012, p212). A 'core' made from a mixture of dung and clay would be formed around a "handling piece" which would create the inside shape of the vessel.

It was believed that the core was originally made from sand, however later studies examining the core of two vessels described the core as a dark-brown flaky material with remains of seeds and leaves, thereby indicating that the core was made with a large amount of organic matter (Bimson and Werner, 1969b, 1969a). It is believed that the pliability of the core was key in preventing the glass from cracking as the organic material was capable of contracting with the glass as it cooled. The core would be coated in clay containing significant iron oxide content and it has been suggested that an outer coating of similarly high iron oxide, but finely ground, mixture of limestone/calcite may then have been applied (Wosinski and Brill, 1968). The core would then be heated and rolled in powdered glass, adding layer upon layer to create the vessel or by trailing molten glass around the core (Figure 6), although other methods have been proposed (Schuler, 1962; Labino, 1966; E M Stern and Schlick-Nolte, 1994).

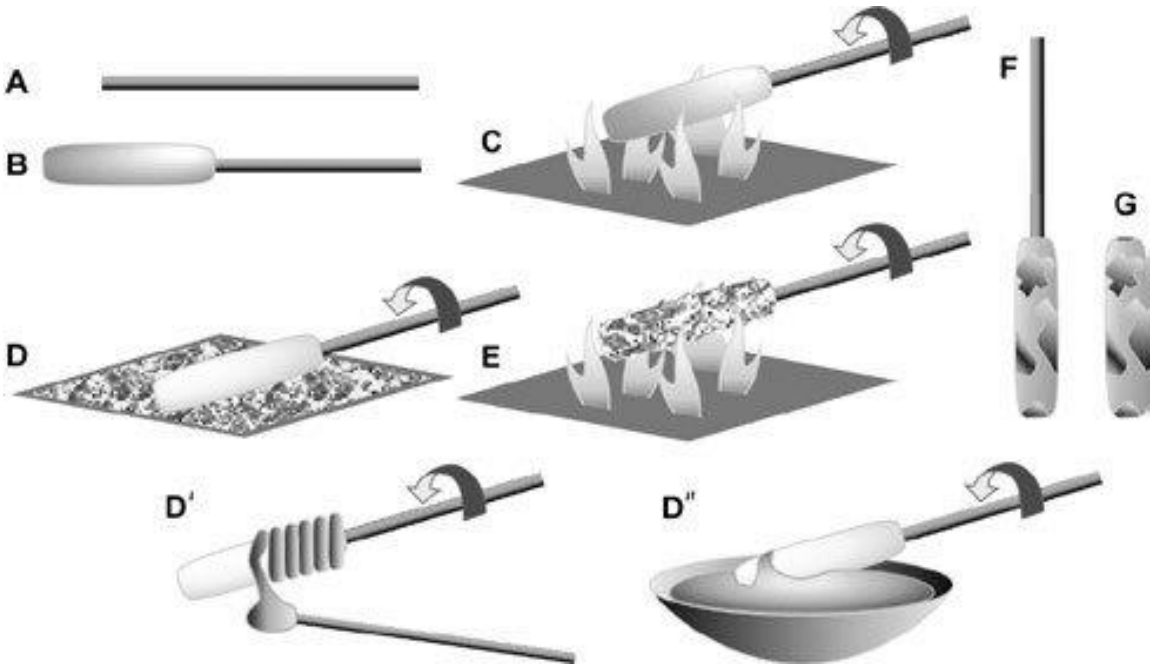


Figure 6: Figure 3. Production of core-formed vessels: (A) metal or wooden rod; (B) formation of core form; (C) firing the core; (D) glass application via rolling in crushed glass; (E) firing of applied layer; (F) completed object; (G) vessel after removal of rod/core. Alternate methods for glass application: (D') coiling strands of softened glass around the form or (D'') dipping the core in molten glass (Rasmussen, 2012).

Coloured glass rods were used to apply patterns to a glass vessel; the rod would be heated until pliable and applied by winding around the vessel. The vessel with the applied decoration would then be marvered on a stone surface and an implement used to "drag" the surface, creating the garland, feather, or chevron patterns (Nolte, 1968, p40-41). Handles, feet and rims would have been formed by manipulating the body while still malleable and decorative elements, such as twisted rods in two or more colours, would be added (see Figure 7 for example) (Nicholson and Henderson, 2000, p203-204).

Completed vessels needed to be cooled gradually in a process called annealing. There is some debate on how this would have been achieved in the LBA; researchers Stern and Schlick-Nolte (1994) have proposed that completed vessels would be placed in the ashes of the working fire to complete the annealing process. Once cooled, the core could be removed from vessels with a wide neck and opening. Vessels with narrow necks presented difficulties, therefore these vessels can appear more opaque due to remnants of the core remaining inside the vessel.

Figure 7: 18th Dynasty c. 1390-1352 BCE. Findspot: Memphis, Egypt. Core formed glass vessel (cosmetic jar). This vessel demonstrates the iconic 18th Dynasty style vessel made from dark blue glass with polychromatic pattern applied to the body and neck. British Museum, EA4741. **(https://www.britishmuseum.org/collection/object/Y_EA4741).**

1.5 Archaeological sites significant to this thesis

This section provides the archaeological background to the sites that are most mentioned in this thesis, thereby enabling the reader to navigate to the information in context with LBA glass. The section starts with the important centres of LBA glassmaking and glassworking and key find sites which are central to the topics discussed in this thesis, and a short background for other relevant, important sites are given.

Archaeological examination of kilns, tools and glassmaking/glassworking debris from workshops is key for identifying glassmaking and glassworking sites. The examination of crucibles has been central in providing important evidence indicating the manufacture of glass from raw materials; specifically by identifying the microstructural state of semifinished glasses which represents the intermediate stages of primary glassmaking (Rehren and Pusch, 2005; Pusch and T Rehren, 2007). However, the study of the earliest LBA glasses in relation to original innovation presents specific challenges; glass that is recovered from Egypt is usually well preserved, owing to the arid environment, whereas glass recovered from excavations in Mesopotamia is frequently degraded owing to the humidity or have decomposed to the point where identification is not possible (Von Saldern, 1970, p204). Mesopotamian glasses that are correctly identified and subsequently recovered may not perform well under analysis, thereby enforcing an archaeological bias.

1.5.1 Centres of glassmaking and glassworking

There are several sites in Egypt associated with glass; the earliest known being at the Palace complex of Malkata which was built during the reign of Amenhotep III (1390-1532 BCE) (Keller, 1983). The second site, Amarna, was founded by the son of Amenhotep III: Akhenaten (1352-1336 BCE) (also known as Amenhotep IV), and occupied until approximately Year 1 of the reign of Tutankhamun, the son of Akhenaten (Van Dijk, 2000, p281; Snape, 2014, p163). The glassmaking complex at Qantir was established during the reign of Rameses II (1279-1213 BCE) (Pusch and Th Rehren, 2007, p129) with the site eventually being abandoned around 1069 BCE (Shaw and Nicholson, 1995, p237). The last proposed Egyptian LBA glass workshop is Lisht, where glass related activity dates between 1295-1070 BCE (Keller, 1983), therefore contemporaneous with glass activity at Qantir. A map and summary of these sites can

be seen in Figure 8 and Table 3: Main glassmaking/glassworking sites in Egypt and the products

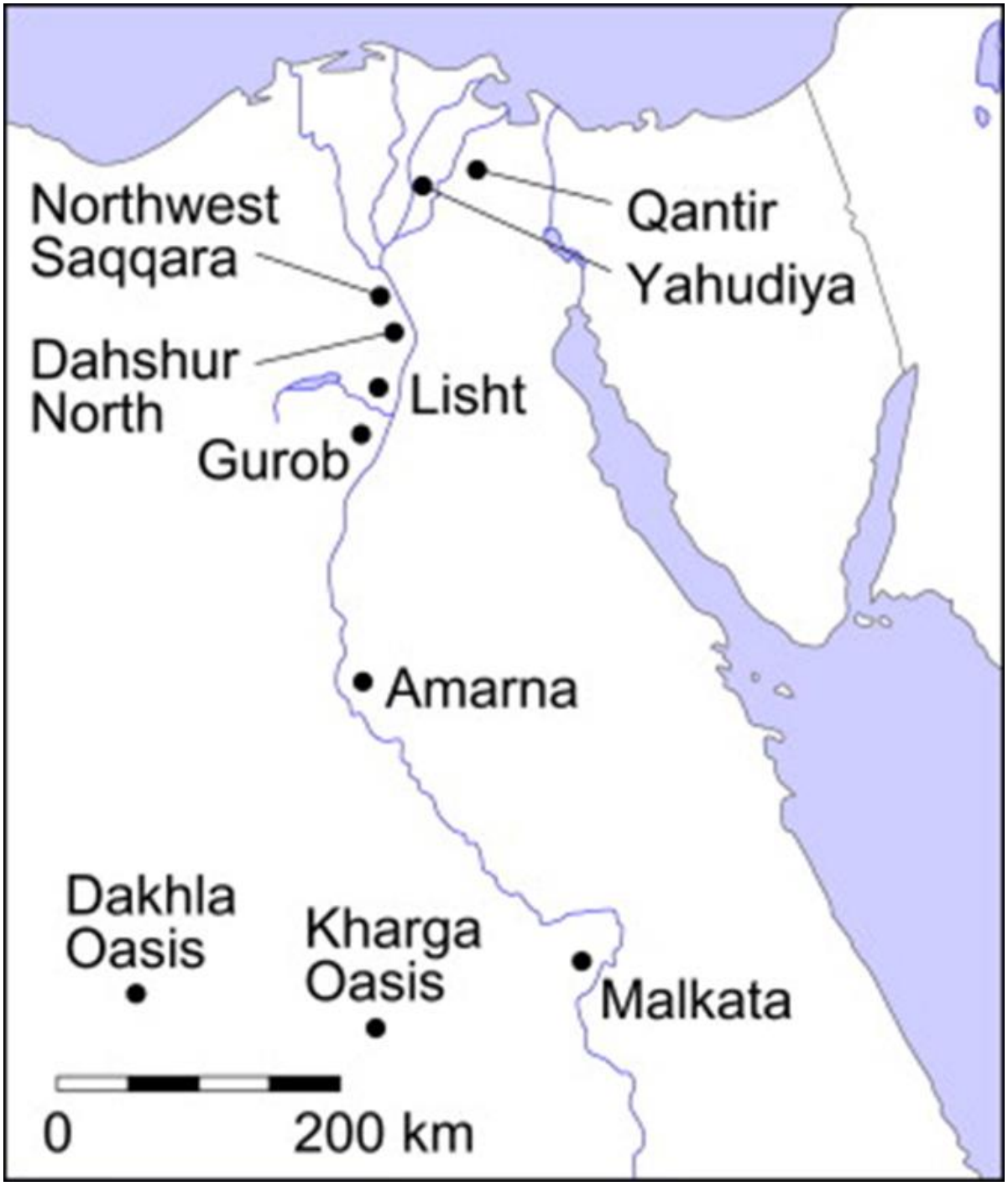


Figure 8: Map showing the location of the four main glassmaking/glassworking sites in Egypt between the 18th – 20th Dynasties (Abe *et al.*, 2012).

Site	Years active (approx.)	Glassmaking	Glassworking	Produced
Malkata	1390 - 1347 BCE	Uncertain	Yes	Vessels
Amarna	1347 - 1335 BCE	Yes	Yes	Ingots Vessels Beads
Qantir	1279 - 1099 BCE	Yes	Possibly	Raw glass ingots
Lisht	1295 - 1070 BCE	Yes	Yes	Vessels Beads Inlays

Table 3: Main glassmaking/glassworking sites in Egypt and the products (Rehren and Pusch, 1997; Mass, Wypyski and Stone, 2002; Shortland, 2012).

1.5.1.1 Malkata

Malkata, located on the west bank of Thebes, is the location of the palace of Amenhotep III and the earliest known excavated site containing evidence of glassworking. Excavations by the Metropolitan Museum uncovered artifacts of glassworking including fragments of crucibles, glass slag, waste vessel fragments, glass rods in several different colours and a piece of partially fired of uncoloured glass (E M Stern and Schlick-Nolte, 1994, p26). To date there are now many hundreds of fragments of glass that have been excavated from the site of Malkata, which indicates the prosperity of the city during the reign of Amenhotep III. However, crucibles excavated from the site were not retained by the museum, therefore this crucial evidence cannot be used to substantiate Malkata as a true glassmaking site (Mass, Wypyski and Stone, 2002). In addition, the archaeological records do not state where the production site was, meaning any subsequent researchers are unable to locate the original site.

1.5.1.2 Amarna

The site of Amarna was founded under the reign of Akhenaten and is one of the most significant sites of study in Egyptology as well as glassmaking. Located on the east bank of the Nile approximately halfway between Thebes and Memphis, the original name of the city, Akhetaten, translates to “Horizon of the Aten” (Snape, 2014, p47, p156). The city was built in a previously unoccupied location in Egypt, effectively ‘virgin soil’, in the 5th year of the reign of Akhenaten

and occupied most likely a year or two after (Grimal, 1992, p227; Van Dijk, 2000, p269). By creating a new city, Akhenaten broke all ties with the traditional religious capital of Thebes and the cult of Amun and sought to establish a simpler religion worshipping the sun disk, Aten. This religious and political reform known as the "Amarna Period" revolutionised the Egyptian way of life, lasting less than 20 years and ending in the first regnal year of his son and successor, Tutankhamun (Shaw, 2003, p281). Amarna became an impressive metropolis; large buildings were constructed for palaces, government offices, temples, and dedicated areas for workmen (Boyce, 1995).

Despite being thoroughly looted in antiquity and exposed to treasure hunters in the 19th century, excavations at Amarna have yielded significant evidence for glassmaking, glassworking, and faience production (Petrie, 1894; Shortland and Tite, 2000). Lilyquist describes the finds from Amarna as "the best provenanced and most numerous compositional values of Egyptian glass up to now" (Lilyquist *et al.*, 1993, p44). Recent excavations in the southern part of the city has revealed numerous glassworking finds as part of a possible bead and amulet workshop, including over 300 glass chips from ingots and 116 glass rods and beads, thereby inferring that the workshops would have processed relatively large amounts of glass (Hodgkinson, 2015).

The initial excavation took place in the winter of 1891-1892 and Petrie, with a young Howard Carter in attendance, discovered remains of what they interpreted as "the sites of three or four glass factories and two large glazing works". In these areas, Petrie described fragments of glass waste, frit, fragments of ceramic vessels used for the fritting process, cylindrical ceramic jars with glass/glaze remains on the external surface (crucibles), beads, glass rods and "hundreds of pieces of glass vases" in addition to other semi-fused pieces of glass (W. M. F. Petrie, 1894, p26). The finds relating to glass from Amarna now reside in several museums including the British Museum, the Manchester Museum and the Ashmolean Museum, Oxford. The majority of the finds are stored at the Petrie Museum of Egyptian Archaeology, University College London. The finds continue to be studied as they represent the most significant evidence and the most detailed information about Egyptian glassworking techniques (Tatton-Brown and Andrews, 1991; E M Stern and Schlick-Nolte, 1994). Petrie had a special interest in glass and recorded that significant quantities of glass were excavated from the central city "palace wasteheaps" and the north-western main city at Amarna (Petrie, 1894).

The site of Amarna is still the subject of ongoing research and excavations; in the 1993 -1994 CE seasons, Nicholson excavated two furnaces in an area that Petri marked as “moulds” on a map from his field notes. Although during his excavations Petrie states that there is no evidence found specifically for glassmaking furnaces, he describes a furnace believed to be used for charcoal burning (W. M. F. Petrie, 1894, p25-26). An experimental reproduction of this furnace using the exact dimensions described by Petrie demonstrated that such a furnace could exceed the 1,100 °C temperature required for glassmaking (Nicholson and Jackson, 1998), however, there is no direct evidence to show that the furnaces identified by Petrie were used specifically for this purpose (Jackson and Nicholson, 2007a; Pusch and Th Rehren, 2007).

Fritting vessels described by Petrie were based on a pan of frit from Amarna which formed the impression of the original production vessel (Petrie Museum UC36457). Once again, there is no physical evidence for the actual fritting vessels from these excavations. Cobalt blue frit is closely associated with the glassmaking process and was found at Amarna in large quantities, however the direct role of frit is unknown (Shortland and Tite, 1998; Shortland and Tite, 2000; Shortland, 2000; Tite and Shortland, 2003; Shortland *et al.*, 2006b). The presence of frit found among glass related debris and of other vitreous materials suggests that the glassmaking process and the materials used was a complex process as denoted by cuneiform texts (Brill, 1970; Jackson and Nicholson, 2007a). It was the presence of frit at Amarna that Petrie proposed it was a site of primary production, and although this was accepted by several researchers, the evidence based on the presence of cylindrical crucibles used for ingot production, was largely circumstantial (Petrie, 1894, p26; Turner, 1956c; Kaczmarczyk, 1986; Nicholson, Jackson and Trott, 1997; Rehren, Pusch and Herold, 1998)

To summarise, the range of archaeological evidence from Amarna shows that a significant glassworking industry was operated from the city as part of a wider complex of craftsmen specialising in the production of vitreous materials (Shortland, 2000; Jackson and Nicholson, 2007b). Several semi-finished glasses identified at Amarna have provided the evidence for primary glassmaking; work by Smirniou and Rehren verified that the microstructural and chemical compositions of finds of raw glass and white working waste from Amarna compared with those found in Qantir, a known primary glass production site (Rehren and Pusch, 2005; Pusch and Th Rehren, 2007; Smirniou and Rehren, 2011).

The textual (Oppenheim *et al.*, 1970) and archaeological evidence (Rehren and Pusch, 2005; Pusch and Th Rehren, 2007) along with the practice of experimental glassmaking to demonstrate Partial Melting and Two Melt Models (Rehren, 2000b; Shugar and Rehren, 2002; Tanimoto and Rehren, 2008) indicates that glass was likely made by executing a number of discrete production steps. This would result in a semi-finished product that required additional working in a second stage before being processed into a final object. The presence of semi-finished glass is an indicator of primary glass production; to date there is no archaeological evidence which shows the trade or transport of LBA glass in its semi-finished state, therefore, its presence at a site strongly suggests that primary glassmaking was being undertaken.

In addition to glassmaking and glassworking, Amarna is a significant site for other archaeological finds connected with glass which are discussed in section 1.5.4.1.2, therefore Amarna is listed twice.

1.5.1.3 Qantir

The site of Qantir, also known as Qantir-Piramesses, is located approximately 100km northeast of modern Cairo in the eastern Nile delta and was founded by Seti I (1294-1279 BCE) and became the capital city during the reign of Ramesses II (1279-1213 BCE) (Shaw and Nicholson, 1995, p237). An expansion of the important city of Avaris, the new city was originally named Pi-Rameses ("House of Ramesses") and was purposely built to appear imposing and impressive to Egypt's enemies (Snape, 2014, p203). The city was strategically situated to better confront the Hittites in the struggle for dominance in the Levant, however, evidence shows that Hittites and Egyptians lived together after a peace treaty between Rameses II and Hattusili III (Pusch and Herold, 1999, p648). International trade could also be better facilitated from the northeast delta region (Van Dijk, 2000, p292). Although the city of Pi-Ramesse was extremely cosmopolitan and the most significant international trade centre in Egypt, it was primarily a military complex built to address the rise in conflict in the Near East (Wilkinson, 2013, p337). Pi-Ramesse was inhabited for approximately 180 years and was finally abandoned in the 21st Dynasty when the eastern branch of the Nile became exhausted and the harbours became unusable (Snape, 2014, p205).

The analytical, archaeological, and experimental work undertaken by Thilo Rehren, and co-researchers have demonstrated that Qantir was a large glassmaking facility, capable of producing many hundreds of ingots, which is indicated by fragments representing 250-300

cylindrical vessels and crucibles (Rehren and Pusch, 2005; Pusch and Th Rehren, 2007, p131). Specifically, Qantir primarily produced red glass on an industrial scale which was a more complex process and required controlled reduction conditions, in addition to producing some cobalt blue glasses and purple (Rehren and Pusch, 2005). Other significant finds providing evidence for raw glassmaking were pure white quartz dust, a complete ingot of red glass and a well preserved crucible containing a corroded block of raw glass (Rehren and Pusch, 2005). It was noted that most of the glass found attached to the ceramic vessels was cuprite-red (Rehren, Pusch and Herold, 1998; Rehren and Pusch, 2005). The evidence for secondary glass production is relatively sparse at Qantir, indicating that this was a glassmaking site only and not glassworking for the production of objects (Shortland, Nicholson and Jackson, 2001, p151).

1.5.1.4 Lisht

Lisht is located approximately 65km south of Cairo on the left bank of the Nile and is the site of a renowned necropolis and Pyramid complex dating to the Egyptian 12th Dynasty (1985-1773 BCE). Lisht is the site of two significant burial complexes which includes the burial of Amenemhat (1985-1956 BCE), the first King of the 12th Dynasty, who established the city and the burial of his son Senwosret I/ Senusret I (1956-1911 BCE).

Glass finds representing glassmaking were excavated from the site including glass waste and slag, glass vessel fragments, blue glass canes and rods, strings of glass and faience beads, a large blue glass ingot and fragments of ceramic crucibles with glass still adhered (Keller, 1983; Kozloff and Bryan, 1992). The presence of half completed glass and faience objects suggested to the excavators that a glaze factory was located in the complex (Mace, 1911, p25) but unfortunately, the various finds from Lisht were catalogued somewhat randomly over the 30 years of the excavations and therefore cannot be attributed to specific archaeological contexts.

The site of Lisht was also a secondary glassworking site and produced vessels, inlays and other items in several colours including green, purple, brown, black, white, yellow and Cu-blue (Keller, 1983). The evidence suggests cobalt blue glass was not produced at Lisht, however evidence of glass recycling is present (Keller, 1983; Brill, 1999b; Mass, Wypyski and Stone, 2002). Research on materials produced at Lisht indicate that these glasses have their own distinctive chemical “fingerprint” characterised by low concentrations of alumina, iron oxide and lime with relatively high soda concentrations compared with other Egyptian glasses (Smirniou, Rehren and Gratuze, 2018).

The glass related activity at Lisht has been dated using finds including scarabs of Seti I (1294-1279 BCE) and Rameses II from the 19th Dynasty and Sethnakht (1186-1184 BCE) first ruler of the 20th Dynasty. These finds indicate that the glass related activities spanned from 1295 BCE to 1070 BCE (Keller, 1983), therefore Lisht is a later, post-Amarna, glassmaking site.

1.5.2 Other sites connected with glassmaking/glassworking.

Two other sites, Menshiyeh (Keller, 1983) and Kom Medinet Ghurab (Kozloff and Bryan, 1992), also known as Gurob, have been indicated as possible sites with evidence of glass processing activities (Hodgkinson, 2017, p8).

1.5.3 Outside Egypt: glassmaking/glassworking centres in Mesopotamia

Although the proposition that Mesopotamia was one of the likely places where glass first originated, the archaeological evidence of primary glass production in this region is virtually non-existent and largely tenuous. Despite very good evidence for production in this area, there is no certain site outside Egypt which is confirmed as a glassmaking site.

The proposed sites for contemporary LBA Mesopotamian glassmaking are Tell Brak in Syria and Nuzi. Tell Brak was an important Mittanian city in the 2nd Millenium which shows evidence of deliberate glass production in the form of core-formed vessels, beads and plaques from around 1500 BCE and some raw glass finds or ingots and glass waste from the 14th century (Oates and Oates, 1991). The site of Nuzi in modern day Iraq was excavated between 1925 and 1933 with core formed vessels and moulded objects being listed among the finds (Barag, 1970) in addition to glass waste and raw glass which indicated a developed industry (Vandiver, 1983).

More details about Mesopotamian sites and the connected archaeological glass finds are described in section 03.

1.5.3.1 Tell Atchana

The site of Tell Atchana, also known as Alalakh, located in modern day Turkey shows potential for being a northern Syrian LBA glass production site (Dardeniz, 2016, 2018). Excavations in 2011 discovered production debris including a crucible with “crystalline phases identified as diopside and silica”, which has been used in previous studies as an identifier of primary glass production (Rehren and Pusch, 2005; Dardeniz, Henderson and Roe, 2022). Other connected

debris included frit and glass along with a heavily damaged kiln; Dardeniz also notes the similarity between the workshop area of Tell Atchana and that of O.45.1 in Amarna possibly suggesting some technology transfer (Jackson and Nicholson, 2007a). Samples analysed using LA-ICP-MS and isotope analysis from the site also indicate a glass trade with Egypt and Mesopotamia. The ceramic finds associated with a glassmaking crucible have dated the finds to the LBI/LBII transitional phase, therefore, the relative chronology indicates that this glassmaking evidence is earlier than any currently known in Egypt (Dardeniz, Henderson and Roe, 2022).

The analysis of some glasses excavated from Alalakh show distinct a composition which are relatively high in yttrium, very low in lanthanum with variable chromium (Dardeniz, 2016), with later work suggesting that the distinguishing signature for Alalakh glasses is vanadium-chromium (Dardeniz, 2018).

1.5.3.2 Mycenae

The proposition of Mycenae as a glassmaking region has been discussed in previous studies seeking to determine the provenance of glasses excavated from several Mycenaean sites. Earlier studies have focused on the source of the cobalt colourant (Sayre and Smith, 1961b, 1974; Dayton and Lamberg-Karlovsky, 1993; Brill, 1999b) or have collected only major elements (Nikita and Henderson, 2006) however later analysis using LA-ICP-MS by Walton *et al*. determined the provenance of glass beads from the palatial centre of Tiryns using trace element composition (Walton *et al.*, 2009). This research confirmed all objects analysed in the study were of Mesopotamian and Egyptian origin, therefore were imports to this region. Glass waste examined from the site may indicate that this was a site for glassworking (Panagiotaki *et al.*, 2005) however substantial archaeological evidence for primary production of glass that dates contemporaneously with Egyptian and Mesopotamian LBA early production is yet to be discovered (Zacharias *et al.*, 2018). Glasses connected with Mycenae are discussed in this thesis as a reference to the LBA trade networks only, and Mycenae as a potential primary glassmaking site is not debated further.

1.5.4 Important sites connected with glass

This section introduces the most important sites connected with glass which are relevant to this thesis. Sites in the main cities of Karnak and Amarna are presented first, then the related

tombs located in Thebes. This section then moves outside the core areas of the capital cities to discuss the Harem Palace site of Gurob.

1.5.4.1 Egypt

1.5.4.1.1 Karnak – Hall of the Annals

The temple of Karnak in Thebes is the largest Egyptian temple and was dedicated to the primary deity Amun-Ra (Legrain, 1929; Wilkinson, 2017, p73). Within the temple is an area termed the "Hall of Annals" which depicts Tuthmosis III dedicating goods to the temple, in celebration of his successful military campaigns in Syria and the Levant. The offerings include what are understood to be glass ingots (see Figure 9) (Wreszinski, 1923-40; Legrain, 1929; Sherratt and Sherratt, 1991).

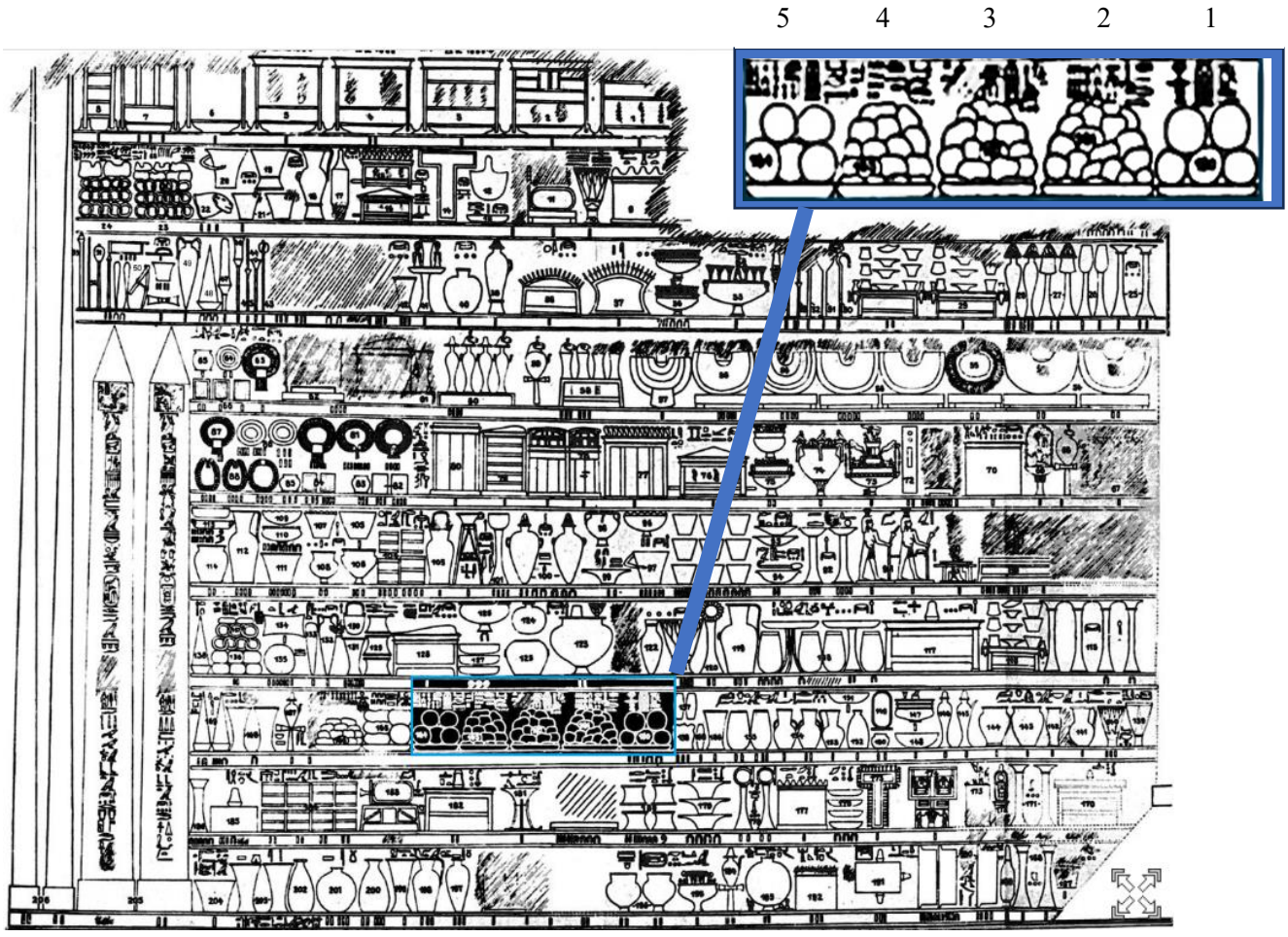


Figure 9: The relief scene showing tributes to the Temple of Amun by Tuthmosis III. The items believed to be glass are highlighted and enlarged in the top right corner image. Adapted from a drawing by Wreszinski (Wreszinski, 1923).

The scene depicts registers of gifts, starting with the most valuable objects of gold and silver followed by precious stones and what is believed to be glass, the round objects being a representation of ingots (Figure 9). The quantity of glass depicted in this scene has been interpreted in slightly different ways owing to the translation of both the terms for glass and of the quantities. Shortland has stated that basket 1 and basket 3 represent ingots and "lumps" of dark blue glass respectively and basket 5 represents light blue coloured glass (Nicholson, 2006; Shortland, 2012, p144). The quantities of glass in baskets 1 and 3 are given as 24 pieces or 55kg, and approximately 60kg respectively making a total of 115kg of dark blue glass (Nicholson, 2006). Basket 5 has two interpretations owing to the reading of one sign: 10913.8 deben which converts to 993kg, or 913 deben equalling 84kg (Sherratt and Sherratt, 1991; Nicholson, 2006), the most likely being the latter (Shortland, 2012, p144).

1.5.4.1.2 Amarna: The Amarna Letters

The Amarna Letters are a series of over 300 clay cuneiform tablets which detail the diplomatic correspondence during the reigns of Amenhotep III (1390-1532 BCE) and Akhenaten (1352-1336 BCE) between Egypt and the Mesopotamian kings of Babylonia, Assyria, Mitanni, and Hatti and also from minor rulers of the Levant (Liverani, 1999) (for an example, see Figure 10). The correspondence were sent during a timeframe of under 30 years and are primarily written in a form of Canaanite-Akkadian, a writing system of ancient Mesopotamia (Moran, 1992). The tablets themselves provide a wealth of information about international relations between the 'Great Powers' (see section 1.6) and their respective cultures. The correspondence deal with a range of subjects, from requests by Levantine rulers for military assistance to assist with squabbles between neighbouring states, to lists of gifts sent by "brother" kings to Egypt. The Amarna tablets have played a key role in establishing the chronology of the period and contemporaneous rulers of the time.

Figure 10: 18th Dynasty c. 14th Century BCE. Findspot: Amarna, Egypt. Clay cuneiform tablets representing communications from Yidya to the king of Egypt. Also known as one of the Amarna Letters. British Museum, E29837. **(https://www.britishmuseum.org/collection/object/W_1888-1013-75).**

1.5.4.1.3 The Valley of the Kings

The Valley of the Kings is located on the West Bank of the Nile in the Wady Biban el-Muluk, opposite Thebes (modern-day Luxor). The site is the royal necropolis for the majority of Egyptian kings from the 18th to the 20th Dynasty.

1.5.4.1.3.1 KV34 – The Tomb of Thutmosis III (1479 – 1425 BCE)

The tomb of Tuthmosis III is significant for this thesis as there are several glass vessels associated with the tomb believed to be some of the earliest glass vessels created: a dark blue lid from a kohl pot and a light blue handled vessel (core-formed). There is also a fragment of light blue glass with a yellow and dark blue decorative pattern applied and a well preserved juglet with a floral motif and an inscription to Tuthmosis III, which is believed to have belonged to Tuthmosis III (Nicholson, 2006). These vessels show that the methods of cold working and core forming glass vessels were practiced contemporaneously (see Figure 5).

1.5.4.1.3.2 KV35 – the Tomb of Amenhotep II (1427-1400 BCE)

The tomb of Amenhotep II contained a large amount of funerary items including furniture, stone, wood, faience and glass vessels, the latter of which there were a considerable amount (Reeves and Wilkinson, 2008, p103). The tomb goods sustained considerable damage and it has been noted that all objects were reduced to fragments. Unlike previous tombs, KV35 was examined with more care and some partial records were made of the excavation (Reeves and

Wilkinson, 2008, p100). Therefore, the tomb of Amenhotep II represents one of the earliest archaeological sites connected with very early glassmaking. The analysis of glass fragments attributed to the tomb of Amenhotep II are presented in chapter 4.

Figure 11: 18th Dynasty c. 1427-1400 BCE. Find spot Valley of the Kings, Thebes. Fragments analysed in chapter 4: Top right: EA64125 middle right: EA64124, bottom right: Find spot (Acquired): Thebes. EA64163. British Museum.

1.5.4.1.3.3 KV62 – The Tomb of Tutankhamun (1336-1327 BCE)

The tomb of Tutankhamun is one of the finest examples of an ancient Egyptian royal burial with a relatively full complement of grave goods; it is all the more impressive because of the short reign of approximately 9 years from a young ruler. The tomb is comparatively undisturbed, although it is estimated that the tomb was entered by looters twice, therefore it is significant for this thesis as it illustrates the breadth of technical skill of glassworkers towards the end of the 18th Dynasty and provides further evidence of the high status of glass in the LBA. Grave goods include two glass headrests made of turquoise and dark blue glass (Brochat and Rehren, 2017), the famous golden burial mask inlayed with dark blue glass, a writing palate made of glass with blue and yellow glass rods in place of reeds, glass figurines, many items of jewellery and objects incorporating glass.

1.5.4.1.4 Wadi Qurud – The Tomb of the Three Foreign Wives of Tuthmosis III

The Tomb of Three Foreign Wives of Tuthmosis III is located in the Wady "D" Gabbanat el-Qurud, southwest of the Valley of the Kings, Thebes, and contained three "Asiatic Princesses" named Menhet, Menwi and Merti and their lavish grave goods (Lilyquist, 2004) (see Figure 12 and Figure 13). The wives were buried in Egyptian style however many of the grave goods were stylistically foreign and were among the earliest foreign women known to be associated with the royal Egyptian New Kingdom household (Lilyquist, 2004, p336). It is estimated that the burial of the three princesses is dated to approximately 25 years before the death of Tuthmosis III.

Figure 12: 18th Dynasty c. 1479-1425 BCE. Findspot: Wadi Gabbanat el-Qurud, Wadi D. Headdress from the Tomb of the Three Foreign Wives of Tuthmosis III, made from gold, semi-precious stones and glass. This headdress demonstrates the fine grave goods buried with the foreign princesses in addition to some of the first uses of glass. Metropolitan Museum of Art, Number: 26.8.117a. https://www.metmuseum.org/art/collection/search/548677

Figure 13: 18th Dynasty c. 1479-1425 BCE. Lotiform chalice made from glass. Find site: Upper Egypt, Thebes, Wadi Gabbanat el-Qurud, Wadi D, Tomb of the Three Foreign Wives of Thutmose III. This chalice demonstrates a typically Egyptian style vessel which was interred with the three princesses. Metropolitan Museum of Art, 23.9.
https://www.metmuseum.org/art/collection/search/544859

The tomb was discovered by looters in 1916 who removed items of gold, jewellery, and other valuables, however items such as stone vessels, cosmetic jars, containers, and a glass vessel likely imported to Egypt was present in the tomb. The majority of the funerary goods were recovered by the Metropolitan Museum of Art and now reside in New York. The standard reference work for the Tomb of the Three Foreign Wives was written by Lilyquist in 2004 and is a comprehensive study of the tomb and the contents (Lilyquist, 2004).

1.5.4.1.5 Gurob

The site of Gurob, also known as Medinet Gurob or Kom Medinet Gurob, is situated in the Faiyum region of northern Egypt and is most well known as the location of the only confirmed Harem Palace in Egypt (Shaw, 2011b). Tuthmosis III established the town, but it is during the reign of Amenhotep III when the site flourished into a thriving community. Flinders Petrie initiated preliminary excavations at Gurob between 1888-1890 and left to concentrate on neighbouring Illahun, leaving the work at Gurob to Hughes-Hughes, a volunteer who had little formal training in archaeology or surveying. Brief plans were drawn when Petrie returned but overall, little was recorded (Petrie, 1891, p15). Later teams excavated the site, mentioning that progress was impeded by lack of documentation from previous excavations. The significant work was undertaken in 1920 by Brunton and Engelbach who focused on the temple and surrounding cemeteries. Glass beads and scarabs were recovered from tombs dating to Amenhotep I, but Brunton and Engelbach caveated the date by stating that pottery recovered from the same tombs were usually attributed to Tuthmosis III (Brunton and Engelbach, 1927). Approximately 15 glass vessels have been excavated from Gurob, dating between the reigns of Tuthmosis III and the Ramesside period, including kohl tubes (Nolte, 1968).

It has been proposed that Gurob is a contemporaneous site to Malkata, or slightly later based on evidence of "glass factories and lime-kilns" (Brunton and Engelbach, 1927, p3; Tait, 1991, p31). Glass finds have been discovered dating from the New Kingdom to the 20th Dynasty including beads, inlays and vessels (Brunton and Engelbach, 1927, p20; Nolte, 1968). However, there is little evidence to suggest this was a true glassmaking site, therefore is not discussed in this context for the purposes of this thesis.

1.5.4.2 Other sites outside Egypt

This section discusses the sites outside Egypt in connection with glass which are relevant to this thesis, starting with Serabit in the Sinai Peninsula, Mesopotamia and Tall Zirā'a in the Levant. The last site discussed is the Uluburun shipwreck which sank just off the coast of Turkey.

1.5.4.2.1 Serabit, Sinai

Serabit el-Khâdim, or Serabit, is the site of an ancient turquoise mining development located halfway down the western coast of the Sinai Peninsula (Figure 14). Serabit became one of the

most significant centres of Egyptian activity in the Sinai-peninsula during mining periods (Wilkinson, 2017, p239). It is also the site of a temple constructed in the early 12th Dynasty and dedicated to the Goddess Hathor, who was considered to be the patron goddess of foreign expeditions and turquoise miners.

Figure 14: Map showing the location of Serabit el-Khadim in relation to the ancient cites of Memphis and Thebes (Koch, 2017).

The temple itself contains many inscriptions which detail the increasing number of turquoise mining expeditions undertaken in the years the mine was active. After 12 years of peace under Amenhotep I (1525-1504 BC), mining was re-established in the 18th Dynasty along and the temples received many repairs and embellishments between the reigns of Hatshepsut (1473 – 1458 BC) and Amenhotep III (1391-1353 BC). The temple also became a famous pilgrimage site with many gifts and offerings being placed as tribute (Caelen, 2013, p7). The last recorded offerings to the site were made in 20th Dynasty during the reign of Rameses VI (1143–1136 BCE). The site of Serabit is discussed later in more detail in chapter 5.

1.5.4.2.2 Nuzi

Nuzi (modern day Yorghan Tepe) is located near the Tigris River and southwest of the city of Arrapha. As part of the Mittani empire, the city reached the height of its importance in the 15th-14th centuries BCE until the 14th Century when it was assimilated by the Hittite uprising and gradually declined thereafter. The actual name of the city "Nuzi" was correctly appointed after the discovery of approximately 5000 clay tablets found in excavations dating from 1925-1931. The excavations also uncovered large amounts of glass, concentrated in Stratum II which is connected with the Mitanni period. The glass finds include beads, pendants, fragments of vessels and around three fragments of raw glass (Shortland *et al.*, 2017)

1.5.4.2.3 Tell Brak

During the 15th Century BCE, Tell Brak was one of the most significant cities in upper Mesopotamia. The city was important for trade and was the centre of Mitanni before being destroyed by Assyria circa 1300BCE. Several cultures inhabited the city and was a religious centre, attracting many pilgrims. Excavations between 1976 and 1993 by the University of London recovered a number of cuneiform tablets and a large cache of gold, silver, carnelian and lapis lazuli. Excavations of the second millennium levels recovered large amounts of glass, glass vessels and glass ingots, including glass gaming pieces and pieces of glass cullet (Oates, Oates and McDonald, 1997, p81; Oates, 2005).

1.5.4.3 The Levant

1.5.4.3.1 Tall Zirā'a

Tall Zirāʿa is located in the Wādī al-ʿArab, northern Jordan, roughly 5 km from the ancient Decapolis city of Gadara. Archaeological evidence shows that the site was almost continuously inhabited for 5000 years, likely due to the fertile soil, proximity of fresh water sources and an artesian spring on the surface of the Tall (Adan-Bajewitz *et al.*, 2017, p14-21).

The Wadi al-'Arab was part of a significant trade route, linking several key cities and ports from the Jordan Valley to the Irbid-Ramtha basin (Soennecken *et al.*, 2021, p13); the route connected the Jordan valley with Ammān, Baġdād or Dimašq (Damascus), the Jezreel plains and Tall al-Ḥiṣn (Beth Shean) and the eastern Jordanian highlands. Internationally, the route was used to connect to the Mediterranean coast via the northern Jordan ford at Ǧisr al-

Mağāmi‘(Gešer), starting in Egypt in the south, across the Sinai peninsula, through Damascus and arriving at Syria-Mesopotamia in the north (Soennecken *et al.*, 2021, p2). Numerous finds at Tall Zirā’a attest to international trade of many types of goods, including ceramic vessels from Cyprus, Greece and Syria, faience and glass from Egypt, and copper from the sites of Faynan in Southern Jordan and/or Timnà, located in modern southern Israel (Adan-Bajewitz *et al.*, 2017).

1.5.4.4 The Uluburun Shipwreck

The Uluburun shipwreck is the best evidence for long-distance glass transport and provides crucial information about the patterns of exchange and production in the Mediterranean. It has been proposed that The Uluburun shipwreck represents an LBA trading vessel which sank close to the east shore of the Uluburun coast in Turkey (Figure 15) containing over 20 tons of cargo from the Levant, Nubia, Cyprus, Mesopotamia and Egypt, including raw copper, oxhide ingots, tin, Canaanite jars, ivory, gold, carnelian and approximately 200 glass ingots (Bass, 1987; Pulak, 2008; Lankton, Pulak and Gratuze, 2022).

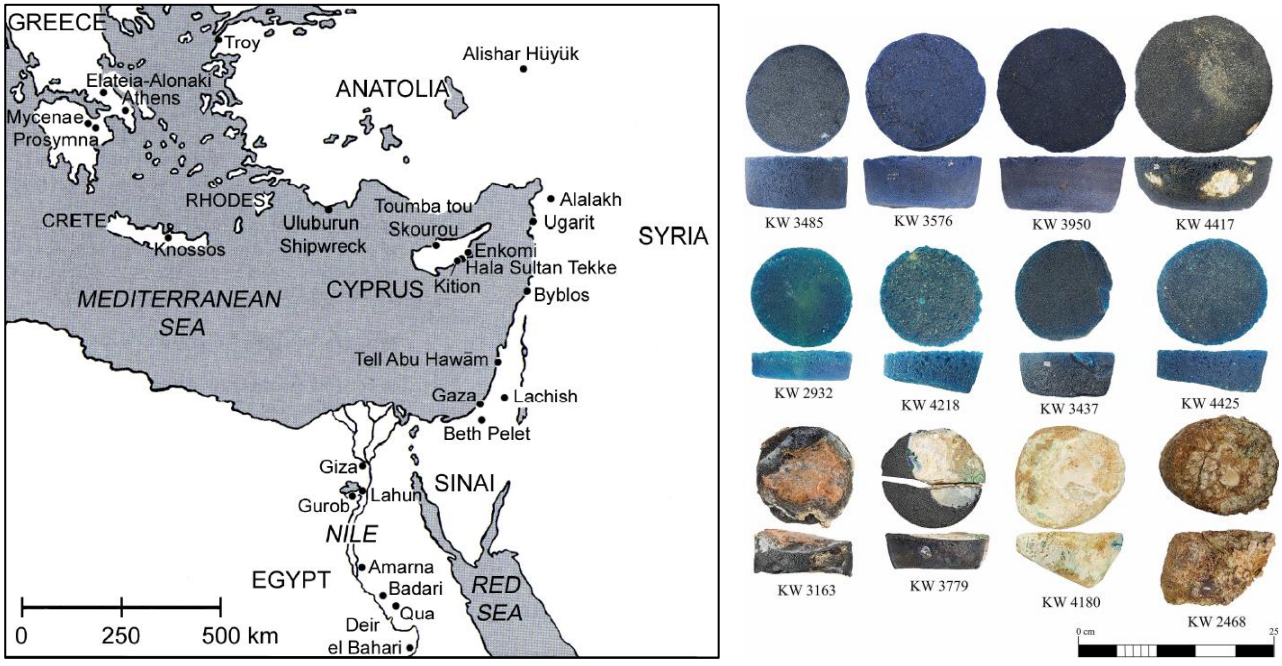


Figure 15: Location of the Uluburun shipwreck (Friedman, 1998, p264, map 1) and selection of the ingots recovered from the wreck.

Therefore, the Uluburun shipwreck contains more LBA glass than any other archaeological site on record which is significant to this thesis and will be discussed further in chapter 8. The cargo bears striking similarities to the diplomatic gifts given between royal courts, therefore it should

also be considered that the vessel represents a diplomatic "gift-giving" ship (Pulak, 2001). Evidence suggests that the ship sank circa 1300 BCE, corresponding with the end of the Amarna period (Manning *et al.*, 2009). It has been suggested that the ship departed from a Syro-Palestinian port and that the destination may have been Mycenae, which was large enough to accept and administer the quantity of goods on the Uluburun vessel. Goods received at Mycenae would likely be distributed to ports such as the southern Tiryns, a known recipient of Egyptian glasses (Walton *et al.*, 2009). The purpose and contents of the Uluburun vessel relating to distribution in the LBA are discussed in further detail in section 1.8.1.

1.6 Egypt and the Near East in the LBA

It is important to provide the historical and geographical setting at the time in which the innovation of glass was placed, in addition to providing an overview of the states who were directly involved with the innovation, trade and consumption of LBA glass. See Figure 16 for a map of the key areas discussed in this thesis.

Egypt, located in north Africa, was fragmented under the rule of several rival kings at the start of the 16th Century; the 15th Dynasty were foreigners, known as Hyksos, who established their northern capital city at Avaris, close to Memphis. The 16th Dynasty consisted of lesser Hyksos Kings who ruled in parallel with the 15th Dynasty (Bietak, 1999, p377). The 17th Dynasty were native Egyptian rulers who controlled Upper Egypt from the southern capital city of Thebes (Grimal, 1992, p187). The Egyptian rulers of the 17th Dynasty campaigned against the foreign factions in the North, successfully expelling the Hyksos, uniting Upper and Lower Egypt and forming the Egyptian 18th Dynasty in c.1550 BCE (Bourriau, 2000, p203).

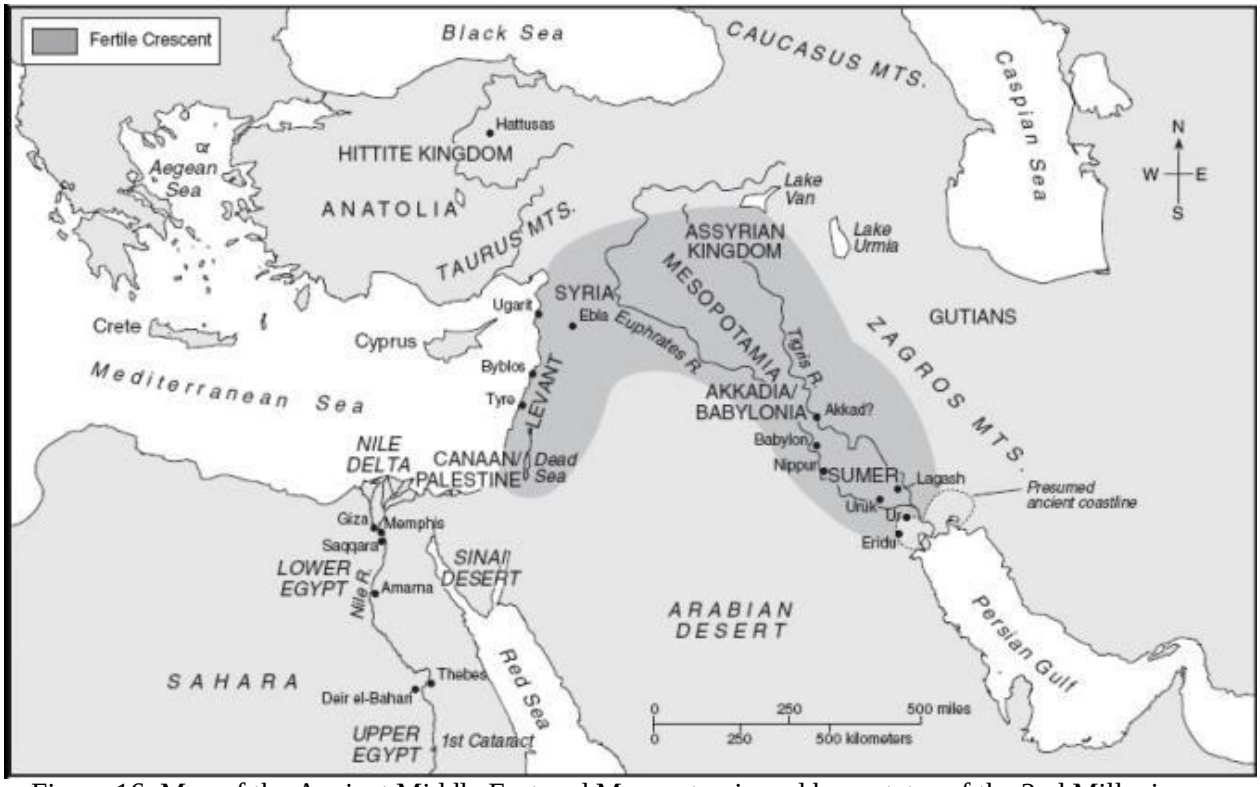


Figure 16: Map of the Ancient Middle East and Mesopotamia and keys states of the 2nd Millenium BCE (http://web.cocc.edu/cagatucci/classes/hum213/Maps/Maps2HistoryAncient.htm).

Subsequent rulers of the 18th Dynasty strengthened Egypt's position as a "Great Power" by asserting military dominance over neighbouring lands. The spoils reaped from successful military campaigns, the increase in trade relations, and the demands for tribute all contributed to the increasing wealth and status of Egypt (Bryan, 2000a). A network of diplomatic relationships between Egypt and other ruling powers in Mesopotamia were formed, including political marriages with foreign princesses (Bryan, 2000; Lilyquist, 2004; Snape, 2014, p48). The 'Great Powers' were Mittani (whose lands encompassed northern Syria and southeast Anatolia), Babylonia (central-southern Mesopotamia), Hatti (Upper Mesopotamia) and Asyria (eastern Mesopotamia): an elite "brotherhood" whose rulers were referred as "Great King" in communications such as the Amarna Letters (see section 1.5.4.1.2, also Table 4 for a chronology of contemporaneous rulers during the Egyptian 18th Dynasty) (Moran, 1992; Mynářová, 2007, p40). Independent and vassal states (for example, in the Levant) were also recognised but were not considered part of the elite brotherhood (Moran, 1992; Cohen and Westbrook, 2000, p6). It should also be noted that the term "Mesopotamia" is used throughout this thesis when referring to the collective LBA Near-Eastern states that made up the lands near the Euphrates and Tigris, including Babylonia and Assyria (Oppenheim, 1977, p35-48).

Egypt had a complicated history of relations with Mittani, who had gone from enemies to diplomatic allies after a peace treaty was formed under Amenhotep II (Bryan, 2000b, p77). Peace was further consolidated when Amenhotep III engaged in a diplomatic marriage with Princess Gilukhepa, daughter of Shuttarna II, King of the Mittani and the sister of Tushratta who succeeded the throne and was a contemporary of Akhenaten (see Table 4) (Bryan, 2000b, p80; Snape, 2014, p48). The Mittani state was overpowered during the invasion of Syria, driven by the Hittite expansion directed by King Šuppiluliumas. It should also be noted that the son of Šuppiluliumas was intended to be married to the widow of Tutankhamun but died enroute, possibly murdered, leading to armed aggression from the Hittite quarter (Moran, 1992, p114-117; Cohen and Westbrook, 2000, p7).

Babylonia was assimilated by the foreign Kassite dynasty at the end of the 16th century but had been on relatively good terms with Egypt, and Assyria, a former vassal state that was now beginning to assert itself as a Great Power. The diplomatic relationship between Egypt and the King of Assyria, Assur-uballit, resulted in some protests from Burraiburiyash, the king of Babylonia. Babylonia eventually made tenuous peace with Assyria following the diplomatic marriage of a daughter and son respectively (Cohen and Westbrook, 2000, p7).

The Levant played a central role as an LBA international communication system in addition to being a strategically important location (Pfälzner, 2012, p770). The established trade routes undertaken by specialist merchants represented an important part of the LBA economy (Sherratt and Sherratt, 1991; Renfrew, 2011, p455-71). The Levant was a suzerainty formed of several independent “city-states” which were frequently subjected to the competing influences of the ‘Great Powers’ of Egypt, Mittani and Hatti in addition to sustaining regular Egyptian military campaigns (Reader, 2003, p349). Political stability between Egypt and Mesopotamia provided the city-states with prosperity and peace with only minor quarrels between Levantine “princes” as detailed in several Amarna Letters (Moran, 1992). Relations between Egypt and Canaan intensified when Tuthmosis III began systematically expatriating the Levantine ruling class to Egypt to condition them to Egyptian society. The intention was to reinstate ‘Egyptianized-Canaanites’ as administrators for the Egyptian state (Ahituv, 1999, p188).

Egyptian chronology (BCE)	Egypt	Approximate Year BCE	Hittite	Mitanni	Assyria	Kassites
1479-1425	Tuthmosis III Hatshepsut (1473 - 1458)	1470	Huzziya II		Ashur-shaduni	
		1460	Muwatalli I	Shaushtatar	Ashur-rabi I	Ulamburiash Kashtiliash III (uncertain) Agum III (uncertain)
		1450			Ashur-nadin-ahhe I	
		1440				
		1430		Parattarna II	Enlil-nasir II	
1427-1400	Amenhotep II	1420	Ḫattušili II	Shaitarna	Ashur-nirari II Ashur-bel-nisheshu	Karaindash
		1410			Ashur-rim-nisheshu	
1400-1390	Tuthmosis IV	1400	Tudḫaliya I	Artatama I	Ashur-nadin-ahhe II	Kadashman-Harbe I
1390-1352	**Amenhotep III**	1390	Arnuwanda I		Eriba-Adad I	Kurigalzu I (uncertain)
		1380	Tudḫaliya II	**Shuttarna II**		Kadashman-Enlil I
		1370	Tudḫaliya III			
		1360	**Šuppiluliumas I**	Artashumara	**Ashur-uballit I**	**Burnaburiash II**
1352-1336	**Akhenaten (Amenhotep IV)**	1350		**Tushratta**		
		1340				
1336-1327	Neferneferuaten			Artatama II		
1336-1327	Tutankhamun	1330	Arnuwanda II	Shuttarna III		Kara-hardash
			Muršili II	Shattiwaza	Enlil-nirari	Nazi-Bugash

Table 4: Chronology of the Egyptian, Hittite, Mittani, Kassite and Assyrian rulers correlating with the Egyptian 18th Dynasty from Tuthmosis III to Tutankhamun. Rulers who are mentioned in this thesis are highlighted in blue (Oppenheim, 1977, p338, 345; Shaw, 2003, p485).

In summary, the relationships between the 'Great Powers' and the Levant were volatile, complex and dynamic. However, the important and formalised convention of diplomatic gift-giving was strictly adhered to (Liverani, 2000).

1.7 The Value of Glass within the LBA Society and Diplomatic Gift-giving

Glass in 18th Dynasty Egypt was one of the most high-status objects in the LBA, only bestowed upon society's elite as indicated by the higher concentration of glass objects present in royal and elite burials, palaces and temples (Nolte, 1968; Oppenheim, 1973; Nicholson and Henderson, 2000, p194). The Hall of Annals in the Temple of Karnak depict the dedication of gifts from Tuthmosis III, believed to be goods claimed from his campaigns in the Near East, or described as "imports" (Hodgkinson *et al.*, 2019). The objects are arranged by order of importance/value, starting with gold and silver, then proceeding with semi-precious stones of turquoise and lapis lazuli depicted as being adjacent to glass, which is followed by bronze and copper. Therefore, this relief confirms that glass is placed among the most valuable tributes (Sherratt and Sherratt, 1991; Shortland, 2001, p214). Where glass is depicted, the royal cartouche appears next to the word for glass: "ḫsbḏ", indicating an exceptional royal interest or connection as no other offering is linked with the royal cartouche (Wreszinski, 1923; Shortland, Nicholson and Jackson, 2001, p151).

The Amarna Letters provide further evidence that glass was considered to be among the most important of gifts given (see section 1.5.4.1.2); glass is the eleventh gift mentioned on letter EA14 before over 50 gifts of gold are listed, indicating that it was a significantly valuable gift. Letter EA14 details the gifts given by the King of Egypt to Burnaburiash II, the Kassite ruler of Karaduniyaš (Moran, 1992, p27-37), and letters from the King of Egypt to the Syria-Palestinian states confirm the increasing royal demand for glass in letters EA 148, 235, 314, 323 and 331 (Moran, 1992, p235, 293, 347, 351, 355). This is notable as glass is the only item in the Amarna Letters for which an entire tablet is dedicated to that single request (all other letters requesting tributes contain demands for several items), indicating that glass is special above all other tributes. Glass was therefore of significant value and exchanged at the highest level between royal courts. Objects such as vessels played an instrumental role in diplomatic gift-giving and bestowed upon preferred members of the court or as tributes to temples (Liverani 2000, p24; Shortland *et al*. 2001, p153).

In addition to its function in royal life, glass was used in some of the most significant archaeological objects found in tombs, such as the gold funerary mask, inlayed with glass, and the glass headrests from the tomb of Tutankhamun (KV62) (Brochat and Rehren, 2017).

1.8 Distribution and trade in the Late Bronze Age

The LBA is renowned as an important period for trade, both raw materials and finished objects. Archaeological evidence for the trade of goods is seen when an object is identified as clearly belonging to a foreign culture. Stirrup jars are a clear example: distinctive pale painted pottery with a "stirrup"-shaped handle that originate from Crete. Stirrup jars have been found throughout the Aegean region but examples have also been found in the Near East and Egypt, thereby representing imports from Crete (Shortland, 2012, p139). These objects expose a direct or indirect exchange between different cultures, in addition to providing evidence of a trade or gift exchange network. These items also provide sequential markers which can be used to reconstruct relative cultural chronologies. The Tomb of the Three Foreign Wives of Tuthmosis III is also an important example of foreign people and goods being transported to Egypt (see section 1.5.4.1.4).

Textual evidence for trade also comes from the Amarna Letters which detail the exchange of many types of gifts, and in great quantities, between the 'Great Powers' including horses, gold, lapis lazuli and servants; this "exchange of gifts" was in effect a "commercial network between courts" (Moran, 1992; Rivero, 2021). The Hall of Annals also details large amounts of items requisitioned from military campaigns and tributes from vassal states (Wreszinski, 1923). It is also likely that glassmakers were 'gifted', loaned or requisitioned as part of the royal gift-exchange (Moorey, 2001, p9).

As discussed, historically items have been provenanced stylistically, however, analytical techniques provide key evidence for trade and transport of goods, specifically methods such as elemental analysis or isotopic techniques to identify and provenance the raw materials or components of an object (Henderson, Evans and Nikita, 2010).

1.8.1 Control and distribution of glass in the LBA

Based on the distribution of glass finds in the proximity of royal residences, it is very likely that the LBA glass industry was the subject of a royal monopoly, and that the production and

distribution of items were strictly controlled by the Egyptian Royal Court (Nolte, 1968; Nicholson, 1995; Shortland, Nicholson and Jackson, 2001, p153). It is often the case that royal patronage develops the arts and it has been argued by Moorey that the elite were central to luxury industries as they possessed the resources required to build and sustain them (Smith, 1981; Moorey, 2001, p4). Glass was highly portable in several forms and was likely distributed according to their value; ingots were exchanged at the highest level between royal courts, objects such as glass vessels were gifted to the elite and smaller items such as beads and small amulets were sold to the general populace (Shortland, Nicholson and Jackson, 2001, p153).

Trace element analysis specifically has been key in establishing a "compositional fingerprint" which differentiates between Egyptian and Mesopotamian glasses. This technique defined by Shortland *et al*. uses the geologically relevant trace elements chromium, lanthanum, titanium and zirconium which has enabled researchers to provenance LBA glasses, some as far as Europe, thereby providing evidence for trade networks (Shortland, Rogers and Eremin, 2007; Walton *et al.*, 2009; Varberg, Gratuze and Kaul, 2015; Varberg *et al.*, 2016).

As discussed in section 1.5.4.4, the Uluburun vessel provides key information about the transport and distribution of glass in the LBA. It has been proposed by Pulak that the cargo aboard the Uluburun vessel specifically represented a royal or elite gift exchange; the cargo showing many parallels with goods discussed in the Amarna Letters (Pulak, 2001, 2008, p299). It is believed that the ship followed the coast anticlockwise to collect goods in a "point-to-point" system (Pulak, 2008, 208-299). It is not known if the transport of glass by sea represented the routine method of distribution, or if the Uluburun vessel, and others like it, were employed at a later stage in LBA glassmaking to support an overall increasing demand and/or supply to a long distance trade industry to the Aegean (Walton *et al.*, 2009; Sherratt, 2016).

An early method to indicate the origin of the ingots recovered from the Uluburun shipwreck was to compare the dimensions of the ingots with crucibles found at Amarna (Nicholson, Jackson and Trott, 1997). Later analysis using LA-ICP-MS by Jackson and Nicholson in 2010 on three of the ingots confirmed that the ingots were Egyptian in origin (Jackson and Nicholson, 2010). Recent analysis by Lankton *et al*. sampled the majority of the ingots (192) which confirmed that all ingots were of Egyptian composition. Further insights from work by Lankton on the ingots recovered from the Uluburun shipwreck show that the majority of the

ingots (90%) were produced in batches of up to at least 16 ingots. Each batch has a high chemical uniformity, substantiating that glass production in Egypt was a highly organised industry which conformed to standardized procedures, capable of producing over 40kg of raw glass per batch (Lankton, Pulak and Gratuze, 2022). The dating of the ship is speculated as sinking shortly after the Amarna period concluded, and both the date and the quantity of glass confirm that the ingots are the products of an organised and large-scale Egyptian glass industry.

In addition to transport by sea, established overland trade routes were widely used throughout the LBA; the advantage of overland transport being that caravans could be monitored by administrators at a series of checkpoints, thereby maintaining control of the consignments (Sherratt, 2016; Huang, 2018). Using the comparative example of the transport of lapis lazuli, three main routes were historically used to connect Mesopotamia to Egypt: two by land and one by sea. The land routes were not exclusive and interlinked creating additional trade networks and were used by both royal executives in addition to some private trade (Huang, 2018). Therefore, it could be suggested that glass may also have followed this transport model, with ingots and vessels being transported by royal caravan or sea directly between courts, and smaller items being distributed along overland networks which evolved over time.

1.9 Structure of the thesis

This thesis takes the paper format structure where each paper has been written by Victoria Kemp as the first author with other authors as detailed. The structure of this thesis follows the preferred PhD thesis format defined in section 2.1 in the Senate Handbook which is the official Cranfield University guidance. The research questions are met within the research papers and are presented under the thesis chapters.

To place this research in context, the first chapter is a literature review which provides a general background which introduces glass as a material by outlining the raw materials such as silica, fluxes and colourants, the general composition, basic structure, and physical properties glasses. This is then refined to glasses of the LBA and describes the specific materials used including the colourants and their sources, and the process by which glasses were manufactured, then worked into objects such as vessels. Understanding the source and elemental characteristics of the raw materials is vital for this thesis as the elements of geologically relevant components remain relatively unchanged when incorporated into the glass, thereby enabling this research to identify and distinguish between sources. Therefore, this information provides the basis for the later research discussions on the archaeometric analysis of LBA and IA glasses and why this is relevant when determining composition type, the colouring strategies used, and identifying the geologically relevant trace elements for determining the provenance.

The literature review then describes the world in which glass was first innovated and developed, introducing the key players and political environment in which glass was established and then describes the archaeological significance of glass as a high-status item, its inherent portability and its role as a crucial part of an international diplomatic gift-giving network and a larger LBA trade network. In summary, the literature review provides a reference guide for the reader to navigate to the key information where required.

Chapters 2 to 7 present the published research undertaken throughout the course of this doctoral research. All papers have been published in peer reviewed journals. A short summary is provided in the section below to introduce the connecting research elements in this thesis (see Table 5 for a summary):

Chapter 2 presents the elemental analysis of blue glass beads from an undisturbed tomb in Gurob, in the southern Faiyum region of Egypt. The beads are dated to between the reigns of

Amenhotep I and Tuthmosis III making this some of the earliest glass manufactured. The glasses analysed from the early context of the New Kingdom cemetery from Gurob dated to between Amenhotep I and Tuthmosis III indicate that glasses made in Mesopotamia were being transported by foreign women likely in connection with the harem palace. It is known that glass was gifted to the King as part of the diplomatic gift-giving protocol, however, this research provides evidence that some early glasses in Egypt were imports from Mesopotamia as personal possessions in the form of jewellery, amulets and vessels, i.e., as finished objects which were transported into Egypt by foreign people of high status.

Chapter 3 builds on the work presented in chapter 2 and discusses the elemental analysis of a scaraboid bead from the same undisturbed context. The provenance of the very early scaraboid glass bead is discussed with a focus on the inhabitants of the tomb and their connection with the Gurob harem palace.

Chapter 4 presents the analysis of polychrome vessel fragments from an early Egyptian royal tomb, KV35, to determine composition and provenance. The fragments are among the first vessels known in Egypt; therefore, this research discusses the archaeological implications for the tomb, the vessels, and the interpretation of early excavation work. The analytical data from this study further indicates that glass fragments from tomb KV35 represent some of the earliest glasses to be manufactured domestically in Ancient Egypt and that Egypt was technologically capable of making several colours using locally sourced raw materials from an early phase in glassmaking history. This is also significant for addressing research question 1 as these glasses pre-date the known archaeological evidence for Egyptian glassmaking sites. Therefore, this paper provides new supporting evidence for an earlier glass industry from at least as early as the reigns of Tuthmosis III and Amenhotep II and potentially a currently undetected glassmaking site in Egypt, the inference being that shortly after the proposed introduction to Egypt, glass was being produced domestically and contemporaneously with imports of glasses from Mesopotamia.

Chapter 5 presents the analysis of a series of rare glass votive offerings from the temple of Hathor at Serabit, Sinai. This research demonstrates how LBA glass compositions develop over approximately 300 years, and how these changes can be used to date glass of unknown provenance. Colourants, specifically cobalt, and stylistic features can be used to provide dating indicators. Consequently, this research establishes that compositional grouping can be used to

date certain colours of unknown glass using analytical data alone or in conjunction with stylistic features, depending on the colourant used. It is clear from the archaeological evidence, specifically from the temple inscriptions, the reports by Petrie and the glass fragments themselves, that significant numbers of glass vessels and items containing inlays were transported to the site of Serabit, likely by royal officials overseeing the mining activities, to be made as offerings to the temple. Therefore, the site of Serabit can be seen as a major consumption site of glass.

Chapter 6 steps outside Egypt to the Ancient Levantine city of Tall Zirā'a and examines glasses through a range of periods, reinforcing the work done in chapter 5 concerning provenance and composition through time and their ability to interpret the dating of stratum and the overall archaeological site. Notably, Tall Zirā'a received glass from both Egypt and Mesopotamia and is thus the second known site to have received foreign glass objects from both 'Great Powers' after the palatial site of Tiryns, Mycenae (at the time of publishing). The presence of Egyptian core-formed vessels establishes that this was an important city with high status, likely indicating that Tall Zirā'a and its resources were key in ensuring successful trading ventures on the route between Egypt and Mesopotamia. The presence of approximately 142 glass fragments recovered from LBA contexts and 287 fragments from IA contexts demonstrates that Tall Zirā'a received significant quantities of glass in many forms (vessels, beads, figurines etc) from both Egypt and Mesopotamia in the LBA, and that the city maintained its affluence and continued to support a thriving trade of luxury goods into the IA. The vessels were likely transported via the same, well established trade route which crossed the Sinai Peninsula, traversed the Levant to Damascus and then arrived in Mesopotamia and the Euphrates. This research confirms that compositional glass grouping and provenance can be used in several ways to provide supporting dating evidence; the analysis not only provided dating evidence for the object itself but also provided supporting evidence for dating the stratum from which they were excavated.

Chapter 7 represents the results of a data exercise using the data from the most important glass vessels of this period from Ancient Egypt described in Nolte's '*Die Glasgefäße im Alten Ägypten'*. It is the first time that this data has been analysed and grouped to examine styles of glass, including typical and atypical features within the LBA, and connected glass production period.

Finally, chapter 8 summarises the conclusions of the previous chapters and discusses the contribution of the research findings to the field of study. Chapter 9 concludes the findings from the research and makes suggestions for further research.

All projects are covered under the ethics approval CURES/16644/2022, the Cranfield University ethics approval scheme.

1.10 Research Questions

The present study focuses on the elemental analysis in conjunction with the archaeological and iconographic evidence to establish new understandings about the earliest glasses to be produced, the development of glass from the 18th Dynasty to the end of the Late Bronze Age as an emerging technology, and its distribution as one of the most valuable and high-status objects in the LBA. It also aims to re-address the role of women in the LBA glass system as a mechanism for the transport of early glasses to Egypt from Mesopotamia.

This research is addressed using four research questions:

Research question 1: Where were the first glasses produced and what does context and analysis tell us about the first glasses?

This thesis demonstrates how the interpretation of elemental analysis of early glasses from significant, strategic sites in Egypt and the Levant provide a more complete understanding of the LBA glass system; compositional analysis provides a wealth of information about where the glasses were produced, the raw materials used, and the colouring strategies. This thesis will discuss how the information can also be used to establish the technological capability of glass producing states at the early stages of glassmaking. This research also discusses how the presence of LBA glasses at specific sites, especially those which provide a firm date for the context, provides significant information about the period of production, the status and function of the site in addition to indicating relationship and trade connections with the glass producing regions. Therefore, this thesis shows how the combination of analytical data in conjunction with the archaeological context, with the consideration of the object itself, establishes new information about these sites and early glasses within the context of the wider LBA glass system.

Research question 2: What is the role of women in the LBA glass system?

Here this thesis examines the role of women in the New Kingdom, specifically within the context of the LBA glass system. Glass beads and a scaraboid bead from an undisturbed tomb in Gurob were analysed to determine the provenance: this thesis discusses how the analytical findings in conjunction with the early date of the tomb provides key information about the transport of glass goods by women. The thesis will further discuss how foreign women of high status, likely in connection with the harem palace, were significant in the transportation, and therefore importation, of the earliest glasses, especially in the setting of diplomatic marriages, which is discussed in this thesis as a likely key factor in the mass transportation of glass objects, gifts and personal possessions.

Research question 3: Can compositional changes in glass from the 18th Dynasty be used for dating?

Here the thesis examines the major, minor and trace element analysis to determine how the composition of LBA glasses can provide dating information to indicate the period of production. Major composition can determine between LBA and IA glasses relatively easily by examining the magnesia and potash contents, which is useful for discriminating between these production periods. This thesis demonstrates how the analyses of LBA glasses from the sites of KV35 in the Valley of the Kings, Serabit in Sinai, and Tall Zirā'a in the Levant were used to identify minor and trace elemental patterns to compare with known compositions and colouring strategies. This thesis also demonstrates how the identification and use of morphological aspects of vessels in conjunction with the compositional data and colouring strategy is crucial for fragment dating.

Research question 4: How was production and transport of glass controlled in Egypt and across the Near East?

This thesis will examine the structure within the Egyptian hierarchy and how the glass production and administration was placed within the royal organisation. This question also discusses why glass appears to have been of singular interest to the 'Great Powers' and how it was controlled and transported as a high-status commodity. This thesis seeks to provide an updated model of the LBA glass system based on the analytical evidence presented in this thesis.

The topics addressed by the four research questions recur through the thesis and are discussed in chapter 8 and chapter 9 in the discussion and conclusion.

Chapter	Paper Title	Research Questions	Citation
2	LA-ICP-MS Analysis of Late Bronze Age Blue Glass Beads from Gurob, Egypt	1, 2, 4	Kemp V, McDonald A, Brock F & Shortland AJ (2020) LA-ICP-MS analysis of late bronze age blue glass beads from Gurob, Egypt, Archaeometry, 62 (1) 42-53.
3	Ancient Biographies: Trace Element Analysis to Investigate Provenance and Transportation Mechanisms of Late Bronze Age Glass.	1, 2, 4	Kemp V, McDonald A & Shortland AJ (2017) Ancient biographies: trace element analysis to investigate provenance and transportation mechanisms of Late Bronze Age glass, Archaeological and Environmental Forensic Science, 1 (2) 161-174.
4	The Investigation and Provenance of Glass Vessel Fragments Attributed to the Tomb of Amenhotep II, KV35, Valley of the Kings.	1, 4	Kemp V, Brownscombe W & Shortland AJ (2022) The investigation and provenance of glass vessel fragments attributed to the tomb of Amenhotep II, KV35, Valley of the Kings, Archaeometry, 64 (1) 147-160.
5	The dating and provenance of glass fragments from the site of Serabit el-Khâdim, Sinai.	3, 4	Kemp V, Delbey T & Shortland A (2023) The dating and provenance of glass fragments from the site of Serabit el-Khâdim, Sinai, Journal of Archaeological Science: Reports, 49 (June) Article No. 103920.

6	Dating and provenance of glass artefacts excavated from the ancient city of Tall Zirāʿa, Jordan.	1, 3, 4	Kemp V, Schmidt K, Brownscombe W, Soennecken K, Vieweger D, Häser J & Shortland A (2020) The dating and provenance of glass artefacts excavated from the ancient city of Tall Zirāʿa, Jordan, Archaeometry, 62 (6) 1164-1181.
7	Identifying and Evaluating Atypical Traits in Ancient Egyptian Glass Vessels attributed to the New Kingdom using Raw Data Analysis and Expert Assessment	1, 3	Kemp V, Rohan R & Shortland A (2021) Identifying and evaluating atypical traits in Ancient Egyptian glass vessels using raw data analysis and expert assessment, Archaeological and Environmental Forensic Science, 2 (1) 1-17.

Table 5: Summary of the chapters and the research questions addressed in each.

2 LA-ICP-MS Analysis of Late Bronze Age Blue Glass Beads from Gurob, Egypt

2.1 Abstract

LA-ICP-MS analysis was undertaken on 37 blue glass beads excavated from a tomb in Gurob, in the Southern Fayum region of Egypt. The tomb was undisturbed, contained the remains of seven females and two children, and dated between the reigns of Amenhotep I (1525-1504 BC) and Tuthmosis III (1479-1425 BC). The glass beads are coloured by copper and the trace element concentrations are compositionally consistent with glasses from Mesopotamia, rather than from Egypt. Therefore, these glass beads represent a rare example of Mesopotamian glass to be discovered in Egypt, in addition to being some of the earliest glass found. Gurob is known to have been the site of a 'harem palace' established in the reign of Tuthmosis III (1479-1425 BC), the implication being that these beads represent luxury items transported into Egypt by high-ranking foreign women, possibly in connection with the harem palace.

2.2 Introduction

The first regular finds of glass appear in the archaeological records of Mesopotamia and Egypt around 1500 BC (Lilyquist *et al*., 1993, p23; Nicholson, 1993, p45-46; Tite & Shortland. 2008, p209), but the exact geographical source of the first glass*making* is still a matter of debate. Excavations have provided supporting physical evidence of glass *making* sites at Qantir and Amarna in Egypt (Lucas and Harris, 1962 p179-194; Jackson and Nicholson, 2007 p13-25; Pusch and Rehren, 2007; Smirniou and Rehren, 2011), and glass*working* at Tell Brak and Nuzi in modern-day Syria and northern Iraq respectively (Henderson, 1998; Shortland *et al.*, 2017). However, the evidence for the manufacture of glass from raw materials is often inferred, particularly in Mesopotamia where poor preservation conditions impact the successful recovery of glass artefacts and no glassmaking site has been confidently identified (Shortland *et al*., 2007; Shortland, 2012, p49). It is very rare to find glass identified as Egyptian in Mesopotamia or vice versa (Walton *et al*., 2009); the sole example being two green glass rods excavated from Amarna in Egypt, trace element analysis of which suggested that the composition was similar to glasses of Mesopotamian origin (Varberg *et al*., 2016).

Glass was an extremely valuable commodity in the Late Bronze Age, the ownership of which was closely controlled by, and limited to, royalty or the elite. Therefore, it played a significant role in the elaborate ritual of gift exchange between Egypt, the Near East and their vassal states (Liverani, 2000, p 24). Contemporary textual evidence for the supply of glass to Egypt appears in the Amarna Letters (EA 148, EA 235, EA 314, EA 323 and EA 331), cuneiform tablets that detail the diplomatic correspondence between Egyptian officials and vassal states during the reigns of Amenhotep III (1391-1353 BC) and Akhenaten (1353-1333 BC) (Moran, 1992; Shortland, 2012 p147; Rehren, 2016) . The text explicitly documents the 'ordering' of glass from the Syria-Palestinian states by the King of Egypt. In addition, the Hall of the Annals in Karnak, dated to the mid-15th Century (Spalinger, 1977) illustrates the apparent import of glass into Egypt from the Levant and Syria, either as spoils of the military campaigns undertaken by Tuthmosis III, or 'gifts' made in tribute by subordinate foreign rulers (Wreszinski, 1923-1940, p50). Physical evidence for the import of glass in this early period has not been found until the results reported in this paper.

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) can be used to quantify geologically significant trace elements in glass, enabling the region of production to potentially be inferred (Shortland *et al*., 2007; Walton *et al*., 2009). Trace elements are introduced during the glass*making* procedure by the addition of raw materials rather than during the glass*working* process, which may have occurred at a different site or another country (Shortland, 2005; Jackson & Nicholson, 2010). These compositional differences have been crucial in distinguishing between glasses manufactured in Egypt and the Near East.

The analysis and provenance of early examples of glass could provide fundamental supporting evidence for the location of primary sites capable of manufacturing glass from raw materials. The subsequent transport of glass and the patterns of exchange would contribute to the understanding of an important emerging technology and the subsequent exchange of its products. A number of mechanisms might be responsible for glass transportation between the two countries: direct diplomatic gifts, personal items brought by royalty, diplomatic parties, others of high status, or even movement of glassworkers. Diplomatic marriages were common in both Egypt and Mesopotamia (Bryan, 2000 p80), and it was customary that the intended bride would be joined by a substantial entourage (Snape, 2014, p48); it can be assumed that glass objects in the form of jewellery were among the personal effects of such elite retinues of women and potentially part of other gifts. Royal harems in Egypt would almost certainly have

included foreign women who were married to the king to secure diplomatic relationships especially with the Hittite and Mitanni nations (Shaw, 2011b). Examples of this include the three 'Foreign Wives' of Tuthmosis III, who may have been residents of the palace at Gurob discussed here, but were buried near Thebes (Lilyquist, 2004, p336). Although little is known of the princesses, they were described as 'Asiatic' women of high status and their tomb contained elaborate headdresses and jewellery inlayed with some of the first glass known, and possibly of foreign, perhaps Mitanni, styles (Feucht 1999, p385). Another later example is the diplomatic marriage between Amenhotep III and Mitanni princess Gilukhepa where it is recorded on a commemorative scarab that she was accompanied by 317 'chief women of the harem' (Snape, 2014, p48). This indicates the size of a palace and the resources required to accommodate multiple royal marriages and associated retinues.

2.3 The Medinet el-Ghurob site

Medinet el-Ghurob, or Gurob, is located in the Faiyum region of Northern Egypt and is of particular interest as it is the site of the only palace identified as a harem (Shaw, 2011b). It has been proposed that the harem palace was established during the reign of Tuthmosis III (1479-1425 BC) with the primary purpose of accommodating royal foreign women who had been married to the King (Hodgkinson, 2017 p188). The palace was situated near the ancient town of Mer-wer and thrived during the reign of Amenhotep III (1390-1352 BC), expanding to provide for larger structures including a fort and a temple, as well as cemeteries and areas of local settlement. The palace itself is a large construction, the enclosure measuring approximately 240x225m, which served as a ceremonial centre as well as having an administrative function (Hodgkinson, 2017 p192). As semi-independent institutions, harems had autonomous economic importance, and therefore significance. The harem palace at Gurob would have also accommodated senior royal wives, lesser wives and concubines in addition to their staff, servants and the harem officials (Kemp, 2006, p288).

In 1920, Brunton and Engelbach excavated the main New Kingdom cemetery at Gurob and discovered three undisturbed tombs at its northernmost point. The three tombs were distinctly separate, located approximately 365 meters from the main concentration of burials and subsequently labelled as Tombs 20, 26 and 27. Tomb 27 was the largest of the three and contained the remains of seven females, two children and their associated grave goods (Brunton and Engelbach, 1927). These goods comprised pottery vessels, one brick-red handled pot, and

a variety of cosmetic items including several kohl pots and a mirror, likely bronze. The smaller finds, including the beads, were scattered by the collapse of the roof and the exact location in the tomb could not be recorded once the tomb was entered. The smaller finds were listed as twenty-nine scarab-like beads, some of which were mounted in silver or gold, and strings of stone and glass beads. The excavators asserted that the three tombs probably belonged to a family group and determined the date by examination of the grave goods as being from the reign of Amenhotep I, but caveated the date by stating that the ceramic vessels were customarily dated slightly later to the reign of Tuthmosis III (Brunton & Engelbach, 1927, p10). It is inferred that the women might have a foreign origin as there is a notable lack of shabtis and canopics in all three of the tombs in the family group, important parts of the Egyptian burial ritual (Ikram, 2015 p129) and other foreign objects are present, for example a spindle bottle. The isolated position of the tomb, the all-female nature of the dead and the "foreignness" speculated on by the excavators all suggest the possibility is that these women were part of the harem and/or its organisation. This study reports the analysis of one of the finds from Tomb 27: a string of blue and clear beads, now in the Hunterian Museum, Glasgow (D.1921.48, Figure 17).

Figure 17: Beads excavated from Tomb 27, Gurob, Egypt in 1920. Bead B1 is lower left and the beads were numbered sequentially anticlockwise to B44 (Hunterian Museum Glasgow, D.1921.48).

2.4 Methodology

D.1921.48 is a string of forty-four beads; beads 1, 2, 9, 15, 24 and 33 are transparent quartz with a partial blue glaze on the surface. This paper reports the analysis of 37 of the remaining 38 beads all of which are made of translucent, blue glass. The single missing bead was bead 28, which fell out of focus during the run; therefore, the results have been omitted from the final reporting. Only 37 beads are therefore discussed in the results.

The beads were ablated directly in the large sample chamber of an ESI New Wave laser ablation system attached to a Thermo X-Series II ICP-MS. The laser ablation settings and ICPMS system were optimised using a series of standards to determine the working conditions used. The laser spot diameter was 80 microns with an energy of 0.42mJ, pulsing at 10Hz. The helium carrier gas flow rate was 500 ml min^{-1} through the laser into an argon stream for the ICPMS. The nebuliser flow rate was 0.6-0.7 L min^{-1}. The spectrometer dwell time was 20ms per mass, and 10 sweeps were averaged. The beads were analysed in three analytical runs, each interposed with gas blank analyses and calibrated against NIST SRM 610 and 612 reference glasses employing the consensus values (Jochum *et al*., 2011). Two measurements of the Corning A standard were carried out in each analytical run, one at the beginning and one at the end and evaluated against the accepted values. Vicenzi and Shortland uses the same sets of values, Wagner slightly different ones (Vicenzi *et al*., 2002; Shortland *et al*., 2007; Wagner *et al*., 2012), see Table 6. The results on the Corning A standard show that the majority of the elements were in good agreement with accepted values; when expressed as a percentage difference between the ascertained and accepted values (RD) the values are typically better than 20%. It should also be noted that the Corning A standard was never intended as an LA-ICP-MS standard, so some trace elements were never intended to be used as standard values. However, agreement in general is good.

Each bead was subjected to three measurements on one spot and the results were averaged. The beads were not cleaned before analysis; however, preablation would remove the very outermost weathering and care was taken to avoid apparent patches of corrosion. Most of the beads are in good condition although some exhibit some surface corrosion mainly in the form of pitting and mottling. During an initial examination of the beads small bubbles in the glass were observed below the surface and were avoided.

	n=6 Corning A, 2 with each analytical run			**Shortland *et al*., 2007/ Vicenzi *et al*., 2002**		**Wagner *et al*., 2012**	
	Average	St dev	prec	ref values	deltawt%	ref values	deltawt%
Li	47	0.8	1.7	46	2.4	51	-7.8
B	548	64.4	11.8	537	2.0	851	-35.6
Na	101387	1050.0	1.0	106083	-4.4	99407	2.0
Mg	16439	242.1	1.5	16043	2.5	15078	9.0
Al	5040	134.0	2.7	5291	-4.8	4339	16.2
Si	316488	1746.3	0.6	310883	1.8	316768	-0.1
K	21031	2022.0	9.6	22639	-7.1	28714	-26.8
Ca	36872	615.8	1.7	35954	2.6	35311	4.4
Ti	4468	286.2	6.4	4226	5.7	4428	0.9
Cr	19	0.7	3.7	17.9	6.2	21	-7.4
Mn	7221	437.1	6.1	6921	4.3	8752	-17.5
Fe	6654	323.0	4.9	6537	1.8	6841	-2.7
Co	1182	128.4	10.9	1188	-0.5	1336	-11.6
Ni	170	6.5	3.8	160	6.3	181	-5.9
Cu	9346	346.9	3.7	7842	19.2	8786	6.4
Zn	502	81.8	16.3	410	22.5	386	30.3
Rb	86.8	2.7	3.1	81.5	6.5	82	5.5
Sr	951	13.9	1.5	860	10.5	897	6.0
Y	0.28	0.0	6.8	n.d.	n.d.	n.d.	n.d.
Zr	44	1.7	4.0	39.9	10.9	37	19.5
Sn	1490	92.4	6.2	1194	24.8	1357	9.8
Sb	14334	1521.6	10.6	10649	34.6	14002	2.4
Ba	4605	175.4	3.8	3905	17.9	4122	11.7
La	0.34	0.0	12.4	0.28	20.7	n.d.	n.d.
Ce	0.27	0.0	9.1	0.24	12.4	n.d.	n.d.
Pb	694	68.1	9.8	595	16.7	678	2.5
Bi	8.6	0.6	7.2	7.8	9.8	9	-4.5
Th	0.30	0.0	6.5	0.30	2.5	n.d.	n.d.
U	0.18	0.0	9.0	0.16	13.5	n.d.	n.d.

Table 6: Average results of the Corning A secondary standards (n = 6), compared to two sets of reference values (Vicenzi *et al*., 2002; Shortland *et al*., 2007; Wagner *et al*., 2012). Values in ppm.

The results were calibrated using the mathematical approach first proposed by Gratuze (1999) as an alternative to the use of an internal standard. The protocol used here was derived from that and follows van Elteren *et al*. (2009). This essentially works in a similar fashion to a normalised EDS system on an SEM. It assumes that all elements are measured and calculates

oxygen by stoichiometry. The total is then normalised to 100% and either presented as weight percent oxide or converted back to elemental ppm (Table 6).

2.5 Results

The data are presented in Table 7.

2.5.1 Major Elements

LA-ICP-MS analysis of the 37 blue glass beads showed that they are a soda lime silicate glass with typically 2-4% K_2O and 5-7% MgO. This major element composition was consistent with a typical LBA, plant ash glass, which have high soda (>15% Na_2O) and significant magnesia (> 3.0% MgO) and potash (>2.0% K_2O). All the beads were coloured by copper, with an average of 1.03 % CuO. Antimony was present only in trace levels (<25ppm Sb), indicating that this was not deliberately added as an opacifier.

2.6 Discussion

All 37 beads appear optically similar in colour however, interesting compositional differences could be observed in the major elements. Figure 18 shows MgO plotted against CaO. Two groups are evident: a low MgO group with MgO content between 5.1% to 5.8%, and a high MgO group with MgO content between 6.2% to 6.9%. The beads in the high MgO group consistently contained the highest concentrations of Na, Li and Cu, and the lowest concentrations of Ti, Y, Mn, Zr. These distinct groupings indicate that the beads were potentially made from two main separate batches of glass, probably from slightly different plant ashes (Figure 18). Two outliers were observed, bead 21 and bead 35; potentially representing other batches. It is rare to be able to analyse all the beds of a necklace. More typically, one or two might be chosen. This is one of the advantages of LA-ICPMS, the very minimal damage caused in sampling allows more objects to be analysed and highlights interesting variations like this.

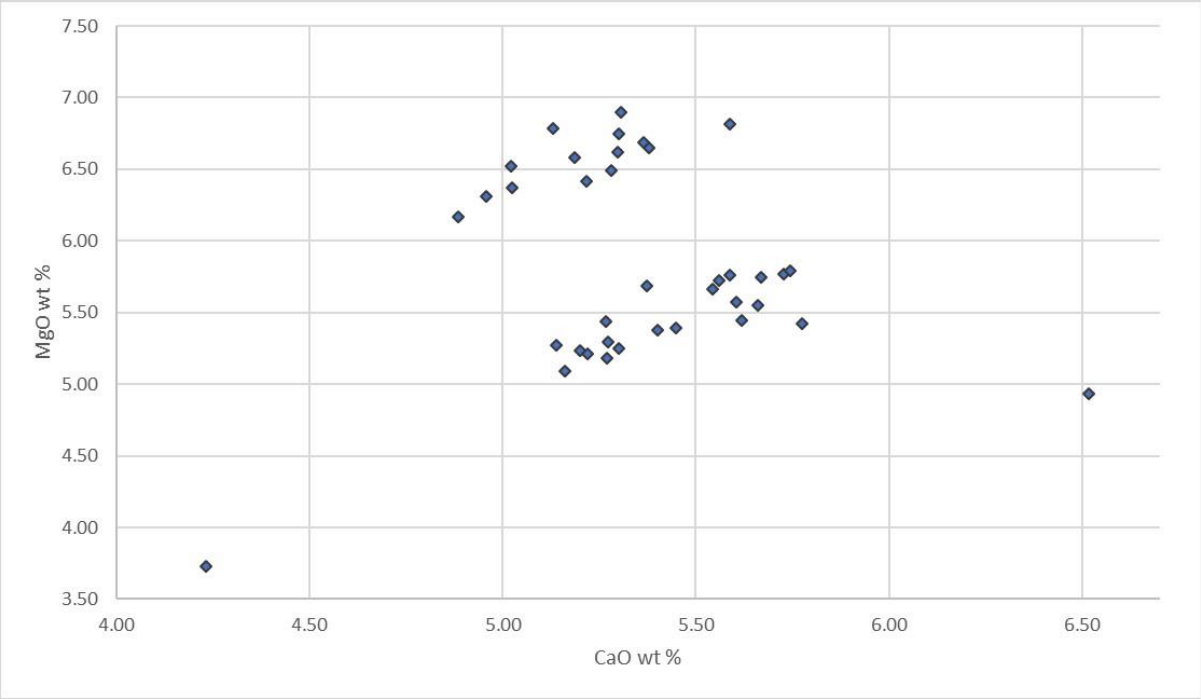


Figure 18: Covariation of MgO with CaO of the blue beads in % indicating two distinct main groups; high and low MgO, with two outliers, potentially representing other batches.

2.6.1 Colourant

Egyptian copper-blue glasses tend to exhibit elevated levels of lead, arsenic and tin (Smirniou *et al*., 2013) which is attributed to the use of bronze as a source of copper for the colourant (Kaczmarczyk *et al*., 1983; Freestone, 1991; Shortland *et al*., 2000). In contrast, Near Eastern glasses tend to have these elements at no higher than trace levels. The beads analysed here contained only trace levels of tin and lead; averaging 17 ppm and 19 ppm respectively, indicating that a purer copper source was used, conforming with the characteristic colourant composition of Near Eastern glasses.

2.6.2 Trace Element Composition

LA-ICP-MS Trace element analysis can provide concentrations of Cr, La, Ti and Zr which form a 'compositional fingerprint' which can be used to distinguish between LBA glasses of unknown sources (Shortland *et al*., 2007). Egyptian glasses exhibit a relatively low Cr/La ratio with a higher, more variable Zr/Ti ratio. Conversely, glasses originating from Mesopotamia exhibit lower, but consistent, Zr/Ti ratios, and higher, more variable Cr/La ratios, Mesopotamian glasses being relatively rich in Cr.

The LA-ICP-MS trace element data (Table 7) shows that the glass beads contained relatively high concentrations of Cr; between 18.7 ppm to 54.2 ppm, with an average of 31 ppm, and lower concentrations of La (1.5 ppm to 3.1 ppm averaging 2.4 ppm). This data was plotted against the trace element values obtained from the LA-ICP-MS analysis of glasses from known Egyptian and Mesopotamian origin (Shortland *et al*., 2007; Walton *et al*., 2009), and illustrated in Figure 19. The beads show a positive correlation with the Mesopotamian glasses, but it was observed that they have an overall higher average Cr concentration than the Mesopotamian glasses analysed in the Shortland (2007) and Walton (2009) studies.

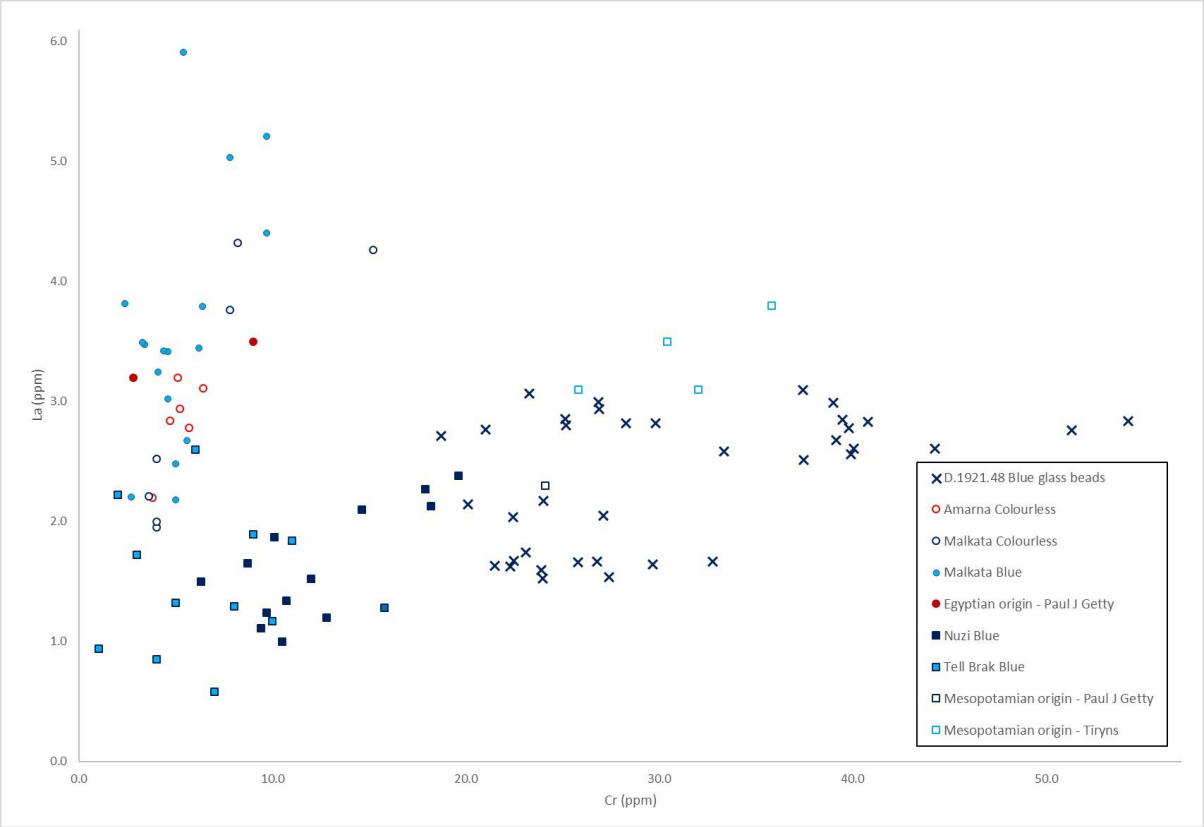


Figure 19: Covariation of La with Cr in the blue beads of unknown origin compared with Egyptian and Mesopotamian blue and colourless glasses of known origin (Shortland *et al*., 2007; Walton *et al*., 2009).

The Ti concentration of the beads ranged from 164 ppm to 452 ppm with an average of 274 ppm; the Zr concentration ranged from 7.0 ppm to 19.2 ppm with an average of 13 ppm. When plotted with the glasses of known origin, the trace element data from the beads are consistent with the composition of the Mesopotamian glasses, illustrated in Figure 20. Trace element compositions therefore strongly suggest that the beads are compositionally consistent with Near Eastern glasses and distinct from almost all the glass previously recovered and analysed from Egypt. They are also early, some of the earliest glass known in Egypt, which has

implications for the study of where the first glass might have originated (see Shortland *et al.,* 2017 for a summary). Traditionally it has been assumed that glass originated in the Near East and this early Near Eastern glass in Egypt tends to support that. However, it is clear that there is glass nearly this early as this in Egypt, so it is far from clear which has priority (Shortland *et al.,* 2017).

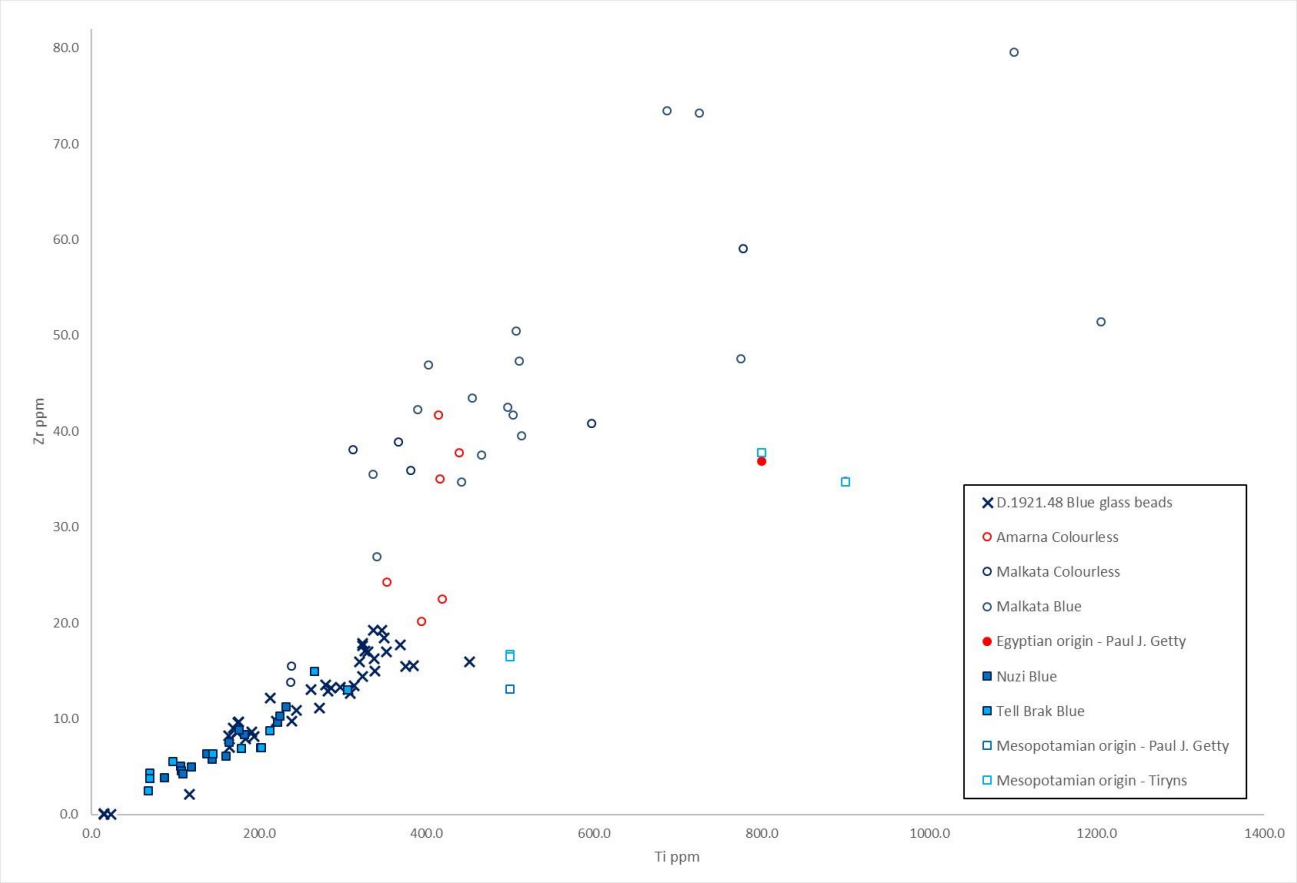


Figure 20: Covariation of Zr with Ti in the blue beads of unknown origin compared with Egyptian and Mesopotamian blue and colourless glasses of known origin (Shortland *et al*., 2007; Walton *et al*., 2009).

Bead	Na^2O	MgO	Al^2O^3	SiO^2	K^2O	CaO	Fe^2O^3	CuO	Li	B	Ti	Cr	Mn	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Sn	Sb	Ba	La	Ce	Pb	Bi	Th	U
B3	16.6	5.2	1.0	68.0	2.3	5.2	0.6	1.0	17	136	269	33	254	18	12	7658	20	10	342	2.6	11.0	3.6	1.7	62	2.2	7.5	9	0.2	0.6	0.2
B4	17.2	5.6	1.0	65.6	3.0	5.6	0.7	0.9	21	122	385	37	303	16	16	7422	38	17	421	2.7	15.5	11.8	10.9	49	2.5	5.3	21	0.2	0.7	0.3
B5	13.2	6.7	0.5	69.5	3.3	5.0	0.3	1.2	31	111	161	27	224	14	12	9212	18	21	356	1.6	6.9	1.1	3.4	29	1.3	3.4	10	0.1	0.3	0.1
B6	16.9	5.6	1.0	66.3	3.0	5.5	0.6	0.9	21	151	331	40	274	13	15	6965	24	17	420	2.5	14.8	6.1	6.4	50	2.2	5.4	8	0.1	0.6	0.2
B7	18.0	6.7	0.5	64.0	3.6	5.4	0.3	1.2	38	84	170	30	247	18	12	9569	20	15	373	1.9	9.0	1.1	3.6	27	1.6	3.3	10	0.1	0.4	0.1
B8	18.2	6.2	0.7	65.2	3.1	4.9	0.4	1.0	24	167	233	20	246	19	13	7798	19	17	392	2.1	9.6	1.6	0.7	37	1.8	4.0	5	0.1	0.4	0.2
B10	18.3	6.6	0.6	64.3	3.3	5.3	0.3	1.1	37	111	169	22	218	14	12	8535	38	15	360	1.8	8.4	7.1	5.5	112	1.4	3.2	14	0.2	0.4	0.1
B11	18.8	6.7	0.8	62.9	3.4	5.5	0.4	1.0	29	193	255	27	237	16	13	7878	47	14	459	2.4	12.8	4.4	6.1	37	1.7	3.7	25	0.2	0.5	0.2
B12	18.5	6.4	0.5	63.9	3.5	5.2	0.4	1.2	39	88	192	21	254	17	13	9428	35	17	361	1.8	8.6	3.5	20.2	28	1.6	3.4	36	0.1	0.4	0.1
B13	16.9	5.7	1.1	66.3	2.7	5.7	0.6	0.8	21	159	323	39	270	13	14	6648	21	16	434	2.8	16.8	50.3	6.4	50	2.3	5.3	10	0.1	0.6	0.2
B14	16.3	5.3	1.1	68.0	2.0	5.4	0.6	0.9	17	139	275	28	248	17	11	7393	18	8	361	3.2	13.4	9.4	0.5	62	2.4	5.2	5	0.2	0.7	0.2
B16	18.8	6.9	0.6	63.9	2.8	5.3	0.3	1.0	40	106	186	25	213	13	12	8212	28	15	353	1.8	7.9	6.0	4.1	24	1.3	3.9	11	0.2	0.3	0.1
B17	15.5	5.4	1.3	68.1	2.1	5.6	0.6	0.9	16	139	309	27	248	17	16	7064	41	8	363	3.2	13.4	4.0	4.6	66	2.5	6.1	27	0.2	0.7	0.2
B18	16.8	5.5	1.1	67.5	1.9	5.4	0.6	0.9	19	137	315	22	242	18	11	6979	19	10	365	3.2	12.8	2.8	1.2	65	2.3	5.4	8	0.3	0.7	0.2
B19	16.7	5.7	1.1	66.4	2.7	5.7	0.6	0.8	21	143	321	41	274	13	15	6677	32	17	448	2.9	16.9	29.6	10.5	54	2.4	5.5	36	0.2	0.6	0.2
B20	17.7	5.8	1.1	65.8	2.3	5.5	0.6	0.9	23	151	344	45	276	13	15	6897	30	16	416	2.8	16.5	47.3	6.8	45	2.2	5.3	21	0.2	0.6	0.2
B21	18.1	4.8	0.8	64.2	3.8	6.4	0.4	1.1	16	111	239	24	227	9	15	8428	35	11	417	2.1	10.6	50.6	4.3	37	1.8	4.1	19	0.1	0.5	0.2
B22	17.8	6.2	0.5	64.7	3.5	4.9	0.4	1.6	38	84	221	24	248	18	13	12788	97	15	337	1.6	9.7	25.2	6.8	27	1.5	3.5	37	0.5	0.4	0.2
B23	15.8	5.2	1.0	68.2	2.5	5.3	0.7	1.0	17	106	283	25	280	21	12	7739	31	12	353	3.0	12.9	2.3	1.0	82	2.9	5.5	8	0.2	0.8	0.2
B25	18.1	6.4	0.5	64.5	3.6	5.0	0.3	1.2	39	79	164	27	246	17	13	9515	41	16	356	1.8	8.2	84.8	4.5	31	1.7	3.5	15	0.2	0.4	0.2

B26	17.0	5.3	1.0	66.6	2.9	5.3	0.6	0.9	21	120	320	40	305	17	16	7502	74	16	410	2.7	15.9	8.9	9.1	50	2.6	5.4	15	0.3	0.7	0.3
B27	16.3	5.1	1.0	67.9	2.5	5.2	0.7	1.0	17	104	286	30	286	22	13	7958	28	9	349	2.9	13.2	19.1	3.0	69	2.8	5.7	12	0.2	0.9	0.3
B29	16.4	5.4	1.0	66.8	3.0	5.5	0.6	0.9	22	111	353	51	297	16	15	7371	26	18	421	2.8	17.0	10.1	8.5	54	2.8	5.6	8	0.2	0.7	0.3
B30	18.1	6.6	0.5	65.1	2.9	5.1	0.3	1.1	40	99	178	26	216	14	12	8567	25	15	347	1.8	9.7	15.3	3.4	24	1.4	4.9	10	0.1	0.3	0.1
B31	16.7	5.6	1.1	66.3	2.8	5.7	0.6	0.9	21	111	337	39	306	16	15	7111	36	17	454	3.2	19.2	12.3	12.9	55	3.0	5.9	14	0.2	0.8	0.3
B32	16.8	5.7	1.1	66.5	2.6	5.5	0.6	0.8	22	140	319	40	265	13	14	6619	113	15	435	3.0	17.4	22.2	9.2	52	2.4	5.6	37	0.2	0.6	0.2
B34	17.8	6.4	0.5	65.0	3.3	5.2	0.3	1.1	38	95	170	23	221	14	12	9075	87	18	368	1.8	8.5	9.1	7.8	29	1.5	3.7	16	1.0	0.3	0.1
B35	15.9	3.7	1.4	69.5	2.9	4.2	0.8	1.1	17	64	451	19	174	4	19	8647	29	25	224	3.2	15.9	16.0	13.5	47	2.7	5.4	62	1.0	0.8	0.3
B36	16.4	5.4	1.2	66.0	2.9	5.8	0.7	1.0	21	111	346	37	303	16	16	7622	79	17	451	3.2	19.2	12.8	11.8	59	3.1	6.1	37	1.3	0.8	0.3
B37	15.9	5.2	1.0	68.5	2.2	5.3	0.7	0.8	17	121	318	24	246	17	11	7102	37	9	367	3.2	14.3	17.1	4.9	77	2.6	5.8	20	0.3	0.7	0.2
B38	18.4	6.6	0.7	64.0	3.3	5.2	0.4	0.9	33	168	208	23	230	16	13	7537	50	14	433	2.3	11.9	11.1	5.5	34	1.7	3.8	20	0.1	0.5	0.2
B39	18.0	6.7	0.6	64.9	2.8	5.3	0.3	1.1	41	99	197	33	218	14	11	8729	24	19	369	1.9	8.2	3.3	5.0	28	1.4	3.5	14	0.1	0.3	0.1
B40	16.8	5.8	1.1	66.2	2.4	5.8	0.6	0.8	22	140	357	55	274	13	14	6607	32	18	456	3.1	18.8	4.8	9.2	48	2.4	5.7	10	0.1	0.6	0.2
B41	16.2	5.4	1.1	68.5	1.8	5.2	0.6	0.9	18	130	304	25	246	17	12	7072	22	8	352	3.1	13.5	2.6	2.2	57	2.3	5.6	9	0.1	0.7	0.2
B42	18.0	6.6	0.5	65.1	2.8	5.2	0.3	1.1	40	96	177	23	215	14	11	8454	19	15	363	1.8	9.7	3.9	3.4	26	1.4	3.5	12	0.1	0.3	0.1
B43	16.7	5.7	1.0	66.5	2.8	5.5	0.6	0.9	21	137	317	40	269	13	15	6808	32	17	446	2.9	17.6	18.4	7.0	52	2.3	5.5	9	0.1	1.0	0.2
B44	16.1	5.3	1.1	68.3	2.0	5.3	0.6	0.9	18	125	312	27	247	17	11	7191	20	10	356	3.1	13.2	20.0	1.1	59	2.4	5.8	11	0.1	1.0	0.2

Table 7: Results of LA-ICP-MS analyses of the blue beads (Oxides in percent oxide; trace elements in ppm).

2.7 Conclusion

The 37 blue glass beads analysed by LA-ICP-MS in this study have trace element compositions consistent with glass manufactured in Mesopotamia, therefore represent the only confirmed finished object of Mesopotamian glass to be discovered in Egypt. The major element composition is consistent with that of standard Late Bronze Age plant ash glass but potentially represents two main compositional groups; a low MgO group and a high MgO group, suggesting that these beads were manufactured from two different batches of glass. A pure form of copper was used as a blue colourant, as opposed to a bronze source which was typically the practice in LBA Egyptian glass technology. The beads were excavated from a previously undisturbed tomb, which contained the remains of seven women and two children. The tomb, and therefore the beads were dated from between the reign of Amenhotep I (1525-1504 BC) and Tuthmosis III (1479-1425 BC) and are therefore some of the earliest glasses identified. The excavators implied that the women were foreign by the manner of the burial and from the associated grave goods and context (Brunton & Engelbach, 1927, p10). The beads found in the tomb are certainly consistent with glass from the Near East. Evidence from the analysis of the beads should be considered alongside the isolated location of the "higher status" brick constructed tomb, which contained only females and children. The nearby harem palace may be the origin of these individuals, and it would be consistent with the evidence if the beads were brought to the among the personal effects transported into Egypt from Mesopotamia by women of status in connection with that palace.

2.8 References

Aruz, J., Benzel, K. and Evans, J. M. (eds) (2008) Beyond Babylon: art, trade, and diplomacy in the second millennium B.C. New York: Yale University Press (Metropolitan Museum of Art).

Brunton, G. and Engelbach, R. (1927) British School of Archaeology in Egypt and Egyptian Research Account, Twenty Fourth Year, 1918 - Gurob. London: British School of Archaeology in Egypt.

Bryan, B. M. (2000) 'The Egyptian Perspective on Mittani', in Cohen, R. and Westbrook, R. (eds) Amarna Relations: The Beginnings of International Relations. Baltimore: Johns Hopkins University Press, pp. 71–84.

van Elteren, J. T., Tennent, N. H. and Šelih, V. S. (2009) 'Multi-element quantification of ancient/historic glasses by laser ablation inductively coupled plasma mass spectrometry using sum normalization calibration', Analytica Chimica Acta, 644(1–2), pp. 1–9.

Feucht, E. (1999) 'Jewelry', in Bard, K. (ed.) Encyclopedia of the Archaeology of Ancient Egypt. Oxford: Routledge, pp. 385–387.

Freestone, I. C. (1991) 'Looking into Glass', in Bowman, S. (ed.) Science and the Past. London: British Museum Press, pp. 37–56.

Henderson, J. (1998) 'Scientific analysis of glass and glaze from Tell Brak and its archaeological implications', in Oates, D., Oates, J., and McDonald, H. (eds) Excavations at Tell Brak, Volume 1: The Mitanni and Old Babylonian periods. Cambridge: McDonald Institute Monographs, pp. 94–98.

Hodgkinson, A. K. (2017) Technology and Urbanism in Late Bronze Age Egypt (Oxford Studies in Egyptian Archaeology). Oxford: OUP Oxford.

Ikram, S. (2015) Death and Burial in Ancient Egypt. American University in Cairo Press (American University in Cairo Press Series).

Jackson, C. M. and Nicholson, P. T. (2007) Brilliant things for Akhenaten: The Production of Glass, Vitreous Materials and Pottery at Amarna Site O45.1. Edited by P. T. Nicholson. London: Egypt Exploration Society.

Jackson, C. M. and Nicholson, P. T. (2010) 'The provenance of some ingots from the Uluburun shipwreck', Journal of Archaeological Science, 37(2), pp. 295–301.

Jochum, K. P. *et al*. (2011) 'Determination of reference values for NIST SRM 610-617 glasses following ISO guidelines', Geostandards and Geoanalytical Research, 35(4), pp. 397–429.

Kaczmarczyk, A. and Hedges, R. E. M. (1983) Ancient Egyptian faience: an analytical survey of Egyptian faience from predynastic to Roman times. Warminster: Aris and Phillips.

Kemp, B. J. (2006) Ancient Egypt: Anatomy of a civilization. 2nd edn. London: Routledge.

Lilyquist, C. *et al*. (1993) 'Part 2. Glass', in Lilyquist, C. and Brill, R. H. (eds) Studies in Ancient Egyptian Glass. New York: Metropolitan Museum of Art, pp. 23–58.

Lilyquist, C. (2004) The Tomb of Three Foreign Wives of Tuthmosis III. New York: Yale University Press.

Liverani, M. (2000) 'The Great Powers' Club', in Cohen, R. and Westbrook, R. (eds) Amarna Relations: The Beginnings of International Relations. Baltimore, pp. 15–27.

Lucas, A. and Harris, J. R. (1962) Ancient Egyptian Materials and Industries. 3rd edn. London: Edward Arnold & Co.

Moran, W. L. (1992) The Amarna Letters. Baltimore: The Johns Hopkins Press.

Nicholson, P. T. (1993) Ancient Egyptian Faience and Glass. London: Shire Egyptology.

Pusch, E. and Rehren, Th. (2007) Rubinglass für den Pharao: Hochtemperatur-Technologie in der Ramses-Stadt. Hildesheim: Gerstenburg.

Shaw, I. (2011) 'Seeking the Ramesside royal harem: new fieldwork at Medinet el-Gurob', in Collier, M. and Snape, S. (eds) Ramesside Studies in Honour of Ken Kitchen. Bolton: Rutherford Press, pp. 453–63.

Shortland, A. J. (2005) 'The raw materials of early glasses: the implications of new LA-ICPMS analyses', in Cool, H. (ed.) Proceedings of the16th International Congress of the Association Internationale pour l'Histoire du Verre, London 2003. London.

Shortland, A. J. (2012) Lapis Lazuli from the Kiln : Glass and Glassmaking in the Late Bronze Age. Leuven: Leuven University Press.

Shortland, A. J. *et al*. (2017) 'The analysis of Late Bronze Age glass from Nuzi and the question of the origin of glassmaking', Archaeometry.

Shortland, A. J., Rogers, N. and Eremin, K. (2007) 'Trace element discriminants between Egyptian and Mesopotamian Late Bronze Age glasses', Journal of Archaeological Science, 34(5), pp. 781–789.

Shortland, A. J. and Tite, M. S. (2000) 'Raw materials of glass from Amarna and implications for the origins of Egyptian glass', Archaeometry, 42(1), pp. 141–153.

Smirniou, M. and Rehren, Th. (2011) 'Direct evidence of primary glass production in Late Bronze Age Amarna, Egypt', Archaeometry, 53(1), pp. 58–80.

Smirniou, M. and Rehren, Th. (2013) ‘Shades of blue - cobalt-copper coloured blue glass from New Kingdom Egypt and the Mycenaean world: A matter of production or colourant source?’, Journal of Archaeological Science, 40, pp. 4731–4743.

Snape, S. (2014) The Complete Cities of Ancient Egypt. London: Thames and Hudson Ltd.

Spalinger, A. (1977) ‘A Critical Analysis of the “Annals” of Thutmose III (Stücke V-VI)’, Journal of the American Research Center in Egypt. American Research Center in Egypt, 14, pp. 41–54.

Rehren, Th (2016) ‘Another order for glass – or: how much glass does Pharaoh need?’

Tite, M. S. and Shortland, A. J. (2008) Production Technology of Faience and Related Early Vitreous Materials. Oxford: Oxford University School of Archaeology (Monograph (Oxford University School of Archaeology)).

Varberg, J. *et al*. (2016) ‘Mesopotamian glass from Late Bronze Age Egypt, Romania, Germany, and Denmark’, Journal of Archaeological Science, 74, pp. 184–194.

Vicenzi, E P *et al*. (2002) ‘Microbeam characterisation of Corning archaeological reference glasses: new additions to the Smithsonian Microbeam standard collection’, Journal of Research of the National Institute Standards and Technology, 107, pp. 719–727.

Wagner, B. *et al*. (2012) ‘Critical assessment of the elemental composition of Corning archaeological reference glasses by LA-ICP-MS’, Analytical and Bioanalytical Chemistry, 402(4), pp. 1667–1677.

Walton, M. *et al*. (2009) ‘Evidence for the trade of Mesopotamian and Egyptian glass to Mycenaean Greece’, Journal of Archaeological Science, 36, pp. 1496–1503.

Walton, M. S. *et al*. (2009) ‘Evidence for the trade of Mesopotamian and Egyptian glass to Mycenaean Greece’, Journal of Archaeological Science, 36, pp. 1496–1503.

Wreszinski, W. (1923) Atlas zur altaegyptischen Kulturgeschichte. Leipzig: J.C. Hinrichs.

3 Ancient Biographies: Trace Element Analysis to Investigate Provenance and Transportation Mechanisms of Late Bronze Age Glass.

3.1 Abstract

LA-ICPMS analysis was carried out on a scaraboid blue glass bead (Hunterian Museum Glasgow, D.1921.39) excavated from Tomb 27 in Gurob, in the Southern Fayum region of Egypt. Gurob is known to have been the site of a "harem palace" established in the reign of Tuthmosis III (1479–1425 BC). The tomb was located at the northernmost point of the New Kingdom cemetery and was undisturbed, containing the remains of seven females and two children, and was dated by the excavators to between the reigns of Amenhotep I (1525–1504 BC) and Tuthmosis III. The glass scarab was coloured by copper and trace element values of La, Cr, Ti and Zr exhibited compositional consistency with glasses from Mesopotamia, rather than from Egypt. Therefore, the glass scarab represents a rare example of Mesopotamian glass to be discovered in Egypt, in addition to being some of the earliest glass found. The finds support iconographic references in the Hall of the Annals at Karnak to the import of early glass into Egypt. The implication is that these beads represent luxury items transported into Egypt by high-ranking foreign women perhaps in connection with the Gurob harem palace.

3.2 Introduction

The theory and practice of both forensic science and archaeology are based on the same underlying principles: both disciplines use standard operating practices, developed over years of best practice, to collect, preserve and examine physical evidence to support scientific propositions, which in turn substantiate facts.

Forensic science and archaeology are correlative and often overlap, not only using similar methodologies but also employing the same analytical techniques which find practical applications in both modern crime investigations and ancient contexts. Although forensic science is concerned primarily with obtaining results for presentation in a court of law, archaeology also relies on the same incontestable recovery and analysis of evidence. The results obtained from archaeological analyses are considered to establish new hypotheses or

support existing theories, which can significantly alter the understanding of historical events, cultures or a specific individual.

Fundamentally, the application of forensic science and archaeology is to examine associated objects to construct a factual narrative of events. This paper examines a glass scarab found in an undisturbed tomb dated to the early New Kingdom era. The trace element analysis undertaken on the scarab provides provenance data, contributing to the biography of the women in connection with a harem palace in Ancient Egypt.

3.3 The resource of grave goods

The provision of grave goods was fundamental in ancient Egyptian funerary practices, and protocol dictated that the deceased be interred with items they used in everyday life, in addition to amuletic objects that would protect the dead, allowing them to continue their existence in the afterlife (Piccione 1999, p841). Burials of the poor would include a few modest belongings, whereas the tombs of the elite would contain prestige items, such as gold jewellery and cosmetics. The quantity and quality of grave goods were directly determined by the material wealth and social importance of the individual, with most items specially made for an individual post-mortem.

When placed in the context of an extensive cemetery, patterns of social stratification can be identified and applied regarding the town, city and area. Jewellery specifically played a significant role in Egyptian life and death; ceremonial jewellery and amulets were purposefully manufactured for the deceased once they had died; these items were placed on the body, within the linen wrappings, as well as in the tomb. It is acknowledged that only a fraction of funerary jewellery remains from the quantity initially produced in the Dynastic period (Aldred 1971, p14). In modern archaeology, grave goods are one of the most critical and common sources of evidence which allow both scientists and archaeologist to establish facts about the culture and society of a group, as well as evidence of the technological capabilities of the era.

The arid environment in Egypt has in many cases allowed both grave goods and human remains to remain remarkably preserved, however the frequent tomb robberies, both in antiquity and relatively recently, has meant that critical information about the Egyptian ‘mortuary cult’ has been lost or destroyed. Before Egyptology and archaeology employed standard operating procedures for recording and excavating, artefacts were removed from affluent burials and

distributed between sponsors and museums, with few records made of the context. These pieces when removed from their original location immediately lose vital information, specifically the contextual meaning and evidential weight; many artefacts also sustain damage due to the clandestine manner of the removal. The discovery of the tomb of Tutankhamun in 1922 was a significant landmark because, for the first time, the relatively undisturbed tomb provided a complete picture of how a king of Egypt was buried. Tutankhamun was not a notable potentate in his lifetime, yet the find revealed the variety and wealth of grave goods that were afforded to a minor ruler. The opportunity enabled Howard Carter to make a meticulous survey of the burial, and the grave goods in context, as well as taking a photographic record over the eight years required to clear the tomb.

The excavators of a small, but significant Egyptian site, Medinet el-Ghurob, or Gurob, in the Southern Faiyum region of Northern Egypt, also employed a more structured approach to earlier excavations in 1918-1920. The work carried out by Brunton and Engelbach was more comprehensively documented than previous investigations, comprising of a plan of the area and town, descriptions of the excavated graves and tombs, as well as lists and diagrams of the items recovered. Most of the smaller or seemingly less valuable items were removed from site and archived in museum legacy collections. In conjunction with the archaeological reports and historical data, the application of more developed analytical techniques to ostensibly less prestigious artefacts from legacy collections can provide new information about domestic technological capability, foreign migration and the transport of luxury items. In the case of Gurob, specifically by foreign women of high status who were resident at the harem palace.

3.4 Foreign women in Egypt

Diplomatic marriages were customary in ancient Egypt and Tuthmosis III (1479-1425 BC), like other Kings of Egypt, entered into several unions with foreign women of high status to cement advantageous relations and political stability with other states (Shaw 2011b; Kemp 1989, p 293). A tomb discovered in 1916 by local villagers in Wadi Qurud (a remote valley southwest of the Valley of the Kings, near modern Luxor) which contained the remains of three women also provides contemporary archaeological evidence of three diplomatic marriages made by Tuthmosis III during his reign. Although the walls of the chamber were undecorated, hieroglyphs on the canopic jars and other grave goods revealed that the tomb was constructed for three ‘Asiatic’ women of high status, who were married to Tuthmosis III (Lilyquist, 2004,

p47). The names of the women: “Manuwai”, “Manhata” and “Maruta” were determined as being West Semitic in origin (Lilyquist 2004, p.333), although the tomb and its grave goods provide the only tangible information on the archaeological record about the three women. It is not known precisely which country they were from, or if they were related. The coffins and remains of the women were in an extremely advanced stage of decomposition due to flood water entering the tomb; therefore, the bodies themselves could not be examined. The tomb was dated to approximately 1450 BC, during the joint reigns of Hatshepsut and Tuthmosis III, which predates the death of Tuthmosis III by approximately 25 years (Lilyquist 2004, p 333). Although considered to be lesser wives of Tuthmosis III, the tomb contained a quantity of glass grave goods including jewellery, bracelets, headdresses and vessels. This collection of royal grave goods is an example of early New Kingdom glass jewellery related to foreign women of high status, potentially from both Egypt and Mesopotamia. The tomb contained a lotiform chalice (Accession Number: 23.9, Metropolitan Museum of Art) bearing the name of Tuthmosis III, which is recognised as stylistically Egyptian (Lilyquist & Brill 1993, p.62). The goldwork was also considered to be primarily Egyptian, apart from the granulated gold beads (Lilyquist 2004, p185). Other pieces in the tomb, however, showed a strong influence from Mitanni design: A wig covering, comprising of gold rosettes, described as the ‘Great Headdress’ (Metropolitan Museum of Art, New York, Accession Number: 26.8.117), is attributed to Near Eastern technique and style. The gazelle diadem (Metropolitan Museum of Art, New York, Accession Number: 26.8.99) also shows strong foreign influence (Feucht 1999, p 385).

Lilyquist proposed that the most likely residence for the three foreign wives of Tuthmosis III would have been at the harem palace at Gurob. Gurob was recurrently inhabited from the pre-dynastic era (circa 3000 BC). However, it was during the 18th Dynasty that the site gained real significance, with a temple and a ‘harem palace’ being established during the reign of Tuthmosis III (Shaw, 2011b). Harems played an essential function in ancient Egypt: the palaces provided accommodation for female members of the royal family, including widows of former kings and lesser wives of the incumbent ruler (Kemp 1989, p288).

3.5 Archaeological excavations at Gurob

Flinders Petrie initiated work at Gurob between 1888-1890, but only preliminary excavations were achieved. The second season of excavations at Gurob was left in the hands of a volunteer,

Hughes-Hughes while Petrie devoted his time to the nearby sites of Illahun and Kahun. Hughes-Hughes had little formal archaeology training or surveying experience, and few records of the excavation were completed. A brief plan of the area was drawn when Petrie returned at the end of the second season to finalise the work (Petrie 1891, p15). Currelly and Loat undertook subsequent excavations in 1904, and a brief investigation by Ludwig Borchardt was completed in 1905. Brunton and Engelbach initiated excavations in 1920 but noted that progress was impeded by the lack of records produced by the previous excavators, particularly when opening graves that had already been cleared (Brunton & Engelbach 1927, p 1).

The excavations undertaken by Brunton and Engelbach focused on the remains of the temple and surrounding cemeteries. The main cemetery contained individuals of lower or middle status and the burials were classified by era, ranging from the 0-1st dynasty to burials from the 19th dynasty (Brunton and Engelbach, 1927, fig. 1). Brunton and Engelbach also surveyed 500 New Kingdom shaft tombs belonging to officials and high-status individuals; this included the tomb of Pi-Ramessu who may have been the son of Seti I.

At the northernmost point of the main cemetery site, point Q, three tombs were discovered in an isolated group; Tombs 20, 26 and 27. The three undisturbed tombs were similar in construction and design, being brick lined with arched roofs and plastered walls (Brunton, G. Engelbach 1927, p10.). The excavators also commented that it was likely that the three tombs belonged to a family group. Tomb 27 was the largest of the three tombs and contained the remains of seven females and two children with associated grave goods. Although larger objects were recorded in situ by Brunton and Engelbach in a scaled plan (Brunton, G. Engelbach 1927, plate XX), the positions of the small objects were not recorded in the publication due to the displacement caused by the accidental collapse of the roof during excavations.

3.6 Evidence of Foreign Occupation at Gurob

Although there is evidence stating that large numbers of foreign women of high status were forcibly transported to Egypt following one of the first campaigns of Tuthmosis III, conclusive evidence for foreign occupation of high-ranking women specifically at Gurob during the reign of Tuthmosis III is limited. The seventh pylon from the temple at Karnak describes the capture and deportation of that the wives and children of the King of Qadesh, and of other Syrian leaders, by the King of Egypt, who were given as servants (Sethe 1907, p185) and subsequently

disappear from the archaeological records. Other textual evidence comes from the Gurob Papyri, discovered by Petrie between 1889 and 1890; Papyrus UCL 32795 states that foreign wives were in residence at the palace in the Ramesside era. It was proposed that foreigners were resident on the site, most likely in connection with the harem (Petrie 1891, p16; Bard 1999, p361).

In the excavation records, Petrie claimed that there were ‘light haired bodies' in the Gurob cemetery and noted the discovery of a custom, previously unseen in ancient Egypt; the burning and deposition of valuable possessions in pits, under the floor of a residence, none of which appeared to contain human remains. Petrie attributed this custom to foreign residents at Gurob (Petrie 1891, p 16), the find being comparable with documented Mesopotamian burial customs (Van De Mieroop 1997, p83; Cohen 2005, p16).

Brunton and Engelbach did not record the presence of canopic jars in any of the three tombs at Point Q, which indicates that the individuals were not mummified, despite being wealthy enough to afford a private tomb (Brunton & Engelbach 1927, p10). Mummification during the New Kingdom era was standard practice for Egyptian burials and had been adopted by non-royal individuals who could afford it (Ikram 2015, p65). However, few canopic jars were in evidence at the site, and most of the tombs at Gurob were regarded as “shaft tombs”, suggesting that a simpler burial was the prevailing practice performed at Gurob. It is the notable lack of shabtis in tombs 20, 26 and 27 which is most significant; shabtis would be expected in an Egyptian burial regardless of status (Ikram, 2015, p129), and they are in evidence elsewhere in contemporaneous tombs about the site. Therefore, the evidence indicates elements associated with a foreign burial. Further studies investigating the extent of the presence of foreigners at Gurob, particularly Hittites and Mycenaeans, are currently ongoing (Hodgkinson 2017, p189). Current fieldwork also aims to establish more information about the Gurob site, including ascertaining a firm chronology of the site, undertaking further excavations of the ‘industrial area’ where kilns were identified, and cataloguing small finds following a series of illicit lootings in 2011-2012 (Shaw, 2011a, 2012).

3.7 The Grave Goods of Tomb 27, Gurob

Among the grave goods recovered from Tomb 27 were thirteen pottery vessels and a kohl pot, sixteen scaraboid beads (including one glass example, the subject of this paper), cosmetic tools and strings of stone and glass beads. Using evidence from the grave goods, Brunton and

Engelbach dated all three burials to the reign of Amenhotep I but did caveat the date by noting that some of the pottery was usually attributed to the reign of Tuthmosis III, therefore giving a conservative date of 1525 - 1425 BC. The scarab is 15mm long by 11mm wide at its widest point; One side is domed, the other side is flat and without inscription (Figure 21). The domed side has two shallow inscribed lines representing the two front legs of the beetle, and a slight depression representing the mouth. In transmitted light, the scarab is translucent blue, with a green tinge. The drill hole can be seen running longitudinally, and was drilled from each end, meeting in the middle. Part of the original threading is present - a stiff thread, probably organic - that still survives extending 2mm from the thread hole.

Figure 21: Scarab D.1921.39. Left in transmitted light and right in reflected light. The thread can be seen at the bottom and the inscribed legs at the top. The thread hole is seen in transmitted light and the black coating in both. The grid is 5mm squares.

A surface ‘coating’ was observed on the two ends of the scarab, particularly at the rear end. The coating appeared dark grey to black but was not present on the raised areas of the scarab or the flat surface on the back.

The scarab was not cleaned before the Environmental Scanning Electron Microscopy (ESEM) or the Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) analysis and care was taken to avoid patches of visible corrosion or coating for the analysis of the body

area of the scarab. The purpose of the ESEM analysis was to produce elemental data from the surface of the glass body, thereby enabling the identification of any original coatings or evidence of decorative settings.

The research question required that LA-ICP-MS analysis was conducted to provide major element compositional data from below the surface of the scarab to identify the scarab as being made from a typical Late Bronze Age high magnesia, plant ash glass. LA-ICP-MS analysis also provided trace element compositional data to confirm the provenance of the scarab by identifying the concentrations of known trace elements which are incorporated during the glass making process and occur in discrete levels, thereby enabling discrimination between the regions of production (Shortland, Rogers and Eremin, 2007).

ESEM and LA-ICP-MS analysis was performed on the scarab; The results of both analyses are presented in Table 8. ESEM was performed using a Hitachi SU3500N, running at 20kV with a live time of 50s. Quantification was carried out with standard EDAX software. The scarab was ablated directly in the large sample chamber of a New Wave 213 laser attached to a Thermo Series II ICP-MS. The conditions for analysis are laid out by Giannini (Giannini, Freestone & Shortland, 2017).

3.8 Results

The LA-ICP-MS analysis of the glass body, showed significantly higher soda with magnesia and potash, confirming that the glass is consistent with the well-documented composition of Late Bronze Age, plant-ash glass (Turner, 1956a, 1956b; Henderson, 1985; Lilyquist *et al.*, 1993), and that the scarab was coloured with copper. The covariant trace element analysis of the scarab showed that it was relatively high in chromium, with an average of 17 ppm, and lower in lanthanum, zirconium and titanium, with an average of 1.6 ppm, 8.1 ppm and 288.8

ppm respectively (

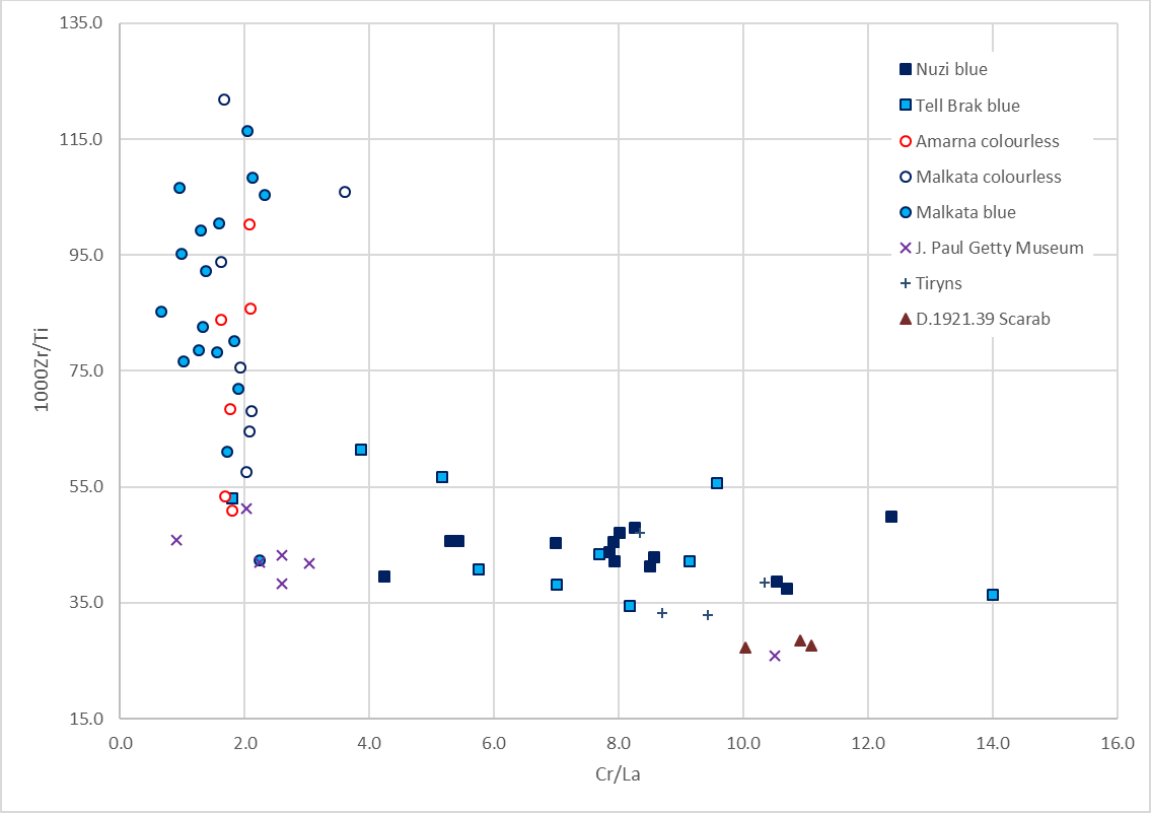
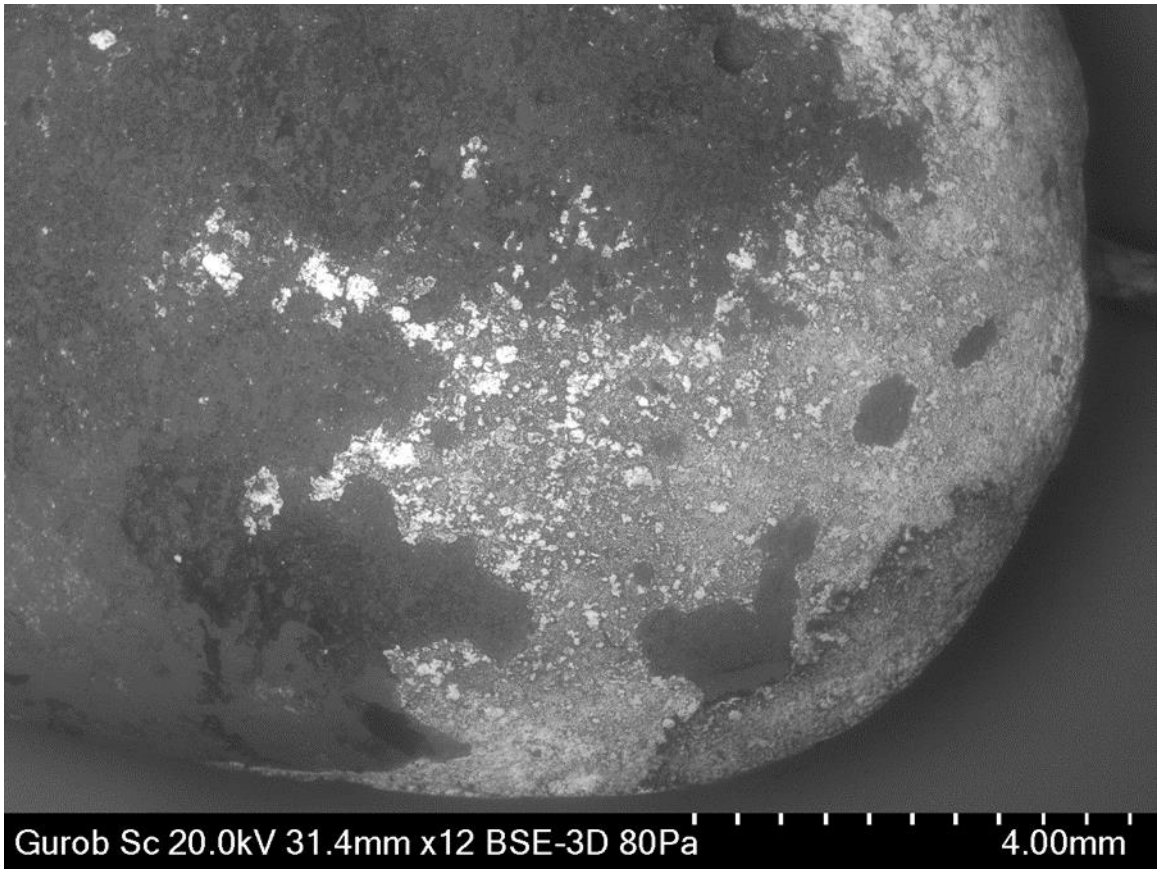


Figure 23). This signature is characteristic of glass made in Mesopotamia rather than Egypt, therefore it is very likely that the scarab represents imported glass from the Near East. Conversely, glasses made in Egypt are characteristically higher in titanium, zirconium, and lanthanum, but lower in chromium.

Egyptian blue glasses which are coloured with copper exhibit characteristically higher levels of lead, arsenic and tin (Smirniou *et al*., 2013) which is attributed to the use of bronze as a source of copper for the colourant (Kaczmarczyk *et al*., 1983; Freestone, 1991, p.43; Shortland *et al*., 2000). The expected level of tin present as an associated element in Egyptian copper-coloured glasses is approximately 10% of the copper value. In contrast, the scarab analysed here had an average copper concentration of 7053.1 ppm, but contained only trace levels of lead, arsenic and tin; averaging 361.9 ppm, 43.9 ppm and 66.7 ppm respectively, indicating that a purer copper source was used, conforming with the characteristic colourant composition of Near Eastern glasses.

Images taken from the ESEM analysis (Figure 22) showed that the dark coating, thought initially to be a weathering layer, appeared bright in the backscatter image; subsequent analysis

showed that the coating contained silver with sulphur and chlorine. It is probable that the scarab was originally mounted in silver, and that the detected sulphides and chlorides are a result of corrosion.



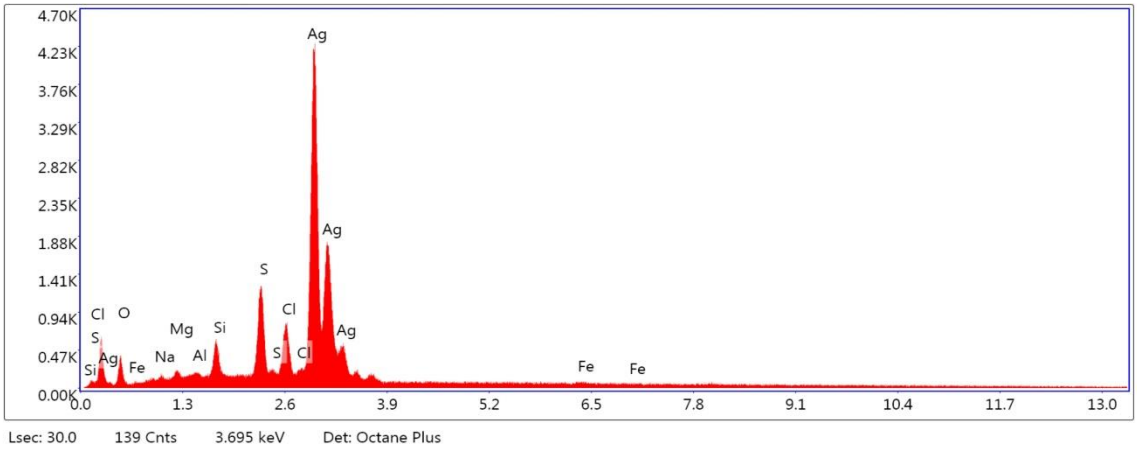


Figure 22: SEM results for the scarab. The image, in backscattered electron mode, shows a bright partial layer on the glass, which the EDS spectra confirms is silver rich.

	ESEM-EDS			LA-ICP-MS		
%						
Na_2O	5.0	4.0	5.4	13.9	12.5	14.9
MgO	4.3	4.4	4.1	2.6	2.5	2.5
Al_2O_3	2.7	2.8	2.6	0.7	0.7	0.6
SiO_2	64.3	69.7	61.9	73	75.6	73.2
P_2O_5	1.6	1.1	2	0.2	0.2	0.2
SO_3	2.7	2.2	3.1	-	-	-
Cl	2.9	2.6	3	-	-	-
AgO	3.8	1.9	4.6		see ppm	
K_2O	1.9	1.8	2.1	2.1	2.0	2.2
CaO	6.9	6.5	6.8	6.2	5.0	5.1
TiO_2	0.3	nd	0.5		see ppm	
Fe_2O_3	1.3	1.2	1.3	0.3	0.3	0.3
CuO	2.4	1.7	2.6	0.8	0.9	0.9
ppm						
Ti	-	-	-	295	285	285
Cr	-	-	-	17	16	17
Zr	-	-	-	9	8	8
Ag	-	-	-	5	10	6
Sn	-	-	-	65	68	66
La	-	-	-	1.6	1.6	1.6

Table 8: Analyses of the scarab by ESEM-EDS and LA-ICP-MS (nd = not detected).

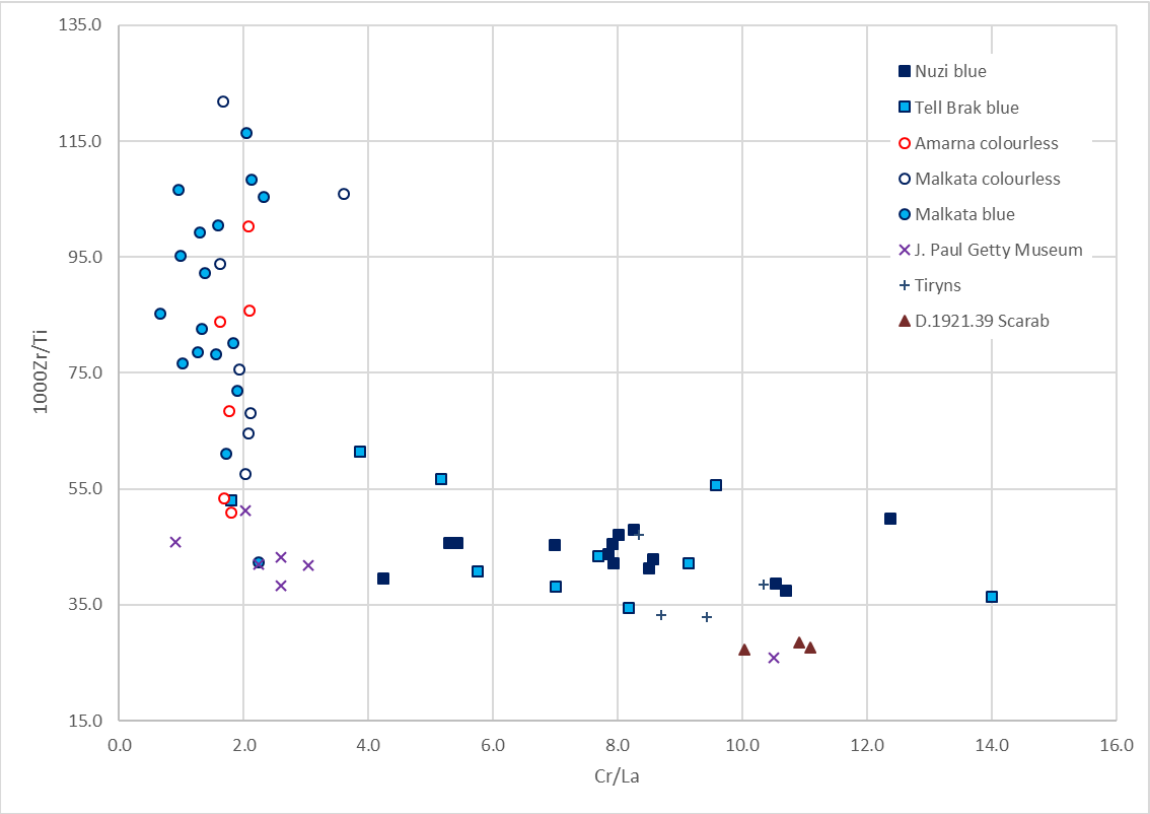


Figure 23: 1000Zr/Ti ppm against Cr/La ppm of the D.1921.39 scarab compared with Egyptian and Mesopotamian blue and colourless glasses of known origin (Shortland, Rogers & Eremin, 2007; Walton *et al.*, 2009).

Compared with the LA-ICP-MS data, the ESEM analysis of the surface suggests lower soda and higher magnesia, alumina, iron and copper due to weathering of the glass. The relatively high levels of sulphur, chlorine and phosphorus on the surface can be attributed to corrosion caused by routine handling, or from contact with substances with a high salt content (Aldred 1971, p.33). The high silver level detected on the surface of the glass which appears uncoated suggests that a larger surface area of the scarab was covered in silver than is evident from the visible black coating.

3.9 Origin of glass and the transportation of luxury items by foreign women of high status

By employing a multi-disciplinary approach to the investigation of the scarab and combining the analysis data with the burial context, this research establishes that Mesopotamian glass was being brought into Egypt possibly from the reign of Amenophis I by foreign women of the social elite. The results of the SEM and LA-ICP-MS analysis confirms that the scarab represents one of the first examples of Mesopotamian glass to be identified in Egypt (Figure

23); It is also the first confirmed Mesopotamian glass object to be presented in a typically Egyptian design. Because Near Eastern glass is generally poorly preserved when excavated domestically, well preserved examples which can be reliably dated to the early New Kingdom contributes to the knowledge of Mesopotamian glassmaking on the archaeological record, and thereby negating the preservation bias.

Further provenance analysis of glass objects from undisturbed, early New Kingdom tombs in Gurob would provide frequency data of foreign versus domestic glass from the earliest known production era, hence providing supporting evidence for the original region of glass production. Supporting evidence for the original production site of glass is supported by textual, stylistic, compositional and technological evidence, the two primary candidates for the original production of glass being Egypt and Mesopotamia. The first significant amounts of glass on the archaeological record come from Egyptian tombs, specifically from Tuthmosis III's tomb and the tombs of the three foreign wives. However, the dating of the first glass vessel is complicated owing to the reburial of Tuthmosis I by his grandson, and it cannot be confirmed if the glass vessels were part of the original grave goods of Tuthmosis I (Shortland 2012, p.50). The glasses from the tomb of Tuthmosis III date to the later part of his reign, whereas the glass items from the tomb of the foreign wives contained pieces which were made approximately 25 years earlier.

The earliest datable glass was discovered in quantity at the site of Tell Atchana in the Levant; unequivocal archaeological evidence of glass making in Syro-Palestine to date is rare (Moorey, 1994, p.202; Shortland *et al.*, 2017). Further evidence of glassmaking and glassworking sites has been proposed by the discovery of glass debris or associated tools and kilns (Pusch & Rehren 2007; Nicholson 2007), particularly in Mesopotamia (Shortland, Rogers & Eremin, 2007; Shortland, 2012). Archaeological evidence of primary production of glass was only recently established in Amarna, Egypt (Smirniou & Rehren, 2011) and green glass rods, Mesopotamian in composition, were discovered as part of glass making debris (Varberg *et al.*, 2016). As discussed, early Mesopotamian glass is generally poorly preserved, and therefore the recovery of intact pieces is rare; It is also equally rare to find Mesopotamian glass in Egypt, and vice versa (Shortland 2012, p.49).

Stylistic and textual evidence has supported the supposition that glass first originated in Mesopotamia and was imported into Egypt initially as a direct result of the successful military

campaigns of Tuthmosis III (Moorey, 1999). The Hall of Annals in Karnak depicts in detail what is believed to show the range of tributes extracted, or given as gifts, from vassal states, which include glass vessels and what has been interpreted as coloured raw glass ingots (Wreszinski 1923, p.50; Moorey 2001, p.9). The Amarna Letters, cuneiform texts dating from between the reigns of Amenhotep III to Tutankhamun, record the orders for glass which were regularly requested by the King of Egypt from vassal states, Canaan and Amurru (Moran 1992, p.351-355). Evidence of other methods of transportation from Mesopotamia to Egypt has also been discussed, such as the capture or loaning of skilled workers, or artisans who were in the employ of the royal court (Moorey 2001, p.11). Studies undertaken by Shortland, Walton and Jackson and Nicholson have demonstrated the efficacy of using trace element analysis to distinguish between glasses made in Egypt and Mesopotamia. Geologically relevant trace elements incorporated into the glass during manufacture can be detected using LA-ICP-MS, thereby determining the origin of production and when placed in the context of the burial, the mechanism of migration of the glass objects themselves (Shortland, Rogers & Eremin, 2007; Walton *et al.*, 2009; Jackson & Nicholson, 2010).

3.10 Discussion

The proposed date of the tomb establishes the scarab as some of the earliest glass on the archaeological record and the first confirmed Mesopotamian glass found in Egypt. The scarab, in connection with the contextual burial at Gurob potentially establishes the importance of women in the transport of early glass from Mesopotamia to Egypt. The grave goods from Tomb 27 contained several items of glass, gold and silver jewellery, which denotes that the women were of elevated status, or in the employ of a high ranking individual; jewels were customarily given to favoured servants and officials as a sign of the owners wealth (Aldred 1971, p.18).

The silver coating detected on the scarab suggests that the body may have been entirely coated in metallic silver, or more likely mounted in a bezel as other examples of this kind of setting were recovered from the site. Brunton and Engelbach also describe another scarab from Tomb 27 as having a silver mount. Silver was rare in Egypt, and there are few examples of it being used in the New Kingdom (Ogden 2000, p.170; Aldred 1971, p.33). Silver items were also found in the tomb of the Three Foreign Wives of Tuthmosis III (Lilyquist 2004, p.152), which draws another contemporary similarity with the tomb at Gurob. Silver coatings on glass are unusual in Egypt, with gold coatings being more common in Egypt and Mycenae. This use of

glass is unknown, but most likely lies in the amuletic value of glass, evident from written sources, which detail in length the power of stones and glass to ward off evil and heal the body (Wilkinson 1971, p.7). The scarab, although characteristically Egyptian, was exported from Egypt in large quantities from the Twelfth Dynasty (1985-1795 BC) to the Levant and subsequently increased in popularity, being widely distributed from Canaan throughout the Mediterranean. In a non-Egyptian context, the scarab may not have inferred religious connotation, however the desire for foreign jewellery may have been a driving factor for the prevalent adoption (Reader, 2003, p.219).

3.11 Conclusion

The data obtained by LA-ICP-MS shows that the scarab is consistent with the known composition of standard Late Bronze Age plant ash glass. The scarab is coloured with a pure source of copper which is indicative of glasses from the Near East. The trace element analysis also indicates that the scarab is consistent with glasses of Mesopotamian origin. The date of the tomb, between Amenophis I (1525-1504 BC) and Tuthmosis III (1479-1425 BC), indicates that the scarab represents some of the earliest Mesopotamian glass to be identified in Egypt, and associated with foreign women of high status living at Gurob. The scarab also represents an early example of Mesopotamian glass being used to make amulets in the shape of a quintessentially Egyptian symbol. The ESEM analysis indicates that the scarab was coated or had been mounted in silver, which is unusual in Egyptian grave goods, suggesting a foreign influence.

3.12 References

Aldred, C. (1971) Jewels of the Pharaohs: Egyptian Jewellery of the Dynastic Period. London: Thames and Hudson Ltd.

Aruz, J. *et al*. (2008) Beyond Babylon: art, trade, and diplomacy in the second millennium B.C. Metropolitan Museum of Art (Metropolitan Museum of Art).

Brunton, G. Engelbach, R. (1927) British School of Archaeology in Egypt and Egyptian Research Account, Twenty Fourth Year, 1918 - Gurob. British School of Archaeology.

Brunton, G. and Engelbach, R. (1927) British School of Archaeology in Egypt and Egyptian Research Account, Twenty Fourth Year, 1918 - Gurob. London: British School of Archaeology in Egypt.

Carter, H. and Romer, J. (2008) The Tomb of Tutankhamun. Max Press.

Cohen, A. C. (2005) Death rituals, ideology, and the development of early Mesopotamian kingship: towards a new understanding of Iraq's royal cemetery of Ur. Brill Academic Publishers (Ancient Magic and Divination).

Feucht, E. (1999) 'Jewelry', in Bard, K. (ed.) Encyclopedia of the Archaeology of Ancient Egypt. Oxford: Routledge, pp. 385–387.

Freestone, I. C. (1991) 'Looking into Glass', in Bowman, S. (ed.) Science and the Past. London: British Museum Press, pp. 37–56.

Giannini, R., Freestone, I. C. and Shortland, A. J. (2017) 'European cobalt sources identified in the production of Chinese famille rose porcelain', Journal of Archaeological Science, 80, pp. 27–36.

Grajetski, W. (2003) Burial Customs in Ancient Egypt: Life in Death for Rich and Poor. Bloomsbury Academic.

Henderson, J. (1985) 'The raw materials of early glass production', Oxford Journal of Archaeology, 4(3), pp. 267–291.

Hodgkinson, A. K. (2017) Technology and Urbanism in Late Bronze Age Egypt (Oxford Studies In Egyptian Archaeology). Oxford: OUP Oxford.

Ikram, S. (2015) Death and Burial in Ancient Egypt. American University in Cairo Press (American University in Cairo Press Series).

Jackson, C. M. and Nicholson, P. T. (2007) Brilliant things for Akhenaten: The Production of Glass, Vitreous Materials and Pottery at Amarna Site O45.1. Edited by P. T. Nicholson. London: Egypt Exploration Society.

Jackson, C. M. and Nicholson, P. T. (2010) ‘The provenance of some ingots from the Uluburun shipwreck’, Journal of Archaeological Science, 37(2), pp. 295–301.

Kaczmarczyk, A. and Hedges, R. E. M. (1983) Ancient Egyptian faience: an analytical survey of Egyptian faience from predynastic to Roman times. Warminster: Aris and Phillips.

Kemp, B. J. (1989) Ancient Egypt: Anatomy of a civilization. 2nd edn. London: Routledge.

Lilyquist, C. *et al*. (1993) ‘Part 2. Glass’, in Lilyquist, C. and Brill, R. H. (eds) Studies in Ancient Egyptian Glass. New York: Metropolitan Museum of Art, pp. 23–58.

Lilyquist, C. (2004) The Tomb of Three Foreign Wives of Tuthmosis III. New York: Metropolitan Museum of Art.

Lucas, A. and Harris, J. R. (1962) Ancient Egyptian Materials and Industries. 3rd edn. London: Edward Arnold & Co.

Van De Mieroop, M. (1997) The Ancient Mesopotamian City. Oxford: Oxford University Press.

Moorey, P. R. S. (1994) Ancient Mesopotamian materials and industries. Oxford: Oxford University Press.

Moorey, P. R. S. (2001) ‘The mobility of artisans and opportunities for technology transfer’, in Shortland, A. J. (ed.) The social context of technological change. Oxford: Oxbow books, pp. 39–58.

Ogden, J. (2000) ‘Metals’, in Nicholson, P. and Shaw, I. (eds) Ancient Egyptian materials and technology. Cambridge: Cambridge University Press.

Petrie, W. M. F. (1891) Illahun, Kahun and Gurob. London: David Nutt.

Piccione, P. A. (1999) ‘Tomb Furnishings’, in Bard, K. (ed.) Encyclopedia of the Archaeology of Ancient Egypt. Oxford: Routledge, pp. 839–841.

Pusch, E. and Rehren, Th. (2007) Rubinglass für den Pharao: Hochtemperatur-Technologie in der Ramses-Stadt. Hildesheim: Gerstenburg.

Reader, A. (2003) Near Eastern Archaeology: A Reader. Edited by S. Richard. Pennsylvania State University Press.

Sethe, K. (1907) Urkunden der 18. Dynastie, Historisch-biographische Urkunden. Vol 3 Part 9/10 of Urkunden des aegyptischen Altertums. Leipzig: J.C. Hinrichs.

Shaw, I. (2007) The royal harim at Medinet el-Ghurob: new fieldwork (2005-7). Liverpool.

Shaw, I. (2011a) 'New fieldwork at the Medinet el-Gurob New Kingdom settlement: investigating a harem palace town in the Faiyum (summary of the 2009-10 seasons)', in Belova, G. A. and Ivanov, S. V. (eds) Achievements and Problems of Modern Archaeology: Proceedings of the International Conference. Moscow: Russian Academy of Sciences Center for Egyptological Studies, pp. 1–18.

Shaw, I. (2011b) 'Seeking the Ramesside royal harem: new fieldwork at Medinet el-Gurob', in Collier, M. and Snape, S. (eds) Ramesside Studies in Honour of Ken Kitchen. Bolton: Rutherford Press, pp. 453–63.

Shaw, I. (2012) 'The Gurob Harem palace project, Spring 2012', Journal of Egyptian Archaeology, 98, pp. 43–54.

Shortland, A. J. (2012) Lapis Lazuli from the Kiln : Glass and Glassmaking in the Late Bronze Age. Leuven: Leuven University Press.

Shortland, A. J. *et al*. (2017) 'The analysis of Late Bronze Age glass from Nuzi and the question of the origin of glassmaking', Archaeometry.

Shortland, A. J., Rogers, N. and Eremin, K. (2007) 'Trace element discriminants between Egyptian and Mesopotamian Late Bronze Age glasses', Journal of Archaeological Science, 34(5), pp. 781–789.

Shortland, A. J. and Tite, M. S. (2000) 'Raw materials of glass from Amarna and implications for the origins of Egyptian glass', Archaeometry, 42(1), pp. 141–153.

Smirniou, M. and Rehren, Th. (2011) 'Direct evidence of primary glass production in Late Bronze Age Amarna, Egypt', Archaeometry, 53(1), pp. 58–80.

Smirniou, M. and Rehren, Th. (2013) ‘Shades of blue - cobalt-copper coloured blue glass from New Kingdom Egypt and the Mycenaean world: A matter of production or colourant source?’, Journal of Archaeological Science, 40, pp. 4731–4743.

Turner, W. E. S. (1956a) ‘Studies in ancient glasses and glass making processes. Part III. The chronology of glass making constituents’, Journal of the Society of Glass Technology, 40, pp. 39–52.

Turner, W. E. S. (1956b) ‘Studies in ancient glasses and glass making processes. Part IV. The chemical composition of ancient glasses’, Journal of the Society of Glass Technology, 40, pp. 162–184.

Varberg, J. *et al*. (2016) ‘Mesopotamian glass from Late Bronze Age Egypt, Romania, Germany, and Denmark’, Journal of Archaeological Science, 74, pp. 184–194.

Walton, M. *et al*. (2009) ‘Evidence for the trade of Mesopotamian and Egyptian glass to Mycenean Greece’, Journal of Archaeological Science, 36, pp. 1496–1503.

Wilkinson, A. (1971) Ancient Egyptian Jewellery. London: Methuen & Co Ltd.

Wreszinski, W. (1923) Atlas zur altaegyptischen Kulturgeschichte. Leipzig: J.C. Hinrichs.

4 The Investigation and Provenance of Glass Vessel Fragments Attributed to the Tomb of Amenhotep II, KV35, Valley of the Kings

4.1 Abstract

Four polychrome glass fragments, excavated from tomb KV35 in the Valley of the Kings, attributed to Amenhotep II, were analysed to further investigate the composition and provenance of early Late Bronze Age glasses. An additional fragment, EA64163, cited by the British Museum as being stylistically analogous to the fragments from KV35, although with a findspot simply recorded as "Thebes", was also analysed. LA-ICP-MS analysis was used to analyse multiple colours on the fragments to determine the major element composition, the colouring strategies and establish provenance using trace element analysis. The resulting data obtained was compared with four polychrome fragments of standard LBA Egyptian composition, excavated from the palace of Amenhotep III at Malkata, previously analysed by SEM-WDS. Analysis showed that the glasses excavated from KV35 are standard LBA glass of Egyptian composition and were most likely produced in Egypt in the 18th Dynasty. The fragment EA64163 is a low magnesia, low potash glass, comparable with Iron Age composition, therefore should be reconsidered as a later glass. The analysis of glasses, excavated from a reliable, early Egyptian context supports the proposition that glass technology for multiple colours was established in Egypt at least as early as 1400 BCE.

4.2 Introduction

The first man-made glass appears in the archaeological record in quantity in the Late Bronze Age (LBA) of Egypt and the Near East. There are early, sporadic finds of glass stretching back to the third millennium BCE (Beck, 1934; Peltenburg, 1987; Moorey, 1994 p190-2), but it is fifteenth century contexts where the first glass in any quantity is found. Most commentators of the last thirty or so years have placed the source of the glassmaking innovation in the Near East, perhaps in Northern Syria (Lilyquist, Brill and Wypyski, 1993; Nicholson, 1993; Moorey, 1999; Shortland *et al.*, 2017). However, recent re-examination of finds and their contexts have suggested that this is by no means as clear as first thought and proposed that it is difficult to determine whether Egypt or the Near East was the source of the first glass (Shortland *et al.*, 2017). Certainly, there are good textual and iconographic sources that show that glass was a

prized commodity in the LBA, with a value similar to a precious stone, at least in the first century of its production (Oppenheim, 1973; Nicholson, Jackson and Trott, 1997). As such, glass was used for several purposes, including beads, inlays, and amulets. However, the most significant object produced in glass was the core-formed glass vessel, manufactured by hot-working the glass around a clay/dung core (Nicholson and Henderson, 2000, p203). The most common body colour was blue, ranging from light to very dark blue hues, and vessels were often decorated with contrasting colours including yellow and white. Glass in green, red, brown, colourless, and black were also used, but less often in vessels (Nolte, 1968). It is also often the case that vessels that appear black are in fact very dark purple, blue, or brown.

Because of its perceived high value and portability as beads, jewellery and ingots, glass was therefore part of a wide-ranging exchange network, with evidence that Egyptian and Near Eastern glass was being transported as far as Mycenae (Walton *et al.*, 2009) and later as far as northern Europe (Varberg, Gratuze and Kaul, 2015; Varberg *et al.*, 2016). The Ulu Burun shipwreck found off the southern coast of Turkey and dating to around 1300 BCE contained a large consignment of glass ingots, some or all of which originated in Egypt (Nicholson, Jackson and Trott, 1997; Pulak, 2001; Jackson and Nicholson, 2010) Glass is therefore an interesting material to attempt to provenance, being of markedly high-value and apparently widely traded.

Glass discovered in Egypt tends to be almost always found in royal tombs in this earliest period, with the first regular finds of glass to be recovered in palaces, temples, workshops, or other urban settings not common until the fourteenth century BCE. Early glass objects excavated in Egypt, such as beads, are seen from the tomb of Queen Ahhotep, mother of Ahmose (1550-1525 BCE), and from contemporary tombs in Qau (Lilyquist *et al.*, 1993, p23). Blue transparent beads and a glass scarab were excavated from a later tomb from the site of Gurob, the location of the Harem palace established during the reign of Tuthmosis III (1479-1425 BCE) although these were items were determined as being Mesopotamian in origin (Kemp, McDonald, A and Shortland, 2017; Kemp *et al.*, 2019). It is during the reign of Tuthmosis III where glass vessels appear in quantity and from multiple sources, such as the tomb of the three foreign wives and the tomb of Tuthmosis III, KV34 (Lilyquist *et al.*, 1993, p25-6). '*Die Glassgefässe im alten Ägypten'* describes and dates (where possible) the largely intact early glass vessels excavated or acquired in Egypt, thereby establishing a timeline (Nolte, 1968).

We are fortunate to have an excellent chronology for the Egyptian kings, which means many of these tombs can be dated to a particular decade, or with even greater accuracy. In the Near East, the pattern is more mixed, and the dating can be problematic, in part due to the less expedient preservation conditions. Work by Dardeniz extends the glassmaking regions to northern Syria, specifically Tell Atchana, Ancient Alalakh, proposing that production in this area may pre-date workshops at Amarna (Dardeniz, 2018). Further evidence is pending to support an early glassmaking industry, specifically a detailed chronology for the site and the dating of pyrotechnic installations at Tell Atchana. It is therefore to Egypt that one first looks in order to investigate the beginning of glass production.

This paper analyses glass attributed to KV35, the Tomb of Amenhotep II (1427-1400 BCE) with the aim of demonstrating whether this early glass might have been made in an Egyptian workshop or imported from the Near East.

4.3 Dating glass

Attempts to date early glass objects stylistically have been problematic. As mentioned above, there seems a preference for many early glass vessels in blue, but certainly not all blue glasses are among the first vessels produced. A safer method of dating is to resort to the classic archaeological procedure of context. For example, it is very likely that glass recovered from the Valley of the Kings tombs of Tuthmosis III (KV34) and Amenhotep II (KV35) dates to those kings' reigns. A second way of dating the glass is where the glass object has a king's name inscribed upon it. Egyptian kings of this period have distinguishing names which are represented in a "cartouche". It is likely that an object that bears a king's cartouche dates to his reign, but some kings were the subject of cults after their death, so it is possible, if unlikely, that they could be later.

This represents the simple pattern for dating an object, but it should be noted that it can be more complex than this. Good examples are two small, turquoise-coloured glass persea fruits which were found by Howard Carter in KV62, the Tomb of Tutankhamen (Lilyquist *et al.*, 1993, p25-6). This tomb dates to 1327 BCE, plus or minus a year or two, but one fruit bears the cartouche of Tuthmosis III, who had been dead for nearly 100 years at this point. It is likely that this is a curated object, saved from his reign, but Tuthmosis III was the subject of a significant cult, so it could have been produced later. It is certainly no later than the completion

of Tutankhamen's tomb. It is therefore safer to regard cartouches as a *terminus post quem*, whereas a secure tomb is a *terminus ante quem.*

4.4 Provenancing glass

Glassworking sites might reveal themselves by having distinctive object types or producing distinctive styles of decoration, although ultimately this has been exceedingly difficult to prove with LBA sites (Rehren, 2000a; Rehren, Pusch and Herold, 2001a; Jackson, 2005). However, glassmaking sites can only be determined by something distinctive in the composition of the glass that they produce. Much work has been devoted to analysing LBA glass in an attempt to determine where it was made and trace element analysis, therefore, has proved useful for provenance studies.

The production of glass objects can be divided into two distinct stages: glass*making* and glass*working*. Glassmaking is the production of glass from its raw materials, in this period quartz pebbles, plant ash, colorant(s) and perhaps a lime source (Brill, 1999b). It requires a furnace capable of temperatures in excess of 1000°C to produce. LBA glasses discovered in Egypt, the Near East and ancient Greece have a silica content of 62-65%, a high soda content of between 15-20% and elevated levels of magnesia, approximately 2-5%, with a similar potash content of between 2-4% and a lime content of 4% (Sayre and Smith, 1961a; Lilyquist *et al.*, 1993; Shortland and Eremin, 2006). However, trace element analysis of LBA glasses has shown a distinct compositional difference between LBA glass found in the Near East and Egypt. The first element shown to distinguish between these two groups was titanium, which is high in Egyptian glasses, but relatively low in Near Eastern glasses (Shortland, Rogers and Eremin, 2007). Further analysis of a full suite of trace elements showed that almost a clear distinction could be drawn between glasses of the Near East and Egypt by plotting covariates of titanium, chromium, lanthanum, and zirconium. It is this method that was successfully used in the provenancing of Mycenaean, Ulu Burun and Levantine glasses (Shortland, Rogers and Eremin, 2007; Walton *et al.*, 2009; Jackson and Nicholson, 2010; Kemp *et al.*, 2020).

4.5 Previous analysis of Amenhotep II glass

The most recent analysis of glass thought to be from the reign of Amenhotep II is by Nicholson and Jackson (Nicholson and Jackson, 2013). The analysis was of a single sherd of a glass vessel now in the Swansea Museum (Swansea 959.3), believed to have originally been part of CG

24804, a particularly fine vessel which was later reconstructed in Cairo Museum (Nolte, 1968, p53; Stern and Schlick-Nolte, 1994, p25). It is 43mm across and features what is quite clearly part of the two cartouches of Amenhotep II. However, the object was recorded as being originally found in KV55, a hotly debated tomb in the Valley of the Kings with connections to the Amarna Royal family (Reeves and Wilkinson, 2008, p120-121; Saleem and Hawass, 2015, p119) Although curatorial history of the sherd is equivocal, it is likely that the piece dates from the reign of Amenhotep II and was originally part of his burial equipment (Nicholson and Jackson, 2013). Nicholson and Jackson carried out trace element analysis using LA-ICP-MS on the piece and compare the trace element plots with Shortland *et al.* (2007). They conclude that it has much in common with the Egyptian composition with relatively high lanthanum and titanium, but in the Cr/La plot, the concentrations of the amber and white samples from the Swansea glass sit slightly outside the general compositional group for Egypt.

This paper provides additional analyses of early glass material on a range of colours from nine fragments from and attributed to tomb KV35 and the palace at Malkata (Newberry, 1900, 1902; Tytus, 1903). The Malkata material is of standard Egyptian LBA glass composition and was analysed as a control to observe whether a small offset from the Egyptian field was directly comparable or reflected slightly different analytical settings in two different LA-ICP-MS systems. By analysing the Malkata controls in the same machine and at the same time as the KV35 unknown small differences in minor and trace elements, indicative of composition, can be observed and compared as well as negating any potential detection drift.

4.6 Methodology

Museum number	Colour	Findspot	Origin
EA64123	Blue	KV35	Fragment from the neck and shoulder of a globular, amphora vessel in translucent dark-blue glass. On the neck and shoulder are decoration in turquoise-blue, yellow, and white.
	Yellow		
EA64124	Purple	KV35	Fragment of a vessel with opaque deep-violet body, decorated with wide threads in yellow, white, light green, and turquoise-blue in a marbleized pattern.
	Yellow		

EA64125	Blue	KV35	Fragment from the shoulder and neck of a vessel in opaque dark-blue glass. There are remains of four impressed units in the form of cornflowers or rosettes represented in top view.
EA59244	Blue White	KV35	Fragment of a jar which had a hemispherical body. with a dark-blue ground. Decorations of chevrons on the neck, clustered festoons on the body, both combining opaque white and yellow.
EA64163	Red White Blue	Thebes (?), stylistically related to fragments in KV35	An unusual fragment with a chequer-board pattern closely following those found in moulded, fused bowls from the tomb of Amenhotep II. Impressed on both the exterior and interior surfaces are registers of opaque red squares and translucent dark-blue squares, alternating. The squares are arranged so that a red and a blue square touch only at their corners.
EA64149	Purple Yellow	Malkata Palace	Fragment from the body of a vessel in deep-violet glass decorated with clustered festoons in white, yellow, and light blue. Directly over these decorations vertical canes were impressed, three of which survive.
EA64151	Purple Yellow	Malkata Palace	Fragment from the lower neck and body of a vessel in opaque amethyst glass, with decorations in yellow, opaque white, and turquoise-blue, probably simple festoons.
EA64154	Black Turquoise White	Malkata Palace	Fragment of bowl: fragment of a shallow, opaque mosaic glass bowl, matt surface. Assembled from several layers of small pieces of brick-red, turquoise-blue, opaque white, yellow, and black glass. The bowl was formed by moulding either in an open mould or by press-moulding.
EA64155	Red Blue Turquoise	Malkata Palace	Fragment of a shallow mosaic glass bowl, composed of small pieces of light- and dark-blue, red, and white glass.

Table 9: Objects analysed by LA-ICP-MS, described in the Catalogue of the Egyptian antiquities of the British Museum: Volume IV, Glass (Cooney, 1976).

The objects analysed in this paper were originally sampled for Shortland *et al.* (2006) and analysed by SEM-WDS. The same SEM blocks and samples were used here. A total of nine objects were selected, all glass vessel fragments. Four are securely provenanced to KV35, the Tomb of Amenophis II, by the British Museum who describe the provenance as "probable"(Cooney, 1976, p52, p143) however it is known that KV35 was later opened and used as a cache for royal mummies (Baikie, 1932). The provenance of fragment EA64163 is given as "probably Thebes" by the British Museum and is described as having "a chequer-board pattern closely following those found in fused bowls from the tomb of Amenhotep II" (Cooney, 1976, p53), being stylistically comparable to the bowl sherd MMA 26.7.1164 from KV35 (Lilyquist *et al.*, 1993, p29, p35).

Three of the fragments attributed to KV35 can be viewed on the British Museum website: https://www.britishmuseum.org/collection/object/Y_EA64163; EA64125 is shown in the top right, EA64124 middle right, EA64163 is pictured on the bottom right (Figure 11 also see Table 9 for descriptions). Four other vessels from the Palace of Malkata dating to Amenhotep III (1390-1352 BCE) were also analysed as controls – by all expectations these should be Egyptian in composition.

The samples were subjected to LA-ICP-MS analysis at the Natural History Museum, London. The instruments used were an Agilent 7700 ICP-Q-MS mass spectrometer coupled to an ESI NWR193 with laser type ArF excimer with an ablation spot of 50µm, as detailed in Table 10.

Laser ablation system	
Instrument	ESI NWR193
Laser type	ArF excimer
Wavelength	193 nm
Pulse duration	<4 ns
Repetition rate	10 Hz
Analysis type	Spot
Spot diameter	50 µm
Fluence	3.5 J/cm^2
Carrier gas (He)	500 ml/min
Primary reference material	NIST 612
Secondary reference material(s)	NIST 610, Corning A, Corning B
Mass spectrometer	
Instrument	Agilent 7700 ICP-Q-MS
Plasma gas flow (Ar)	1.1 l/min
Individual element dwell time	0.01s
Analysis duration	60s
Blank duration	30s

Table 10: Conditions for the LA-ICP-MS analysis.

Each sample was analysed at five different spots, avoiding any obvious weathered areas. Corning A standard was run throughout the LA-ICP-MS analysis to check for accuracy and drift. The results on Corning A secondary standards show good agreement for the most elements, with the standards averaging less 10% error on the accuracy. Results consistent with Kemp *et al*., 2020 (Kemp *et al.*, 2020).

(next page) Table 11: Average results of the LA-ICP-MS analyses showing major and minor elements of the samples from KV35, the palace at Malkata and the fragment stylistically attributed to KV35, findspot cited by the British Museum as Thebes in %.

Sample Number	Colour	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	MnO	FeO	CoO	CuO	Sb_2O_3	PbO
KV35														
EA64123	Blue	17.5	3.7	1.8	66.1	0.10	0.72	8.9	0.24	0.12	0.11	0.03	0.19	0.04
EA64125	Blue	19.5	3.9	2.9	61.6	0.22	1.24	7.5	0.29	0.18	0.25	0.21	1.5	0.02
EA59244	Blue	19.9	5.1	2.8	61.2	0.17	1.09	8.4	0.25	0.24	0.16	0.03	0.08	0.02
EA64124	Purple	19.4	3.7	0.74	65.4	0.23	2.61	6.9	0.61	0.15	0.01	0.01	0.01	0.00
EA59244	White	18.9	4.9	0.74	60.4	0.15	1.89	9.9	0.02	0.15	0.00	0.01	2.6	0.04
EA64123	Yellow	16.3	3.2	0.65	59.1	0.25	1.85	7.7	0.10	0.17	0.00	0.11	1.4	8.4
EA64124	Yellow	18.5	5.5	0.59	60.3	0.14	2.30	9.7	0.02	0.10	0.00	0.07	2.7	0.04
Malkata Palace														
EA64154	Black	15.6	3.7	0.79	65.9	0.17	2.15	7.5	1.95	0.18	0.02	1.6	0.02	0.09
EA64155	Blue	19.5	4.8	1.9	62.1	0.22	1.77	6.8	0.19	0.15	0.20	0.31	1.5	0.01
EA64149	Purple	20.3	3.7	0.73	64.5	0.24	2.71	6.8	0.61	0.16	0.01	0.06	0.01	0.00
EA64151	Purple	17.1	3.3	0.40	66.8	0.21	3.07	8.0	0.55	0.30	0.01	0.06	0.01	0.00
EA64155	Red	14.7	3.8	0.96	53.1	0.22	2.14	8.8	0.02	0.25	0.02	13.1	2.1	0.14
EA64154	Turquoise	17.6	5.2	0.65	60.2	0.17	2.41	7.8	0.02	0.15	0.01	2.4	2.9	0.05
EA64155	Turquoise	19.7	4.7	0.48	59.8	0.25	2.45	7.0	0.03	0.13	0.01	2.9	2.3	0.03
EA64154	White	19.1	4.7	0.71	62.5	0.22	2.30	7.6	0.02	0.15	0.00	0.07	2.5	0.04
EA64149	Yellow	14.9	4.3	0.73	52.6	0.21	2.43	7.5	0.22	0.30	0.00	0.06	4.0	11.5
EA64151	Yellow	18.0	3.2	0.38	67.6	0.18	3.05	6.2	0.46	0.30	0.01	0.03	0.02	0.41
Fragment stylistically related to KV35, findspot cited by the British Museum as "Thebes"														
EA64163	Blue	17.9	0.98	2.6	67.9	0.10	1.03	6.2	0.81	0.78	0.10	0.47	0.48	0.24
EA64163	Red	13.7	1.9	3.1	58.7	0.73	1.90	10.2	0.74	0.60	0.02	2.8	0.40	4.4
EA64163	White	15.4	0.79	2.2	61.7	0.14	1.12	5.8	0.85	0.25	0.02	0.04	6.8	4.6

Sample Number	Colour	Li	Be	B	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Zr	Nb	Ag	Sn	Sb	Cs	Ba	La	Ce	Au	Pb	Bi	Th	U
KV35																														
EA64123	Blue	5.9	0.09	131.8	489	5.8	4.3	1884	933	888	466	251	650	5.3	4.0	670	45.6	1.4	0.34	12	1565	0.06	53.6	2.7	6.3	0.03	338	0.03	0.64	0.40
EA64125	Blue	10.2	0.00	93.8	661	11.2	7.6	2220	1432	1931	974	1711	2477	19.4	6.4	505	48.8	1.9	0.25	42	12562	0.09	57.3	3.9	10.5	0.12	18.5	0.01	1.00	0.69
EA59244	Blue	8.3	0.23	141.3	791	11.3	5.0	1899	1856	1269	848	207	1840	5.2	7.8	560	47.2	2.3	0.17	9.4	703	0.12	66.6	4.8	11.8	0.02	14.8	0.05	1.23	0.71
EA64124	Purple	9.6	0.18	70.4	588	13.8	5.1	4717	1131	4.6	4.5	110	25.3	0.9	9.8	738	58.9	1.7	0.16	1.1	6.8	0.11	75.2	3.4	6.6	0.00	1.7	0.05	0.84	0.52
EA59244	White	7.8	0.08	69.7	463	7.5	5.3	164	1181	3.9	8.1	101	26.4	55.0	11.7	985	42.1	1.5	0.29	1.1	21970	0.21	40.0	3.0	6.0	0.00	41.0	0.04	0.77	0.31
EA64123	Yellow	6.3	0.11	79.8	444	6.5	10.4	795	1349	3.1	6.3	840	3615	23.6	11.1	1294	37.4	1.3	1.7	4.2	11630	0.12	99.8	2.6	4.7	0.04	78370	3.1	0.57	0.57
EA64124	Yellow	5.5	0.00	64.5	345	6.0	4.1	178	788	1.7	6.0	57.0	22.9	66.6	10.7	1127	32.6	1.2	0.21	0.85	22153	0.28	35.5	2.2	4.2	0.06	35.9	0.04	0.54	0.22
Malkata Palace																														
EA64154	Black	6.1	0.14	49.0	656	34.6	7.7	15095	1406	11.8	17.9	12833	38.9	39.3	9.7	651	58.5	1.7	0.68	705	182	0.12	185	3.6	6.4	0.17	79.8	0.26	0.62	1.02
EA64155	Blue	9.4	0.09	79.2	421	6.2	4.2	1443	1191	1592	892	2476	1296	12	6.2	563	31.2	1.2	1.4	2.0	12386	0.07	41.7	2.2	5.4	0.04	13.4	0.02	0.52	0.18
EA64149	Purple	7.7	0.03	73.1	583	13.9	5.1	4747	1229	4.7	4.4	49.9	25.7	0.9	8.8	727	63.4	1.7	0.32	1.1	7.5	0.11	77.3	3.5	6.9	0.04	1.63	0.05	0.89	0.54
EA64151	Purple	9.2	0.10	56.7	291	5.9	4.1	4242	2367	4.7	5.6	47.3	98.9	1.3	13.2	1372	36.9	0.88	0.03	0.94	11.5	0.14	45.8	1.9	3.7	0.00	3.94	0.00	0.47	0.56
EA64155	Red	7.8	0.13	59.0	766	12.0	9.1	176	1963	18.0	89.2	104726	32.6	530	9.4	828	51.9	1.9	7.9	1993	17637	0.12	51.5	3.4	6.6	0.29	1279	0.78	0.78	0.32
EA64154	Turquoise	7.2	0.00	77.5	419	6.4	3.2	129	1145	4.4	14.8	19371	24.5	130	12.7	966	37.8	1.3	0.78	1652	24074	0.14	32.8	2.5	5.0	0.33	44.3	0.14	0.62	0.22
EA64155	Turquoise	9.6	0.06	76.3	370	5.7	3.5	243	1025	6.6	16.3	22927	25.7	111	8.8	579	29.2	1.0	1.8	571	19405	0.09	34.6	1.9	3.8	0.35	28.9	0.09	0.46	0.17
EA64154	White	6.8	0.07	73.7	419	6.4	4.9	141	1160	2.9	7.3	56.4	18.2	57.4	10.0	550	29.8	1.5	1.1	1.6	21179	0.15	43.9	3.0	5.8	0.04	38.5	0.04	0.66	0.20
EA64149	Yellow	5.7	0.08	106	441	9.2	14.1	1687	2328	3.7	19.1	495	7581	49.1	11.2	1140	40.0	1.3	1.5	3.7	33459	0.17	251	3.1	5.7	0.07	107019	0.95	0.72	0.85
EA64151	Yellow	6.6	0.28	49.9	277	5.8	3.9	3577	2358	4.4	5.1	245	82.3	1.0	11.0	969	33.1	0.87	0.67	0.96	13.0	0.11	35.1	1.6	3.4	0.06	3818	0.01	0.44	0.46
Fragment stylistically related to KV35, findspot cited by the British Museum as "Thebes"																														
EA64163	Blue	7.0	0.06	210	1188	22.7	26.3	6299	6028	754	31.0	3793	85.8	7.1	7.1	431	99.3	3.2	3.6	92	3994	0.11	218	7.7	14.7	0.04	2210	0.2	1.7	1.4
EA64163	Red	6.5	0.20	134	1764	30.0	29.9	5718	4700	178	25.2	22321	148	101	10.7	667	145	5.3	7.7	2933	3325	0.20	280	10.3	20.3	0.06	40387	3.8	2.4	1.4
EA64163	White	5.9	0.21	132	950	19.6	22.9	6552	1913	15.1	13.7	280	42.9	22.9	6.4	417	88.4	2.8	5.0	396	56556	0.08	221	7.3	13.3	0.24	42726	3.0	1.6	1.3

(Previous page) Table 12: Average results of the LA-ICP-MS analyses in ppm.

4.7 Results

The results are presented in(next page) Table 11 (Previous page) Table 12, showing analyses of the glasses excavated from KV35 and fragment EA64163, which has been stylistically ascribed to KV35, and glasses from the palace at Malkata.

4.8 Discussion

High magnesia/high potash glasses

All samples apart from fragment EA64163 are consistent with Late Bronze Age plant ash glasses which are characterised by a high magnesia and high potash content.

4.8.1 Malkata

The glass samples analysed here that were excavated from the palace at Malkata are all compositionally standard LBA glasses of Egyptian composition, which have been widely published. These can therefore be used as a reference to comparatively discuss the samples attributed to KV35.

The black glass in EA64154 contains the highest concentration of manganese in the study group (2.0% MnO) with elevated levels of copper (1.6% CuO), therefore making this glass optically very deep purple-blue to achieve a black hue.

The blue glass from EA64155 is coloured with both cobalt and copper at 0.2% and 0.3% respectively, and opacified with 1.5% of an antimony opacifier, most likely calcium antimonate (A. Shortland, 2002). EA64155 exhibits the elevated levels of aluminium, manganese, nickel and zinc and low concentrations of potash, which is the expected composition pattern for LBA Egyptian glass coloured with cobalt (Shortland and Eremin, 2006; Shortland, Rogers and Eremin, 2007).

The Malkata turquoise glasses, EA64154 and EA64155, are similar in major element composition and colouring strategy; these glasses are coloured with a relatively higher concentration of copper (2.4% and 2.9% CuO respectively) and are opacified with an antimony

constituent (containing 2.9% and 2.3% Sb_2O_3 respectively), thereby representing typical copper coloured, opacified, turquoise glasses of Egyptian composition.

The two purple glasses, EA64149 and 64151, are both coloured with a concentration of 0.6% manganese. Although there is a slight variation in the major elements, both glasses exhibit standard LBA Egyptian purple glass composition.

The red glass, EA64155, exhibits noticeably lower levels of silica and soda compared with the other coloured glasses: 53.1% (SiO_2) and 14.7% (Na_2O) respectively. However, this corresponds with the WDS analysis findings in Shortland and Eremin (2006) of LBA Egyptian red glasses. The glass is coloured with copper and represents the highest concentration of the study group (13.1% CuO). An antimony opacifier (2.11% Sb_2O_3) with some trace concentrations of lead (0.1% PbO) was also detected.

The white glass, EA64154, contains excess antimony (2.5% Sb_2O_3) suggesting this glass is opacified by calcium antimonate (A. Shortland, 2002), representing a typical LBA Egyptian white glass composition (Shortland and Eremin, 2006). The two yellow glasses show variation between their respective major element compositions and colouring strategies: EA64149 contains high levels of lead (11.5% PbO) whereas EA64151 contains comparatively low concentrations of lead (0.4% PbO), however both are comparable with known compositions of LBA Egyptian yellow glasses (Shortland and Eremin, 2006).

4.8.2 KV35

The glasses excavated from KV35 are typical high magnesia, high potash (HMHK) plant ash glasses comparable to the glasses analysed from Malkata and standard Egyptian LBA glasses produced in the 18th Dynasty (Shortland and Eremin, 2006), both in major elemental composition and colouring strategy. The two blue glasses coloured only with cobalt, EA64123 and EA59244, show the expected elevated levels of aluminium, manganese, nickel and zinc and relatively low concentrations of potash that are characteristic of LBA Egyptian cobalt coloured glass. The composition of the blue cobalt-copper coloured glass from KV35, EA64125 is comparable to that of Malkata, EA64155, specifically with regards to the colouring strategy, which is almost identical, containing similar concentrations of cobalt, copper, and antimony.

The purple glass, EA64124, is coloured with manganese and compares well with the purple glasses from Malkata, particularly EA64149 which is almost identical to the KV35 purple glass.

The white glass from KV35, EA59244, is almost compositionally identical to EA64154 from the palace at Malkata; the lime content is the only major difference which is 9.9% in the KV35 white glass and 7.6% in the Malkata glass. As mentioned above, the two yellow glasses from Malkata exhibit notably different compositions; the two yellow glasses from KV35 also show some variation between the two compositions. EA64123 from KV35, comparable with EA64149, contains lead (8.4% PbO) and antimony (1.4% Sb_2O_3), therefore likely coloured yellow by lead antimonate (A. Shortland, 2002). However, lead was not detected in the yellow glass in EA64124 but exhibits elevated levels of antimony (2.65% Sb_2O_3). The two KV35 glasses exhibit decreased levels of manganese compared with the two yellow glasses from Malkata.

4.8.3 EA64163, a low magnesia/low potash glass

Across the three glasses, EA64163 contains an average magnesia content of 1.2% MgO and an average potash content of 1.4% K_2O, which is notably different compared with the compositions of the HMHK glasses from Malkata and KV35. Natron glasses, using a soda-mineral flux, are characteristically low in magnesia and potash, containing concentrations of less than 1.5% each. Therefore, the major element composition of the glasses constituting EA64163 are comparable with natron glasses commonly produced in the Iron Age (IA) (Sayre and Smith, 1961; Freestone, 1991, p39-40).

The blue, red and white glasses comprising the EA64163 fragment exhibit over double the concentrations of the major elements aluminium, manganese and iron in addition to containing over double the average concentrations of the geologically relevant trace elements titanium, chromium, lanthanum and zirconium compared with those from the HMHK group. This elevated concentration is also seen across the rare earth and transition metal elements analysed. The cobalt-copper coloured blue glass in EA64163 exhibits elevated levels of manganese, iron, and lead, compared with the KV35 and Malkata blue glass samples in the study group. The cobalt colourant used to colour the EA64163 blue glass is compositionally consistent with

cobalt sources used to colour later glasses (Abe *et al.*, 2012). This is significantly different to the zinc-rich Egyptian cobalt used to colour the HMHK glasses and is likely from an Iranian source, characterised by low levels of nickel and zinc, with an elevated concentration of manganese. (Kaczmarczyk, 1986; Mass, Wypyski and Stone, 2002).

The red glass in EA64163 exhibits notably low levels of silica and a low soda concentration, containing 58.7% and 13.7% respectively, comparable with the silica and sodium levels observed in the red glass EA64155 from Malkata. However, as mentioned previously, the EA64163 glass contains significantly elevated levels of aluminium (3.1% Al_2O_3), manganese (0.7% MnO), iron (0.6% FeO), copper (2.8% CuO) and lead (4.4% PbO). As discussed in the HMHK section, the composition of red glasses is known to be variable, however, the red glass from EA64163 is distinctly different from the standard LBA Egyptian glass and that of EA64155 from Malkata in both major element and colourant composition.

The white glass in EA64163 has the highest lime concentration in the study at 10.2% and contains the highest concentration of antimony in the study group (6.8% Sb_2O_3). Two studies on LBA Egyptian white glass conducted by Mass *et al*. (2002) and Shortland *et al*. (2006) showed that the antimony concentration did not exceed 3.9% and 3.3% respectively. Therefore, the antimony content of EA64163 is significantly higher than the expected antimony content in an LBA white glass. In addition, EA64163 contains 4.6% PbO compared with the white glasses from KV35 and Malkata that contain no detectable lead content.

Therefore, both major and trace element compositions, in addition to the colouring strategies for the blue, red and white glasses are notably different to the HMHK glasses from the KV35 tomb and Malkata groups, thereby making them notably distinct from standard LBA glasses produced in the 18th Dynasty.

4.9 The provenance of the glass fragments from and stylistically attributed to KV35

Titanium, chromium, lanthanum, and zinc can be used to distinguish between glasses most likely manufactured in Egypt, and those produced in the Near East. Figure 1 shows the data from the glasses excavated from KV35, the fragment stylistically attributed to KV35 and the fragments from the palace at Malkata plotted in a covariant plot of La against Cr, compared with the data from the Swansea fragment (Nicholson and Jackson, 2013) and data from the

glasses in Shortland *et al*. (2007). As mentioned, the majority of the glasses from the study show a positive correlation with those of Egyptian composition, however, two yellow glasses, EA64123 from KV35, and EA64149 from Malkata appear to lie between the Egyptian and Near Eastern compositions due to the high chromium content. This indicates that yellow glasses may have been produced at a third site using chromium rich raw materials, or that raw yellow glass may have been imported from the Near East, which was then diluted with Egyptian colourless glass (Mass, Wypyski and Stone, 2002). The glasses comprising EA64163 can be seen as the outliers in Figure 24. Figure 25 shows the same data plotted in 1000Zr/Ti against Cr/La. This plot provides greater distinction between the Egyptian and Near Eastern trace element compositions. The analysis strongly suggests that all the HMHK glasses from KV35 and the palace at Malkata are of Egyptian manufacture, paralleling the analysis of the Swansea fragment (Nicholson and Jackson, 2013).

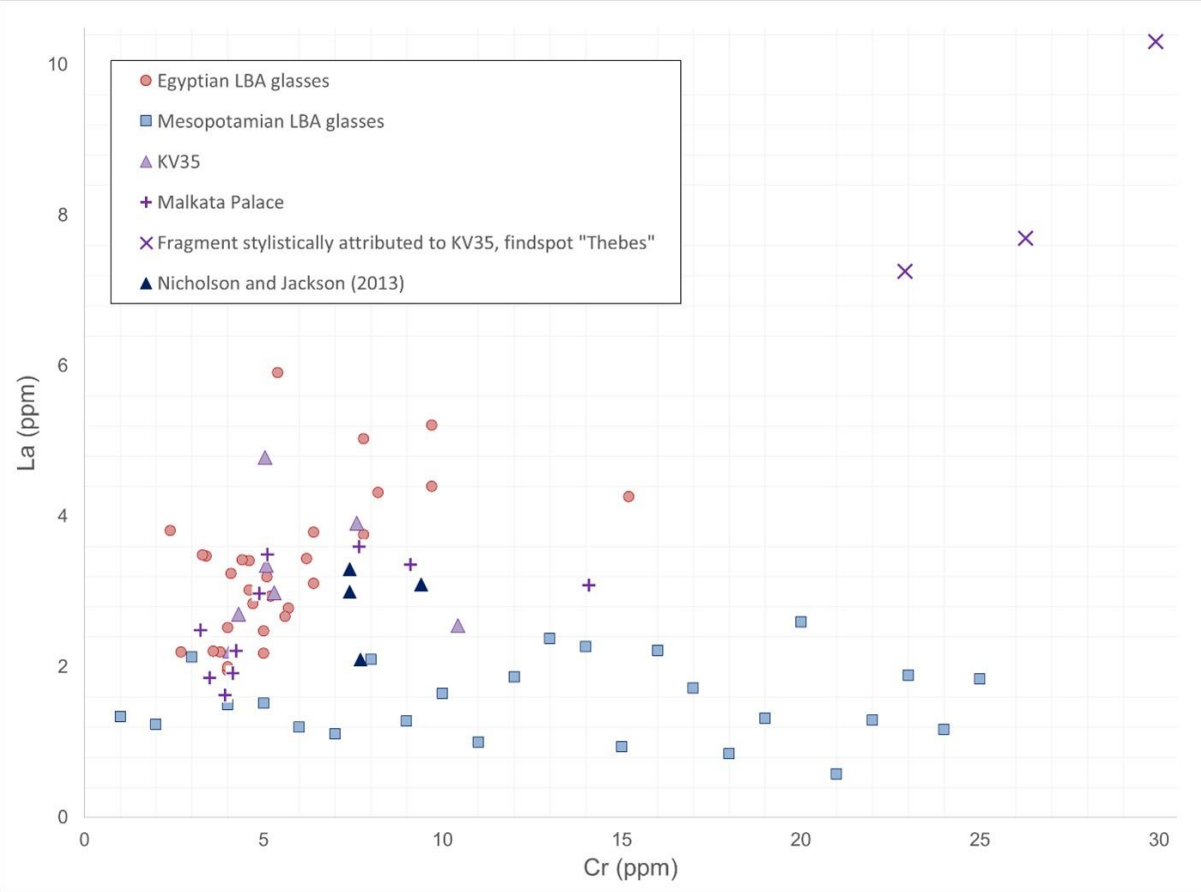


Figure 24: Covariant plot of La with Cr comparing the glasses from KV35, the palace at Malkata, the fragment attributed to KV35 (findspot described by the British Museum as “Thebes”) and the Swansea fragment (Jackson and Nicholson 2013). Samples are plotted against the Egyptian and Mesopotamian glasses of known origin (Shortland, Rogers and Eremin, 2007).

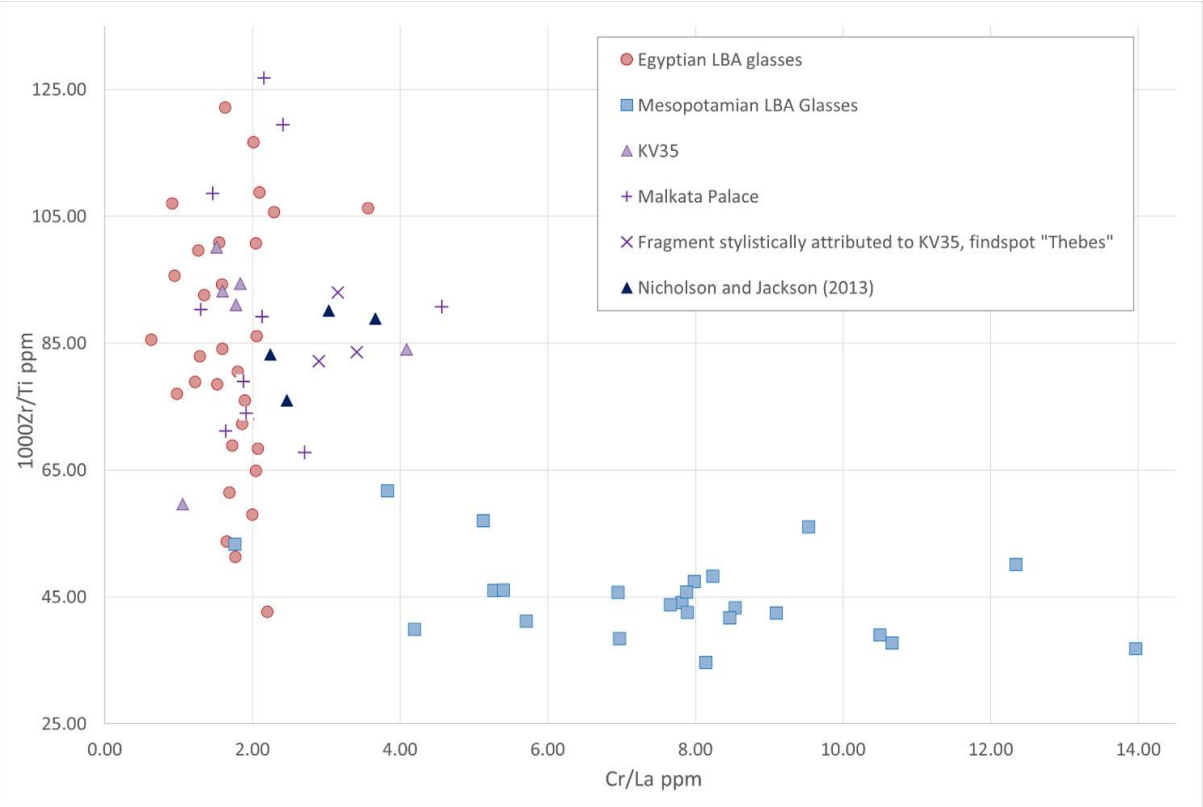


Figure 25: Covariant plot of 1000Zr/Ti with Cr/La comparing the glasses from KV35, the palace at Malkata, the fragment attributed to KV35 (findspot described by the British Museum as "Thebes") and the Swansea fragment (Jackson and Nicholson 2013). Samples are plotted against the Egyptian and Mesopotamian glasses of known origin (Shortland, Rogers and Eremin, 2007).

4.10 Conclusion

The four fragments recorded as being excavated from the tomb KV35 in the Valley of the Kings are of standard LBA Egyptian composition and compare well to the glasses from Malkata. In addition, all the colours analysed on each fragment are comparable to those of Egyptian provenance, the implication being that early Egyptian glassmaking technology was refined enough at this early stage of glassmaking history to produce glasses in several colours using a range of compositions and obtaining domestically sourced raw materials distinct from the Near Eastern sources. This signifies that early glassworkers working in Egypt were not as dependent on imported glasses manufactured in the Near East as previous research has speculated. The analysis of fragment EA64163, which is only stylistically attributed to Amenhotep II, shows that the composition of all three colours is significantly different compared with the same colour groups in the LBA glasses from KV35 and Malkata. This is established in the major, minor and trace element findings in the raw materials of the glass and the colourants; the low

magnesium, low potash content exhibited by EA64163 is characteristic of later glasses produced in the IA using natron as an alkali flux.

4.11 References

Abe, Y., Harimoto, R., Kikugawa, T., Yazawa, K., Nishisaka, A., Kawai, N., Yoshimura, S. and Nakai, I., 2012, Transition in the use of cobalt-blue colorant in the New Kingdom of Egypt, Journal of Archaeological Science, 39(6), 1793–1808.

Baikie, J., 1932, Egyptian Antiquities in the Nile Valley: A Descriptive Handbook, Routledge, London.

Beck, H., 1934, Glass before 1500 BC, Ancient Egypt, Macmillan, London.

Brill, R. H., 1999, Chemical analyses of early glasses: Volume 1 (tables) and 2 (catalogue), Corning Museum of Glass, Corning, New York.

Cooney, J. D., 1976, Catalogue of the Egyptian antiquities of the British Museum: Volume IV, Glass, British Museum, London.

Dardeniz, G., 2018, The Preliminary Archaeological and Scientific Evidence for Glass Making at Tell Atchana/Alalakh, Hatay (Turkey), Anatolian Archaeological Studies, Japanese Institute of Anatolian Archaeology, Proceedings of JIAA Late Bronze Age Glass Workshop held at 27th-28th September, 2014 in Kaman, Turkey.

Freestone, I. C., 1991, Looking into Glass, (ed. S. Bowman) Science and the Past. British Museum Press, London, 37–56.

Jackson, C. M., 2005, Glassmaking in Bronze Age Egypt, Science, 308, p. 1750-1752.

Jackson, C. M. and Nicholson, P. T., 2010, The provenance of some ingots from the Uluburun shipwreck', Journal of Archaeological Science, 37(2), 295–301.

Kaczmarczyk, A., 1986, The source of cobalt in ancient Egyptian pigments, (eds. J. S. Olin, M. J. Blackman) Proceedings of the 24th International Archaeometry Symposium, Smithsonian, Washington, 369–376.

Kemp, V., McDonald, A., Brock, F., Shortland, A. J., 2019, LA-ICP-MS analysis of Late Bronze Age blue glass beads from Gurob, Egypt, Archaeometry, 62(1), pp. 42–53.

Kemp, V., Schmidt, K., Brownscombe, W., Soennecken, K., Vieweger, D., Haser, J., Shortland, A., 2020, Dating and provenance of glass artefacts excavated from the ancient city of Tall Zirāʿa, Jordan, Archaeometry 62(6), pp. 1164-1181.

Kemp, V., McDonald, A and Shortland, A. J., 2017, Ancient Biographies: Trace Element Analysis to Investigate Provenance and Transportation Mechanisms of Late Bronze Age Glass, Archaeological and Environmental Forensic Science, 1.2, pp. 161–174.

Lilyquist, C., Brill, R. H. and Wypyski, M. T., 1993, Studies in Early Egyptian Glass. Metropolitan Museum of Art, New York.

Lilyquist, C., Brill, R. H., Wypyski, W. T. and Koestler, R. J., 1993, 'Part 2. Glass', in (eds. C. Lilyquist, R. H. Brill) Studies in Ancient Egyptian Glass. New York: Metropolitan Museum of Art, 23–58.

Mass, J. L., Wypyski, M. T. and Stone, R. E., 2002, Malkata and Lisht glassmaking technologies: towards a specific link between second millennium BC metallurgists and glassmakers, Archaeometry, 44(1), 67–82.

Moorey, P. R. S., 1994, Ancient Mesopotamian materials and industries, Oxford University Press, Oxford.

Newberry, P. E., 1900, Extracts from My Note-books (III). PSBA 22.

Newberry, P. E., 1902, Extracts from My Note-books (V). PBSA 24.

Nicholson, P. T., 1993, Ancient Egyptian Faience and Glass, Shire Egyptology, London.

Nicholson, P. T. and Henderson, J., 2000, Glass, (eds. P. T. Nicholson and I. Shaw) Ancient Egyptian materials and technology, Cambridge University Press, Cambridge.

Nicholson, P. T. and Jackson, C., 2013, Glass of Amenhotep II from Tomb KV55 in the Valley of the Kings, The Journal of Egyptian Archaeology, 99, 85–99.

Nicholson, P. T., Jackson, C. M. and Trott, K. M., 1997, The Ulu Burun glass ingots, cylindrical vessels and Egyptian glass, Journal of Egyptian Archaeology, 83.

Nolte, B., 1968, Die Glassgefässe im alten Ägypten, Münchner Ägyptologische Studien, Verlag Bruno Hessling, Berlin.

Oppenheim, A. L., 1973, Towards a history of glass in the ancient Near East, Journal of the American Oriental Society, 93, 259–266.

Peltenburg, E. J., 1987, Early faience: Recent studies , origins and relations with glass, in (eds. M. Bimson and I. C. Freestone) Early vitreous materials. British Museum, 5–29.

Pulak, C., 2001, The cargo of the Uluburun ship and evidence for trade with the Aegean and beyond, in Bonfante, L., Karageorghis, V., and Costakis and Leto Severis Foundation (eds. C. Nicosia) Italy and Cyprus in antiquity 1500 - 450 BC: proceedings of an international symposium held at the Italian Academy for Advanced Studies in America at Columbia University, November 16-18, 2000. Nicosia: The Costakis and Leto Severis Foundation, 13–60.

Reeves, N. and Wilkinson, R. H., 2008, The Complete Valley of the Kings: Tombs and Treasures of Egypt’s Greatest Pharaohs, Thames & Hudson, London.

Rehren, Th., 2000, New aspects of ancient Egyptian glassmaking, Journal of Glass Studies, 42, 13-24.

Rehren, Th., Pusch, E. and Herold, A., 2001, Problems and possibilities in workshop reconstruction: Qantir and the organisation of LBA glass workshops, (ed. A. J. Shortland) The social context of technological change, Oxbow books, Oxford.

Saleem, S. N. and Hawass, Z., 2016, Scanning the Pharaohs: CT Imaging of the New Kingdom Royal Mummies, American University in Cairo Press, Cairo.

Sayre, E. V and Smith, R. W., 1961, Compositional categories of ancient glass, Science 133, 1824–1826.

Shortland, A., 2002, The use and origin of antimonate colorants in early Egyptian glass, Archaeometry, 44(4), pp. 517–530.

Shortland, A. J. and Eremin, K., 2006, The analysis of second millennium glass from Egypt and Mesopotamia, Part 1: new WDS analyses, Archaeometry, 48(4), 581–605.

Shortland, A. J., Kirk, S., Eremin, K., Degryse, P. and Walton, M. S., 2017, The analysis of Late Bronze Age glass from Nuzi and the question of the origin of glassmaking, Archaeometry, 60(4), 764–783.

Shortland, A. J., Rogers, N. and Eremin, K., 2007, Trace element discriminants between Egyptian and Mesopotamian Late Bronze Age glasses, Journal of Archaeological Science, 34(5), 781–789.

Stern, E. M. and Schlick-Nolte, B., 1994, Early glass of the ancient world: 1600 B.C.-A.D. 50 : Ernesto Wolf collection., Verlag Gerd Hatje, Ostfildern.

Tytus, R. de P., 1903, Preliminary report on the re-excavation of the palace of Amenhetep III, Winthrop Press, New York.

Varberg, J., Gratuze, B. and Kaul, F., 2015, Between Egypt, Mesopotamia and Scandinavia: Late Bronze Age glass beads found in Denmark, Journal of Archaeological Science, 54, 168–181.

Varberg, J., Gratuze, B., Kaul, F., Hansen, A. H., Rotea, M. and Wittenberger, M., 2016, Mesopotamian glass from Late Bronze Age Egypt, Romania, Germany, and Denmark, Journal of Archaeological Science, 74, 184–194.

Walton, M., Shortland, A. J., Kirk, S. and Degryse, P., 2009, Evidence for the trade of Mesopotamian and Egyptian glass to Mycenean Greece, Journal of Archaeological Science, 36, 1496–1503.

5 The Dating and Provenance of Glass Fragments from the Site of Serabit El-Khâdim, Sinai

5.1 Abstract

Serabit el-Khâdim, located on the western coast of the Sinai Peninsula, is the site of an ancient turquoise mine established in the early 12th Dynasty (c. 1985 BCE) and active between the 18th and 20th Dynasties (c. 1550-1136 BCE). The temple dedicated to Hathor at Serabit detail the number of offerings made, thereby recording the level of activity at Serabit during each reign. The last offerings were made by Rameses VI (1143-1136 BCE) corresponding with the collapse of the Late Bronze Age before the site was abandoned. 976 glass fragments were given to the Ashmolean Museum by Flinders Petrie following his 1905-6 excavations. 41 fragments from the collection were selected for LA-ICP-MS analysis with the aim of provenancing and dating an unknown collection of glass using composition and available stylistic features to further narrow the date of manufacture and therefore indicate the possible workshop of origin. The analysis showed that all 41 fragments are of Egyptian provenance and of standard Late Bronze Age high magnesia plant ash glass, except one fragment which is a unique example of natron blue glass applied as decoration to a white plant ash vessel body. Subtle compositional differences show that 18th Dynasty plant ash glass, plant ash Ramesside glass and natron Ramesside glass are all present, therefore corresponding with the known Egyptian activity at Serabit.

Keywords: Glass; New Kingdom; Ramesside; Late Bronze Age; Serabit el-Khâdim; Sinai; LA-ICP-MS; Composition

5.2 Introduction

Serabit el-Khâdim, or Serabit, is an ancient mining development located approximately 7km east of the modern port of Abu Zenima, halfway down the western coast of the Sinai Peninsula. Due to the inhospitable environment, ancient Sinai was regarded as little more than a land bridge connecting Egypt and the Levant until the discovery of turquoise in the early dynastic period (c. 3150 BCE) (Mumford, 1999, p722). Strongly associated with ancient Egyptian jewellery, turquoise is a relatively rare stone and compounded with religious significance (Aldred, 1971, p34), therefore it was a highly prized, luxury item and used extensively for

amulets and jewellery (Aston, Harrell and Shaw, 2000, p62). Despite the extraction of turquoise being exceedingly labour-intensive (Aldred, 1971, p128), the ancient Egyptian market was particularly lucrative, and private Egyptian workers, military forces and ranking officials were dispatched to ensure the successful recovery of the stone (Redford, 1992, p79). Thus, Serabit became what was arguably one of the most significant centres of Egyptian enterprise in the Sinai-peninsula (Wilkinson, 2017, p239).

In the early 12th Dynasty (c. 1985 BCE), a temple dedicated to the Goddess Hathor, also named "the Mistress of Turquoise" and the "Lady of Malachite" was constructed; Hathor was the deity responsible for foreign expeditions and was believed to be the patron goddess of turquoise miners (Giveon, 1978, p54-62). Serabit was also a popular pilgrimage site with many gifts and offerings being placed at the temple as tribute, making evident the ancient Egyptian belief that mining expeditions would only be successful if the proper religious respects were paid (New, 1932; Mumford, 2006; Caelen, 2013). The temple itself contains numerous inscriptions denoting the increasing number of turquoise mining expeditions undertaken from the reign of Amenemhat I (1985-1956 BCE), the first king of the 12th Dynasty, to Amenemhat IV (1786-1777 BCE). Mining activities ceased at the end of the 12th Dynasty (c. 1785 BCE) following the immigration of the Canaanites and invasion of the Hyksos (Barrois, 1932; Grimal, 1992, p391), and only resumed when political stability returned following the formation of the New Kingdom (Mumford, 1999, p724). After 12 years of peace under Amenhotep I (1525-1504 BCE), mining was re-established along with the tradition of monument building; repairs, extensions and embellishments were made to the temple between the reigns of Hatshepsut (1473–1458 BCE) and Amenhotep III (1390-1352 BCE) (Mumford, 1999a, p725; Wilkinson, 2017, p239). It is from the mid-18th Dynasty (c. 1550 BCE) that glass vessels and objects were included as part of the temple offerings. Strictly administered and regulated by the Egyptian royal court, glass became one of the highest symbols of elite status in the New Kingdom (Shortland, Nicholson and Jackson, 2001, p153), therefore the presence of glass core formed vessels at the temple demonstrates the high value of offerings made to Hathor and confirms the importance of turquoise mining activities at Serabit.

According to the temple inscriptions, 71 votive offerings were placed at Serabit between the reigns of Tuthmosis III and Ay (1327-1323 BCE) (Mumford, 2006) and an estimated 329 votives were placed between the reigns of Rameses 1 (1295-1294 BCE) and Tawosret (1188-1186 BCE), with 66 votives offered during the Iron Age (IA) reigns of Sethnakht (1186-1184

BCE) onwards (Mumford, 2006). Further building work, offerings and inscriptions were made between the reigns of Rameses IV (1153-1147 BCE) and Rameses VI (1143-1136 BCE), which were the last recorded activities, with the mines subsequently being abandoned, corresponding with the collapse of the Late Bronze Age (LBA) (Eckenstein, 1921, p63). Periods of mining activity at Serabit and political and social stability in Egypt and the Near East are therefore analogous, indicating that even highly profitable endeavours were abandoned during times of political crisis (Giveon, 1978, p51).

5.3 The Excavation at Serabit

The temple at Serabit was re-discovered in 1762 by Carsten Niebuhr and revisited by several scholars, whose work was largely limited to making copies of inscriptions (Eckenstein, 1921, p17). The first extensive excavation was undertaken by Petrie in the winter of 1905-6, which resulted in the first complete plan of the temple with over 300 photographs taken of the site (Petrie, 1904).

According to Petrie's excavation notes, the temple offerings were mainly of "glazed ware", such as vases, bowls and cups, as well as other offerings such as *menats*, bracelets, sistra and wands. The damage to the offerings was so extensive that no item was observed intact, with the remains forming a layer on the temple floor "two or three inches thick" (Petrie, 1906, p138). After attempting some reconstruction work, Petrie concluded that a large portion of the fragments were missing, likely scattered outside the temple and left to disintegrate in the severe atmospheric conditions (Petrie, 1906, p122, p139).

5.4 Samples

The Serabit expedition finds were divided between several museums, including the Cairo Museum, the British Museum, London, and the Ashmolean Museum, Oxford (Petrie, 1906, p123). 976 glass fragments from Serabit (Accession number E.4486) reside at the Ashmolean Museum (Simpson, 1990). Most fragments are on average between 1 to 4 centimetres, and are coated with a white, salt deposit or the distinctive red-brown deposit that reflects the red Nubian sandstone geology of Serabit. Although heavily coated with deposits, some fragments that have sustained recent breakage show good preservation. The colours are remarkably vibrant; turquoise, light and dark blue hues, black, brown, green and white are included in the collection. Also visible on some fragments are fine examples of feather and garland patterns applied in

white and yellow, as well as rims created from thin, twisted coloured glass rods. Handles and other defining features allows the inference of the vessel type, therefore it can be speculated that pots, amphora, spherical vessels, pomegranate vessels and *kratiskeros* were among those presented to the temple (Nolte, 1968), in addition to items with glass inlays.

Forty-two fragments which exhibited good preservation, glass matrix uniformity and clarity of colour were selected for laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analysis. Description of the fragments are included in Table 13. All fragments included in the study are relatively small, therefore the pattern described per fragment cannot be considered as descriptive of the complete object. Small samples were taken from the fragments with a pair of wire cutters and then mounted in resin blocks and polished**.**

Acc. #	Main body colour	Opaque/ Translucent	Fragment description	Shape and approximate size in centimetres
OX122	Black	Semi translucent	Vessel fragment with feather, garland or arcade dragged pattern applied in two colours: white and apparent yellow/brown. Transecting thicker white band bordering the pattern.	3.0 x 2.5
OX144	Black	Semi translucent	Vessel fragment with straight white band applied transecting the fragment.	2.5 x 1.5
OX299	Black	Translucent	Vessel fragment with straight white band applied transecting the fragment.	3.0 x 2.0
OX358	Amber/brown	Translucent	Vessel fragment with decorative threads of yellow/white visible on the cross section. Pattern imperceptible.	2.5 x 1.5
OX420	Brown	Translucent	Vessel fragment with garland pattern applied in at least two different colours.	4.0 x 4.0
OX561	Brown	Translucent	Vessel fragment with possible decoration applied in yellow.	Oblong fragment 2.0 x 2.5
OX189	Mid Blue	Translucent	Vessel fragment with flat arcade/garland pattern applied with three colour thread combination.	3.5 x 3.0

			Pattern appears to be applied in the pattern form rather than using an implement to drag over the surface, forming the pattern.	
OX193	Dark blue	Translucent	Vessel fragment with elaborate feather pattern applied in apparent white and yellow threads.	Roughly triangular 1.5 x 3.0
OX414	Dark blue	Opaque	Unknown object. No perceptible pattern, prominent white thread transecting the fragment.	3.5 x 1.5
OX433	Dark blue	Translucent	Vessel fragment with possible garland pattern applied in lighter colour.	3.0 x 2.0
OX437	Dark Blue	Translucent	Vessel fragment with possible garland pattern applied in at least two different colours. Rim made from twisted threads.	2 fragments, both 2.0 x 1.5
OX669	Dark blue	Translucent	Vessel fragment with regular white garland/arcade pattern applied in lighter colour.	Triangular fragment 2.5 x 1.5
OX84	Dark blue	Translucent	Vessel fragment with possible feather pattern and two white transecting bands.	2.5 x 3.0
OX107	Dark blue	Semi translucent	Possible vessel fragment with no perceptible pattern.	1.5 x 2.0
OX183	Dark blue	Translucent	Vessel fragment with elaborate pattern (possibly feather) applied in at least three colours	Triangular 3.5 x 2.0
OX200	Dark blue	Translucent	Vessel fragment with pattern applied with yellow, white and light blue threads.	Roughly triangular fragment approx. 3.2 x 1.7 at widest point
OX481	Black/dark blue	Semi translucent	Vessel fragment with white thread present in rim section.	Triangular fragment 2.0 x 2.0

OX501	Dark blue/black	Semi translucent	Unknown object type with no perceptible pattern.	Oblong fragment 3.0 x 2.0
OX70	Light blue	Translucent	Vessel fragment with yellow and dark blue thread applied in a straight design.	1.5 x 2.5
OX103	Turquoise	Translucent	Unknown object type with no perceptible pattern.	3.0 x 2.5
OX127	Mid blue	Translucent	Unknown object type with no perceptible pattern. Semi translucent.	2.0 x 3.5
OX195	Blue	Semi translucent	Vessel fragment with consistent, even feather pattern applied in three (?) colours.	3.5 x 2.0
OX198	Light blue	Translucent	Vessel fragment with apparent feather pattern applied in yellow and white threads, thicker white band transecting the fragment.	Triangular fragment 2.5 x 3.0
OX235	Light blue	Semi translucent	Vessel fragment with possible feather pattern applied in yellow and white threads.	2.0 x 2.0
OX429	Turquoise blue	Translucent	Vessel fragment with no perceptible pattern. Rim contains merged yellow and blue glass.	4.0 x 4.0
OX442	Light blue	Translucent	Vessel fragment with possible garland or feather pattern applied. Rim applied with at least two colours of twisted glass of apparent white and dark blue.	2.5 x 2.0
OX472	Turquoise blue	Translucent	Vessel fragment with feather pattern applied in two other colours, one possibly yellow.	2.5 x 2.0
OX482	Blueish green	Translucent	Vessel fragment with garland pattern applied with at least two different colours, one being yellow. Rim applied in solid opaque yellow.	Triangular fragment 2.0 x 2.0
OX488	Mid blue	Translucent	Vessel fragment with no perceptible pattern, rim applied in darker blue and white twisted glass.	Square fragment 1.0 x 1.0

OX897	Light blue	Translucent	Vessel fragment with no perceptible pattern.	Square fragment 1.7 x 1.5
E.4486	Green	Opaque	Unknown object type. Fragment is flat with no perceptible pattern applied	Irregular shaped fragment 2.5 x 2.0
E.4486.1	Green	Semi translucent	Unknown object type with no perceptible pattern.	Irregular shaped fragment 2.5 x 2.0
OX140	Green	Opaque	Unknown object type with no perceptible pattern.	1.5 x 2.0
OX484	Green/blue	Translucent	Rounded fragment - "leaf" from a pomegranate vessel? Yellow rim applied to the edge of rounded section.	Rounded fragment 2.0 x 1.5
OX77	Black/Purple	Translucent	Vessel fragment with pattern applied in at least two different coloured threads.	3.0 x 2.0
OX85	Purple/brown	Translucent	Unknown object type with no perceptible pattern.	6.0 x 3.0
OX641	White	Opaque	Vessel fragment with dark blue/black band visible under red deposit, white prominent thread transecting fragment	Oblong fragment 3.2 x 1.7
OX264	Yellow	Semi translucent	Vessel fragment with no perceptible pattern.	Roughly triangular fragment 3.0 x 1.7 at widest point
OX444	Yellow	Opaque	Vessel fragment with no perceptible pattern. Rim applied in white and black/dark brown coloured glass.	2.5 x 2.5
OX334	Dark red	Semi translucent	Unknown object type with no perceptible pattern.	2.0 x 2.0
OX226	Amber/brown	Translucent	Vessel fragment with undetermined pattern applied in two lighter colours, possible yellow and white.	3.0 x 2.0

Table 13: Description of glass fragments from Serabit selected for analysis by LA-ICP-MS.

5.5 Methodology

The analyses were carried out with an Agilent 8900 triple quadrupole ICP-MS coupled with an ESI New Wave Research NWR 193 ArF excimer laser. The operating conditions for the laser ablation system were set at 7J/cm^2 with a frequency of 15Hz and a spot size of 70 µm. The ICP-MS was operated with a RF power set at 1380W, a plasma gas flow of 15 L min^{-1} and an auxiliary gas flow of 0.90 L min^{-1}. Helium was used as carrier gas (800 mL min^{-1}) in single MS mode with no cell gas. The ICP-MS was tuned before each session on the glass SRM NIST612 to achieve high sensitivity and stability (RSD < 5%). The plasma condition was monitored with U/Th ratio (0.9–1.1) and ThO/Th ratio was used to assess a low oxide level (ThO/Th < 0.01). The ICP-MS was setup in full-quant mode for the acquisition of 42 masses. Gas blanks were recorded during the 15 sec warm-up time and 15 sec washout time. Each sample was analysed in triplicate with 60 sec of ablation per spot. The first 20 sec of ablation were considered as pre-ablation and were not used in the calculation of the concentration. Quantitative data were obtained using the calibration protocol described by Van Elteren *et al*. (Van Elteren, Tennent and Šelih, 2009) using linear combination of a set of four glass SRMs as external standards (NIST 612, NIST 610, Corning B and Corning D) and SiO_2 as the internal standard. The full set of SRMs used as external standards were regularly measured in the batches and the results were comparable to the accepted values (E P Vicenzi *et al.*, 2002; Jochum *et al.*, 2011; Wagner *et al.*, 2012).

5.6 Results

The glasses contain between 16.0% and 22.8% Na_2O ((Next page) Table 14) therefore represent the expected values for un-weathered Egyptian LBA glass. All samples contain an average of 4.2% MgO and 1.7% K_2O, thus compare with standard Egyptian LBA plant ash glasses produced in the 18th Dynasty (Sayre and Smith, 1961a; Lilyquist *et al.*, 1993; Shortland and Eremin, 2006) The exception is the Co+Cu blue glass from fragment OX641 which is discussed separately.

(Next page) Table 14: Average results for the LA-ICP-MS analyses showing major and minor elements of the samples from Serabit (%).

(From page 143) Table 15: Average results for the LA-ICP-MS trace elements analyses of the samples from Serabit (ppm).

			Major and minor elements [wt %]												
High Magnesia High Potash															
As. Number	**Colour group**	**Translucent/ Opaque**	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**K_2O**	**CaO**	**MnO**	**Fe_2O_3**	**CoO**	**CuO**	**Sb2O3**	**PbO**
OX122	Black	Opaque	16.01	4.64	0.73	67.89	0.11	1.31	7.47	0.02	0.43	0.00	0.01	0.00	0.00
OX144	Black	Opaque	17.75	4.93	0.66	61.72	0.10	1.89	8.11	0.02	0.67	0.00	0.12	0.38	2.42
OX299	Black	Semi-translucent	18.47	4.65	0.76	62.75	0.13	1.76	9.40	0.02	0.43	0.00	0.00	0.00	0.00
Black average			**17.41**	**4.74**	**0.72**	**64.12**	**0.11**	**1.65**	**8.33**	**0.02**	**0.51**	**0.00**	**0.04**	**0.13**	**0.81**
OX358	Brown	Opaque	17.80	4.09	0.65	64.21	0.15	1.61	6.52	0.03	0.45	0.00	1.84	0.15	0.92
OX420	Brown	Opaque	18.34	3.50	0.41	64.99	0.16	1.53	5.81	0.02	0.28	0.00	2.02	0.19	0.88
OX561	Brown	Translucent	18.15	5.33	0.44	63.56	0.16	2.06	6.94	0.03	0.37	0.00	0.87	0.05	0.53
Brown average			**18.10**	**4.30**	**0.50**	**64.25**	**0.16**	**1.73**	**6.42**	**0.02**	**0.37**	**0.00**	**1.58**	**0.13**	**0.78**
OX189	Co blue	Translucent	20.79	5.33	3.17	59.25	0.11	0.98	7.99	0.21	0.44	0.07	0.02	0.03	0.00
OX193	Co blue	Translucent	18.77	3.50	1.10	65.90	0.10	0.93	7.08	0.08	0.52	0.13	0.03	0.01	0.01
OX414	Co blue	Opaque	19.66	3.36	2.12	62.33	0.18	1.20	8.22	0.18	0.33	0.18	0.01	0.29	0.00
OX433	Co blue	Translucent	20.66	4.94	2.25	58.74	0.09	0.84	9.73	0.11	0.47	0.10	0.01	0.07	0.00
OX437	Co blue	Translucent	20.35	5.41	3.01	59.88	0.12	0.93	7.74	0.16	0.50	0.08	0.02	0.00	0.00
OX669	Co blue	Translucent	20.30	5.10	2.96	60.19	0.13	0.99	7.85	0.15	0.47	0.07	0.02	0.00	0.00
Co Blue average			**20.09**	**4.61**	**2.43**	**61.05**	**0.12**	**0.98**	**8.10**	**0.15**	**0.45**	**0.10**	**0.02**	**0.07**	**0.00**
OX84	Co+Cu blue	Translucent	20.13	3.57	1.54	64.62	0.09	0.60	6.06	0.18	0.71	0.10	0.35	0.09	0.03
OX107	Co+Cu blue	Opaque	20.67	3.98	1.37	63.29	0.15	1.21	6.25	0.09	0.43	0.19	0.15	0.28	0.00
OX183	Co+Cu blue	Translucent	19.27	4.64	1.56	61.05	0.16	1.51	8.26	0.11	0.49	0.06	0.97	0.07	0.00
OX200	Co+Cu blue	Translucent	22.27	3.51	2.95	61.04	0.09	0.90	6.24	0.20	0.52	0.10	0.22	0.00	0.00
OX481	Co+Cu blue	Opaque	19.05	3.80	1.33	66.23	0.15	1.12	5.61	0.08	0.40	0.16	0.13	0.25	0.00
OX501	Co+Cu blue	Opaque	21.67	3.90	1.39	58.89	0.15	1.07	8.79	0.14	0.90	0.07	0.18	0.50	0.16
Co+Cu blue average			**20.51**	**3.90**	**1.69**	**62.52**	**0.13**	**1.07**	**6.87**	**0.13**	**0.58**	**0.11**	**0.33**	**0.20**	**0.04**

			Major and minor elements [wt %]												
High Magnesia High Potash															
As. Number	**Colour Group**	**Translucent/ Opaque**	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**K_2O**	**CaO**	**MnO**	**Fe_2O_3**	**CoO**	**CuO**	**Sb2O3**	**PbO**
OX70	Cu blue	Translucent	16.69	3.98	0.83	67.27	0.17	1.46	7.29	0.02	0.46	0.00	0.45	0.02	0.05
OX103	Cu blue	Translucent	18.35	4.28	0.37	62.97	0.16	2.27	9.16	0.01	0.22	0.00	0.49	0.04	0.28
OX127	Cu blue	Translucent	18.58	3.44	0.55	64.88	0.16	1.74	7.57	0.02	0.33	0.00	0.97	0.01	0.00
OX195	Cu blue	Opaque	19.31	3.23	0.35	64.37	0.23	2.52	6.21	0.02	0.28	0.00	0.42	1.28	0.00
OX198	Cu blue	Semi-translucent	18.15	4.28	0.83	63.95	0.17	1.51	7.59	0.02	0.46	0.00	1.05	0.26	0.01
OX235	Cu blue	Translucent	18.09	4.49	0.53	66.08	0.21	1.41	6.57	0.02	0.33	0.00	0.71	0.02	0.00
OX429	Cu blue	Translucent	18.69	4.80	0.73	62.77	0.21	2.44	7.75	0.02	0.41	0.00	0.76	0.00	0.00
OX442	Cu blue	Opaque	22.81	3.33	0.36	60.72	0.22	2.57	6.80	0.02	0.31	0.00	0.58	0.44	0.00
OX472	Cu blue	Opaque	19.44	4.46	0.63	61.17	0.18	1.87	8.18	0.02	0.39	0.00	1.24	0.60	0.02
OX482	Cu blue	Translucent	16.69	3.66	0.78	67.58	0.15	1.22	7.41	0.02	0.48	0.00	0.38	0.07	0.14
OX488	Cu blue	translucent	20.48	4.16	0.51	63.00	0.18	1.76	6.32	0.03	0.31	0.01	1.65	0.02	0.00
OX897	Cu blue	Translucent	18.05	4.42	1.10	65.83	0.19	1.45	6.48	0.02	0.33	0.00	0.69	0.02	0.00
Cu blue average			**18.78**	**4.04**	**0.63**	**64.22**	**0.19**	**1.85**	**7.28**	**0.02**	**0.36**	**0.00**	**0.78**	**0.23**	**0.04**
E.4486	Green	Opaque	18.54	4.72	0.39	61.34	0.20	2.42	9.07	0.01	0.28	0.00	0.01	0.16	1.46
E.4486.1	Green	Semi-translucent	20.01	3.88	0.49	65.32	0.16	1.87	6.22	0.02	0.32	0.00	0.01	0.00	0.00
OX140	Green	Semi-translucent	18.82	4.87	0.47	63.20	0.11	1.65	8.97	0.02	0.28	0.00	0.01	0.00	0.00
OX484	Green	Opaque	17.22	4.33	0.48	61.41	0.15	2.07	9.20	0.02	0.42	0.00	0.01	0.50	2.81
Green average			**18.65**	**4.45**	**0.46**	**62.82**	**0.16**	**2.00**	**8.37**	**0.02**	**0.33**	**0.00**	**0.01**	**0.16**	**1.07**
OX77	Purple	Translucent	18.28	3.65	0.57	65.04	0.20	2.26	6.98	0.75	0.71	0.00	0.05	0.00	0.00
OX85	Purple	Translucent	19.69	3.79	0.58	63.08	0.18	1.94	8.50	0.27	0.34	0.00	0.01	0.00	0.00
OX444	Purple	Translucent	19.43	3.39	0.80	63.90	0.17	1.83	7.58	0.21	0.80	0.09	0.00	0.00	0.00
Purple average			**19.13**	**3.61**	**0.65**	**64.01**	**0.18**	**2.01**	**7.69**	**0.41**	**0.62**	**0.03**	**0.02**	**0.00**	**0.00**

OX122	White	Opaque	18.43	4.01	0.48	64.60	0.21	2.34	6.70	0.03	0.28	0.00	0.18	0.85	0.01
OX641	White	Opaque	21.75	3.35	0.54	61.49	0.17	1.71	6.27	0.02	0.31	0.00	0.16	2.26	0.00
White Average			**20.09**	**3.68**	**0.51**	**63.05**	**0.19**	**2.02**	**6.48**	**0.02**	**0.30**	**0.00**	**0.17**	**1.56**	**0.01**
OX264	Yellow	Opaque	19.71	4.79	0.40	59.00	0.22	2.47	9.56	0.01	0.29	0.00	0.09	0.20	1.51
OX444	Yellow	Opaque	17.07	4.65	0.65	56.34	0.10	1.76	7.75	0.02	1.31	0.00	0.10	1.40	7.36
OX561	Yellow	Opaque	18.04	4.40	0.49	58.99	0.16	2.05	9.32	0.02	0.46	0.00	0.08	0.72	3.35
Yellow average			**18.27**	**4.61**	**0.51**	**58.11**	**0.16**	**2.09**	**8.88**	**0.02**	**0.69**	**0.00**	**0.09**	**0.77**	**4.07**
OX334	Red	Opaque	20.55	3.79	0.41	63.91	0.24	2.20	5.45	0.02	0.26	0.00	1.20	0.14	0.01
OX226	Amber	Translucent	19.91	4.23	0.38	64.74	0.26	2.80	5.43	0.03	0.25	0.00	0.01	0.00	0.00
Low Magnesia Low Potash															
OX641	Co+Cu blue	Opaque	21.80	0.49	1.00	64.94	0.03	0.91	2.69	0.01	0.69	0.08	1.33	1.08	2.76

Trace elements (ppm)

High Magnesia High Potash

As. Number	Colour group	Translucent/ Opaque	Li	Be	B	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Zr	Nb	Ag	Sn	Sb	Cs	Ba	La	Ce	Au	Pb	Th	U
OX122	Black	Opaque	5.9	0.1	54	427	7.5	5.3	186	3012	6.7	7.6	46.4	10.8	1.3	7.3	670	22.5	1.5	0.1	2.2	26.1	0.2	49.5	3.2	6.1	0.0	13.4	0.6	0.2
OX144	Black	Opaque	5.2	0.2	65	338	6.7	5.3	148	4665	1.9	4.7	926	15.1	8.5	8.1	710	29.2	1.3	6.1	7.4	3174	0.1	37.7	2.3	4.7	0.0	20991	0.6	0.2
OX299	Black	Semi-translucent	4.9	0.1	70	446	8.3	6.6	170	3010	1.9	4.1	24.8	12.6	1.2	8.8	1075	38.4	1.6	0.4	0.6	21.0	0.2	39.2	2.9	5.7	0.0	2.7	0.7	0.3
Black average			**5.3**	**0.2**	**63**	**403**	**7.5**	**5.8**	**168**	**3562**	**3.5**	**5.4**	**332**	**12.8**	**3.7**	**8.0**	**819**	**30.0**	**1.4**	**2.2**	**3.4**	**1074**	**0.2**	**42.1**	**2.8**	**5.5**	**0.0**	**7002**	**0.6**	**0.3**
OX358	Brown	Opaque	6.8	0.1	88	372	6.6	5.8	215	3165	10.9	13.6	14727	24.8	26.8	6.9	507	33.3	1.2	4.1	746	1211	0.1	42.4	2.4	4.6	0.7	7927	0.5	0.3
OX420	Brown	Opaque	4.1	0.1	72	240	5.0	4.9	128	1946	2.9	9.7	16155	223	40.4	7.2	524	27.0	0.8	4.5	1517	1574	0.1	48.5	1.8	3.4	3.7	7648	0.4	0.3
OX561	Brown	Translucent	7.2	0.1	74	237	5.5	3.9	231	2571	3.9	6.8	6972	758	37.8	6.6	593	16.8	1.0	1.6	343	423	0.1	37.9	2.3	4.4	0.4	4599	0.4	0.2
Brown average			**6.0**	**0.1**	**78**	**283**	**5.7**	**4.9**	**191**	**2561**	**5.9**	**10.0**	**12618**	**335**	**35.0**	**6.9**	**541**	**25.7**	**1.0**	**3.4**	**869**	**1070**	**0.1**	**42.9**	**2.1**	**4.2**	**1.6**	**6725**	**0.5**	**0.2**
OX189	Co blue	Translucent	9.1	2.6	84	328	6.2	4.1	1607	3059	562	369	141	698	2.3	5.0	703	32.1	1.2	0.0	6.4	217	0.1	29.4	3.0	8.2	0.0	6.9	41.9	41.9
OX193	Co blue	Translucent	7.0	0.8	148	434	7.4	4.4	646	3614	1060	1260	250	279	2.3	3.9	495	38.1	1.3	0.1	15.7	85.5	0.0	32.6	2.5	5.3	0.0	47.9	0.4	0.2
OX414	Co blue	Opaque	5.6	0.6	106	311	4.9	3.2	1398	2291	1391	820	52.4	1600	6.0	6.0	1328	29.3	1.0	0.1	1.4	2463	0.1	31.1	2.2	6.1	0.0	19.2	0.4	0.2
OX433	Co blue	Translucent	10.3	2.2	133	457	7.6	7.1	861	3262	787	877	89.6	462	3.1	5.2	1084	58.5	1.6	0.2	5.9	558	0.1	45.0	3.3	7.5	0.0	10.6	0.6	0.3
OX437	Co blue	Translucent	9.6	1.7	132	407	7.1	3.7	1274	3473	638	423	648	762	2.5	4.7	725	37.9	1.4	0.1	7.4	8.4	0.1	33.3	3.6	9.5	0.0	5.2	1.1	0.7
OX669	Co blue	Translucent	9.9	1.5	128	377	6.9	4.1	1158	3286	515	310	128	547	2.2	4.9	736	38.9	1.4	0.1	4.3	9.2	0.0	34.2	3.4	8.3	0.0	5.2	0.7	0.3
Co Blue average			**8.6**	**1.6**	**122**	**386**	**6.7**	**4.4**	**1157**	**3164**	**826**	**677**	**218**	**725**	**3.1**	**4.9**	**845**	**39.1**	**1.3**	**0.1**	**6.9**	**557**	**0.0**	**34.3**	**3.0**	**7.5**	**0.0**	**15.8**	**7.5**	**7.3**
OX84	Co+Cu blue	Translucent	10.9	0.9	134	678	11.3	8.0	1383	4967	788	634	2776	250	10.0	4.7	418	49.1	2.4	0.3	209	714	0.1	49.4	4.9	10.1	0.1	299	1.1	0.7
OX107	Co+Cu blue	Opaque	8.4	0.4	120	473	8.4	6.5	704	3015	1476	1331	1209	358	11.1	5.9	517	46.8	1.6	0.3	68.4	2346	0.1	40.3	3.2	6.6	0.2	29.0	0.4	0.9
OX183	Co+Cu blue	Translucent	7.1	0.5	98	476	8.7	6.1	857	3405	482	259	7748	664	30.7	9.4	807	38.5	1.8	1.1	789	552	0.2	42.5	3.5	7.7	0.2	43.1	0.8	0.4
OX200	Co+Cu blue	Translucent	9.9	1.8	132	474	7.2	5.8	1547	3644	781	570	1742	821	5.6	5.3	701	46.0	1.5	0.3	100	16.9	0.1	40.1	3.1	7.4	0.2	13.4	0.7	0.3
OX481	Co+Cu blue	Opaque	6.2	0.4	123	452	6.9	5.4	646	2822	1256	1186	1061	291	8.6	4.9	427	39.2	1.4	0.2	59.9	2122	0.1	36.5	2.7	5.4	0.2	26.8	0.6	0.3
OX501	Co+Cu blue	Opaque	10.6	0.7	73	585	12.4	9.9	1087	6292	527	343	1474	221	17.5	4.1	757	39.6	1.7	0.4	186	4175	0.1	46.2	3.2	7.0	0.3	1427	1.1	0.8
Co+Cu blue average			**8.9**	**0.8**	**114**	**523**	**9.1**	**6.9**	**1037**	**4024**	**885**	**721**	**2668**	**434**	**13.9**	**5.7**	**604**	**43.2**	**1.7**	**0.4**	**235**	**1654**	**0.1**	**42.5**	**3.4**	**7.3**	**0.2**	**306**	**0.8**	**0.5**

High Magnesia High Potash

As. Number	Colour group	Translucent/ Opaque	Li	Be	B	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Zr	Nb	Ag	Sn	Sb	Cs	Ba	La	Ce	Au	Pb	Th	U
OX70	Cu blue	Translucent	5.3	0.2	75	480	8.2	6.5	164	3241	5.7	7.0	3591	20.4	13.2	7.0	479	30.6	1.6	0.3	179	208	0.1	41.7	3.2	6.2	0.1	413	0.7	0.3
OX103	Cu blue	Translucent	6.3	0.1	83	198	3.9	2.7	82	1507	2.2	3.6	3896	149	7.5	6.5	1092	17.9	0.7	0.6	201	301	0.1	25.9	1.4	2.6	0.4	2442	0.3	0.1
OX127	Cu blue	Translucent	5.8	0.1	78	335	6.5	3.0	135	2340	3.6	7.0	7747	13.8	22.4	7.4	569	29.9	1.1	0.6	536	91.7	0.1	29.1	2.1	4.2	0.5	24.7	0.5	0.2

OX195	Cu blue	Opaque	6.2	0.1	87	194	5.5	3.7	193	1974	4.0	4.3	3352	52.2	30.2	6.6	552	12.9	0.7	1.4	104	10715	0.1	44.9	1.8	3.4	0.1	28.3	0.3	0.6
OX198	Cu blue	Semi-translucent	7.3	0.0	62	452	8.7	5.3	186	3223	7.9	10.7	8363	24.1	32.6	8.0	630	30.3	1.6	0.4	330	2188	0.1	43.0	3.3	6.4	0.2	45.8	0.7	0.3
OX235	Cu blue	Translucent	4.7	0.1	79	278	5.7	4.0	177	2297	3.6	5.9	5641	13.2	19.4	5.5	532	15.5	1.0	0.3	330	184	0.1	28.9	2.1	4.2	0.1	38.3	0.4	0.2
OX429	Cu blue	Translucent	6.3	0.1	72	459	7.6	5.4	173	2899	2.4	5.7	6089	17.6	18.8	8.5	920	41.0	1.5	0.9	414	5.5	0.1	38.4	2.7	5.3	0.9	16.7	0.6	0.3
OX442	Cu blue	Opaque	6.7	0.1	64	189	6.3	3.6	146	2141	1.8	3.1	4658	41.6	23.1	7.1	602	14.9	0.7	0.7	160	3640	0.1	42.8	2.0	3.8	0.1	16.2	0.4	0.9
OX472	Cu blue	Opaque	7.9	0.1	73	379	7.6	4.8	177	2700	6.7	8.9	9879	21.2	63.2	6.5	737	30.4	1.3	0.7	366	5016	0.1	38.7	2.7	5.3	0.2	132	0.6	0.3
OX482	Cu blue	Translucent	4.1	0.2	84	485	8.1	6.5	168	3340	20.9	18.2	3049	21.1	8.8	4.4	667	26.0	1.3	0.4	269	548	0.1	44.8	2.7	5.4	0.1	1181	0.6	0.3
OX488	Cu blue	translucent	5.2	0.1	77	302	5.7	3.4	225	2159	57.4	48.1	13206	61.6	32.5	5.9	497	16.0	1.0	1.0	913	179	0.1	33.8	1.9	3.7	0.3	26.0	0.4	0.2
OX897	Cu blue	Translucent	4.2	0.1	77	272	5.5	3.9	177	2282	3.6	5.6	5527	13.0	18.7	5.6	514	14.8	0.9	0.4	322	205	0.1	28.4	2.0	4.0	0.1	40.5	0.4	0.2
Cu blue average			**5.8**	**0.1**	**76**	**335**	**6.6**	**4.4**	**167**	**2509**	**10.0**	**10.7**	**6250**	**37.4**	**24.2**	**6.6**	**649**	**23.4**	**1.1**	**0.6**	**344**	**1940**	**0.1**	**36.7**	**2.3**	**4.5**	**0.3**	**367**	**0.5**	**0.3**
E.4486	Green	Opaque	5.7	0.1	75	219	4.3	3.3	106	1980	1.4	2.5	58.1	710	2.6	11.0	1314	24.3	0.8	0.3	1.4	1322	0.1	72.4	1.7	3.3	0.0	12641	0.4	0.2
E.4486.1	Green	Semi-translucent	4.2	0.1	72	292	5.7	4.6	158	2243	1.6	3.2	43.8	12.4	1.0	8.3	535	21.2	1.0	0.1	1.1	13.0	0.1	29.4	1.7	3.3	0.0	2.4	0.4	0.2
OX140	Green	Semi-translucent	6.5	0.1	62	270	5.2	5.2	128	1948	2.1	3.3	98.2	19.8	1.2	33.1	1232	28.7	1.0	0.1	2.1	7.2	0.6	24.0	1.9	3.9	0.0	12.7	0.4	0.2
OX484	Green	Opaque	5.5	0.1	69	288	5.5	4.8	125	2966	1.8	3.5	54.2	1067	4.5	9.6	1397	36.0	1.0	0.5	2.9	4155	0.1	89.7	2.1	4.2	0.0	24358	0.5	0.4
Green average			**5.5**	**0.1**	**70**	**267**	**5.2**	**4.5**	**129**	**2284**	**1.7**	**3.1**	**63.6**	**452**	**2.3**	**15.5**	**1120**	**27.6**	**1.0**	**0.3**	**1.9**	**1374**	**0.2**	**53.9**	**1.8**	**3.7**	**0.0**	**9254**	**0.4**	**0.2**
OX77	Purple	Translucent	9.1	1.0	65	341	8.9	4.3	5795	4948	9.7	12.3	386	157	3.6	8.5	552	23.5	1.3	0.4	11.3	33.7	0.1	50.4	3.0	5.8	0.0	26.9	0.6	0.6
OX85	Purple	Translucent	6.2	0.1	58	384	7.8	5.8	2080	2389	2.2	3.3	51.6	22.9	1.7	8.2	897	37.2	1.3	0.1	3.1	0.9	0.1	57.1	2.3	4.5	0.0	4.2	0.5	0.3
OX444	Purple	Translucent	6.3	0.4	84	491	8.0	7.1	1651	5606	717	281	30.8	132	1.1	5.9	787	29.7	1.5	0.0	1.4	11.7	0.1	45.8	2.6	6.2	0.0	8.8	0.7	0.3
Purple average			**7.2**	**0.5**	**69**	**405**	**8.2**	**5.7**	**3175**	**4314**	**243**	**99**	**156**	**104**	**2.1**	**7.5**	**746**	**30.1**	**1.3**	**0.2**	**5.2**	**15.4**	**0.1**	**51.1**	**2.7**	**5.5**	**0.0**	**13.3**	**0.6**	**0.4**
OX122	White	Opaque	8.6	0.1	100	315	5.4	3.3	205	1981	1.4	2.6	1401	12.6	23.3	4.9	576	21.8	0.9	0.1	1977	7137	0.1	37.3	1.9	3.6	0.0	63.4	0.4	0.2
OX641	White	Opaque	4.5	0.1	71	335	6.7	3.3	169	2173	1.9	2.9	1304	15.1	30.5	4.9	555	13.3	1.0	0.3	1.2	18899	0.1	30.2	1.9	3.7	0.3	27.1	0.5	0.4
White Average			**6.6**	**0.1**	**86**	**325**	**6.1**	**3.3**	**187**	**2077**	**1.6**	**2.7**	**1353**	**13.9**	**26.9**	**4.9**	**565**	**17.5**	**1.0**	**0.2**	**989**	**13018**	**0.1**	**33.8**	**1.9**	**3.7**	**0.2**	**45.2**	**0.4**	**0.3**
OX264	Yellow	Opaque	6.1	0.1	74	237	4.6	3.6	108	2058	1.4	2.7	700	914	3.0	10.9	1371	24.6	0.8	0.4	12.5	1672	0.1	72.0	1.8	3.5	0.0	13053	0.4	0.2
OX444	Yellow	Opaque	5.3	0.4	59	341	6.8	5.4	146	9148	2.0	4.7	827	23.5	23.2	7.4	687	27.3	1.2	11.3	1.6	11654	0.1	38.4	2.3	4.5	0.0	63781	0.6	0.3
OX561	Yellow	Opaque	5.7	0.1	67	295	5.6	5.3	127	3247	1.8	3.7	669	1426	5.8	9.4	1542	36.5	1.0	0.6	3.0	6037	0.1	107.7	2.2	4.2	0.0	29053	0.7	0.4
Yellow average			**5.7**	**0.2**	**67**	**291**	**5.7**	**4.7**	**127**	**4818**	**1.7**	**3.7**	**732**	**788**	**10.7**	**9.2**	**1200**	**29.4**	**1.0**	**4.1**	**5.7**	**6454**	**0.1**	**72.7**	**2.1**	**4.1**	**0.0**	**35295**	**0.6**	**0.3**
OX334	Red	Opaque	5.3	0.1	85	263	5.6	4.0	167	1853	4.2	8.0	9584	17.1	41.5	6.6	424	13.1	0.8	0.9	952	1140	0.1	32.0	1.7	3.3	0.1	45.8	0.4	0.2
OX226	Amber	Translucent	5.3	0.1	91	300	4.2	4.1	255	1719	0.8	1.6	41.9	9.3	0.8	3.9	391	19.1	1.0	0.0	0.4	3.2	0.1	32.5	1.8	3.4	0.0	1.1	0.4	0.1
Low Magnesia Low Potash																														
OX641	Co+Cu blue	Opaque	7.7	0.2	102	591	9.3	6.9	83	4819	667	12.0	10662	92.6	88.3	5.3	222	50.0	1.8	1.1	31.4	8998	0.1	42.4	3.0	6.0	1.6	23930	0.7	0.8

5.7 Provenance

Shortland *et al*. demonstrated that by using a covariant plot of Cr/La vs 1000Zr/Ti, glasses of Egyptian and Mesopotamian origin can be distinguished (Shortland, Rogers and Eremin, 2007). The trace elements from the Serabit study group (Table 15) were plotted against the glasses of known Egyptian and Mesopotamian origin, showing that all Serabit glasses are of Egyptian provenance (Figure 26).

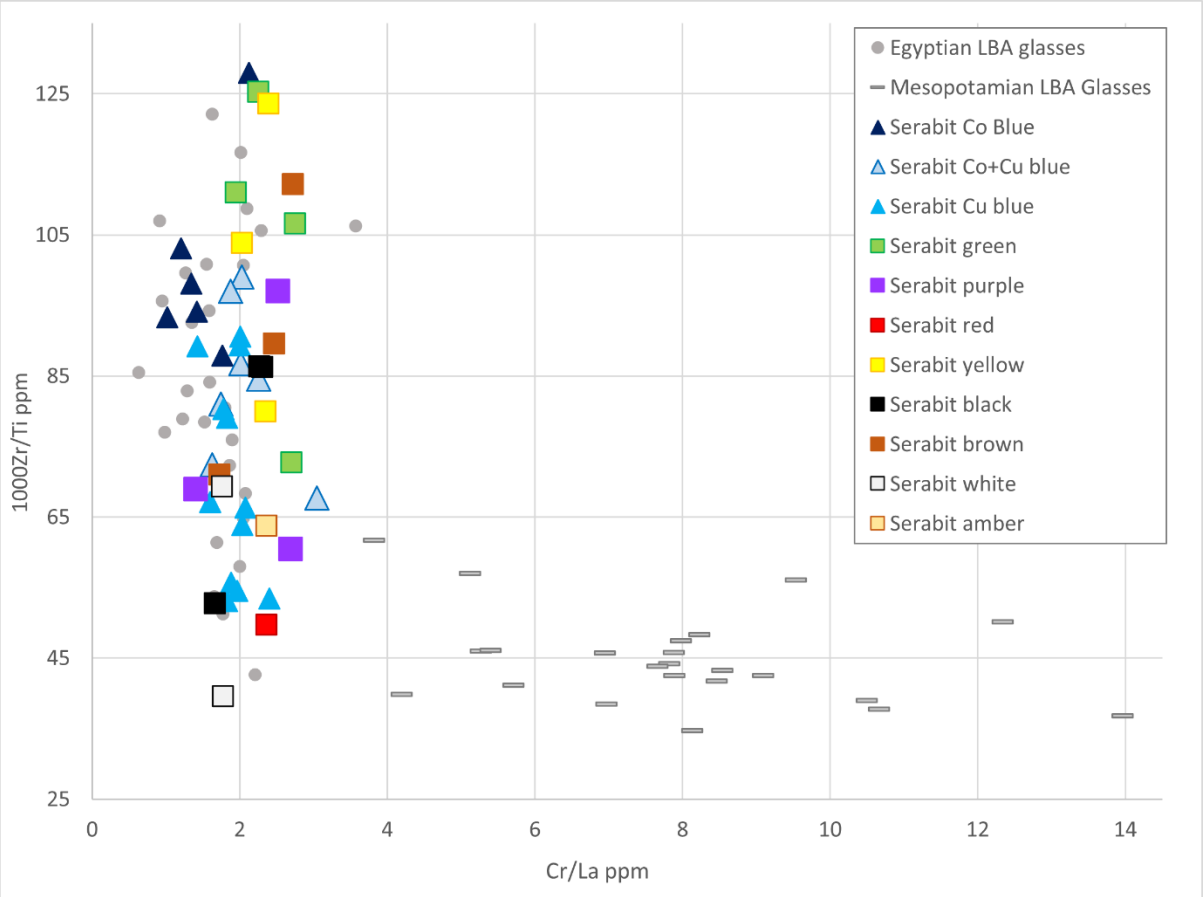


Figure 26: Covariant plot of Cr/La vs. 1000Zr/Ti comparing the glasses from Serabit. Samples are plotted against the Egyptian and Mesopotamian glasses of known origin (Shortland, Rogers and Eremin, 2007).

5.8 Discussion

5.8.1 Style and workshops

Vessels produced between the reigns of Amenhotep III and Akhenaten are considered to represent the “golden era” of Ancient Egyptian glassmaking due to the fine artistry and high

quality of production. New Kingdom vessels are typified by the *amphoriskos* and *krateriskos* shape, created primarily in blue hues, with yellow and white threads applied in feather and garland patterns. Ramesside vessels by comparison show a diversity in colour and shape (such as the introduction of pomegranate and pilgrim flasks) often with no or basic patterns applied. Ramesside glasses are notably less sophisticated, both in glass quality and artistry following the decline of the glass industry after the end of the 18th Dynasty (c. 1295 BCE) (Nolte, 1968).

Two significant Ramesside glass workshops are known: debris from Qantir indicates that this was a primary glassmaking site between c. 1300-1270 BCE (Pusch and Rehren, 2007, p131) for the mass manufacture of red glass (and some cobalt glasses) in the form of ingots rather than objects (Rehren, Pusch and Herold, 2001a; Rehren and Pusch, 2005; Rademakers, Rehren and Pernicka, 2017). The later site of Lisht is known to have produced vessels and other items, such as inlays, in a range of colours including Cu-blue, yellow, white, black, purple, brown and green dated to between 1295-1070 BCE (Keller, 1983). Notably, evidence of cobalt blue glass production at Lisht has not been confirmed, however, evidence of recycling is present at this site (Keller, 1983; Brill, 1999b; Mass, Wypyski and Stone, 2002). Research indicates that glasses produced at Lisht have a distinctive chemical signature, characterised by low levels of lime, alumina and iron oxide in addition to relatively high concentrations of soda compared with other Egyptian glasses (Smirniou, Rehren and Gratuze, 2018). Also, Lisht Cu-blue glasses generally contain very little, if no, tin; therefore, both factors can indicate later Lisht glasses, or be used as exclusion criteria when comparing unknown samples.

Gurob has been identified as a lesser Ramesside glassworking site (Brunton and Engelbach, 1927 Shaw, 2007) and the available analyses suggest that white, black, Cu-blue (with elevated tin) and Co+Cu-blue glasses were worked at the site, the latter containing the “Type R” cobalt source, used exclusively in Ramesside glasses and characterised by low Zn, elevated Ni and lower Al compared with New Kingdom Co-glasses (Abe *et al.*, 2012; Lankton, Pulak and Gratuze, 2022).

5.8.2 Cobalt Blue

All six glasses in the Co blue group contain between 0.84% and 1.2% K_2O with an elevated average content of 2.43% Al_2O_3, therefore comparable to standard CoO Egyptian LBA glasses, which are well published (Shortland and Eremin, 2006; Shortland, Rogers and Eremin, 2007; Kemp, Brownscombe and Shortland, 2021). The glasses in this group are coloured with an

average of 0.1% CoO and exhibit elevated levels of associated elements Mn, Ni, and Zn and with an average of 0.15%, 677ppm, and 725ppm respectively. Therefore all glasses in the Serabit CoO group are coloured with the characteristic cobaltiferous alum used exclusively in the Egyptian 18th Dynasty, known as "Type A", hence were likely manufactured between the reigns of Tuthmosis III (1479-1425 BCE) and Akhenaten (1352-1336 BCE (Kaczmarczyk, 1986; Abe *et al.*, 2012).

5.8.3 Co+Cu Blue

The six glasses contain between 0.06-0.19% CoO and 0.13-0.97% CuO, therefore conform to the definition of Co+Cu glasses (Shortland and Eremin, 2006; Smirniou and Rehren, 2013). All Serabit Co+Cu blue glasses contain an average concentration of 1.69% Al_2O_3 with elevated Ni, Zn, and Mn, hence characteristic of the Type A cobalt source used exclusively in the 18th Dynasty (Kaczmarczyk, 1986; Abe *et al.*, 2012). Therefore, all six Co+Cu glasses were likely produced in the 18th Dynasty. In addition, several fragments from both the Co- and Co+Cu-blue groups exhibit finely applied patterns in several colours and styles, supporting the evidence that these were produced in the 18th Dynasty, likely by expert craftsmen at Malkata or Amarna (Shortland, 2012, p62).

5.8.4 Copper blue

All 12 Cu-blue glasses in this group are within known LBA Egyptian Cu-blue composition ranges, coloured with an average of 0.78% CuO and contain associated elevated levels of Sn of between 104ppm and 913ppm, indicative of a bronze copper source (Kaczmarczyk and Hedges, 1983; Shortland and Eremin, 2006; Shortland, Rogers and Eremin, 2007). Cu-blue glasses are one of the most prevalent types of glass in the Egyptian LBA and outliers of indicative elements can make dating difficult. One dating indicator for later Cu-blue glasses is the use of lead-rich bronze used in the Ramesside period (Rademakers, Rehren and Pernicka, 2017). However, this presents challenges as atypically high lead contents are observed in several studies examining Egyptian Cu blue glasses which are firmly dated to the 18th Dynasty (Shortland and Eremin, 2006; Shortland, Rogers and Eremin, 2007; Lankton, Pulak and Gratuze, 2022).

OX195, OX198 and OX235 exhibit fine examples of feather patterns in yellow and white, therefore are stylistically typical of 18th Dynasty vessels (Nolte, 1968). Two of the Serabit Pb-

rich glasses, OX70 and OX482, have basic yellow patterns applied, therefore the high lead may be due to contaminated crucibles or represent less skilful vessels produced at a later workshop using a lead rich bronze. Stylistic elements on the remaining fragments are either obscured by thick surface deposits or do not have a perceivable pattern, therefore cannot be used to further narrow the production epoch.

5.8.5 Yellow

Although variations are observed in Egyptian LBA yellow glasses, notably in the concentrations of Sb and Pb, the three yellow glasses are comparable with published Egyptian LBA compositions (Shortland and Eremin, 2006; Shortland, 2012; Kemp, Brownscombe and Shortland, 2021). In the 18th Dynasty, yellow glass is more commonly used for decorative elements but became more common for ground colour after the Amarna period (Nolte, 1968). OX264 and OX561 are similar in composition, but different formats; OX264 is a yellow monochrome fragment with no distinguishable pattern whereas OX561 is a brown glass fragment with an undetermined yellow pattern (possibly uneven feather?) applied. Only seven yellow vessels are described in '*Die Glassgefässe im alten Ägypte',* all of which are broadly dated to between the reigns of Tutankhamen (1336-1327 BCE) to Pinodjem II (990-969 BCE) the latter whose reign stands at the end of the 21st Dynasty, therefore it is likely that OX264 is a vessel produced after the Amarna period. OX561 is described in the brown glass section.

OX444 is a rounded, opaque, yellow core formed vessel fragment with a dark and white glass twisted decoration. Two opaque yellow pilgrim flasks, described in *Die Glassgefässe im alten Ägypten*, dated between the 19th and 20th Dynasty, show strong stylistic similarities (Nolte, 1968, p75). OX444 also contains the highest Sb_2O_3, PbO, and Fe_2O_3 content of the group and exhibits significantly higher concentrations of As and Ag with significantly lower concentrations of Zn and Sr, which indicates that the lead source may have been derived from a by-product of silver production, litharge (Mass, Wypyski and Stone, 2002). This would account for the higher Ag content and the low Zn content, which would be considerably depleted during this process. The processing of litharge is a later practice, and therefore supports the proposition that this vessel was likely produced between the 19th and 20th Dynasty (Nolte, 1968). The purple glass from the same fragment (described in the later section) also provides strong evidence for classification of OX444 as a Ramesside glass.

5.8.6 Black

The three black Serabit glasses have the highest average MgO of all the colour groups at 4.74% and the highest Al_2O_3 concentration at 0.72% in the study group, excluding those glasses containing significant cobalt. The Serabit black glasses contain very low levels of Co, Cu and Mn and therefore reflect the colouring strategy that achieves a dark/black hue without the apparent deliberate addition of colourants (Turner, 1956b; Sayre and Smith, 1974). OX122 and OX299 are similar in composition and both appear closer to LBA Egyptian colourless glasses (Shortland, Rogers and Eremin, 2007) compared with early black glasses from the reigns of Tuthmosis III and Amenhotep II, that achieved black hues by colouring the glass a very deep blue or purple using copper, cobalt, manganese or a combination of colourants (Lilyquist, Brill and Wypyski, 1993, p36; Jackson and Nicholson, 2007, p107). Interestingly, the composition of OX144 is comparable with green samples E.4486 and OX484, which also contain trace levels of CuO and elevated Sb_2O_3 and PbO with lower concentrations of Fe_2O_3 and Al_2O_3, indicating that both glasses were manufactured according to an exacting process, possibly at the same workshop.

The Fe-black colouring strategy is identified in other black glasses from Amarna and in later glasses from Lisht, Gurob and Timna (Brill, 1999b; Shortland and Eremin, 2006; Lankton, Pulak and Gratuze, 2022). Therefore, the black Serabit glasses represent later Fe-black glasses, which appear from the reign of Akhenaten. A particularly skilful feather pattern is applied to OX122 which could indicate that this was an early Fe-black glass vessel produced at Amarna.

5.8.7 Green

The four Serabit green glasses fall into two distinct groups: The first group, E.4486 and OX484, contain 0.16% and 0.5% Sb_2O_3, high concentrations of 1.46% and 2.81% PbO respectively, and notably elevated zinc which suggests that they were opacified with lead antimonate (A. J. Shortland, 2002). The second group, E.4486.1 and OX140, contain below 50ppm of Zn, Sb_2O_3 and Pb. All four glasses contain trace CuO, therefore the green hue is likely achieved from natural impurities in the raw materials (Schreurs and Brill, 1984; Varberg, Gratuze and Kaul, 2015).

Remarkably, SEM-WDS analysis of 15 green glasses (working debris, rods and vessel fragments) from the LBA Egyptian sites of Malkata and Amarna (Shortland and Eremin, 2006),

and LA-ICP-MS analysis of 10 green glasses from Amarna (Lankton, Pulak and Gratuze, 2022) showed that all 25 samples were coloured using CuO, 24 of which were opacified using lead antimonate. Research undertaken by Varberg *et al*. identified green glass rods from Amarna that showed three distinct compositions and were of both Egyptian and Mesopotamian origin, confirming not only the exchange of glass between the two regions, but also that both Cu and non-Cu green colouring strategies were worked contemporaneously at Amarna (Varberg *et al.*, 2016). E.4486.1 and OX140 specifically are comparable with a green glass rod from the Varberg study, 7412, which is of Egyptian provenance and exhibits similar low concentrations of Sb, Pb, and Zn all below 50ppm with low levels of CuO (Varberg *et al.*, 2016).

Therefore, the four green Serabit glasses are likely produced from the Amarna period onwards, however, one of the green fragments, OX484, has a distinctive rounded edge with a yellow rim, likely a "leaf" from the neck of a pomegranate vessel. A green pomegranate vessel with a yellow rim is described in *Die Glassgefässe im alten Ägypten* (Accession Number AF 1571, p133, plate number XXVII) and a virtually identical vessel is currently held at the Metropolitan Museum of Art, New York (Accession Number 44.4.52). Pomegranate vessels are broadly dated between the reigns of Tutankhamen (1336-1327 BCE) to Pinodjem II (990-969 BCE) (Nolte, 1968), therefore OX484 represents a later non-Cu green glass produced after the Amarna period (Nolte, 1968).

Brown

The three brown Serabit glasses are compositionally similar and follow the same colouring strategy, containing between 0.87% and 2.02% CuO and likely opacified using lead antimonate. They contain the associated high levels of Sn and As at 867ppm and 33ppm respectively, indicating a bronze Cu source was used. The Serabit brown glasses are therefore compositionally different to brown glasses analysed in the 2006 Shortland *et al*. study which include an early glass, twelve glasses from Malkata and Amarna, and two glasses from Lisht, all of which have no deliberately added colourant (Shortland and Eremin, 2006). Brown vessels are rare and are broadly dated from the reign of Tutankhamun to Pinodjem II (Nolte, 1968), although some brown glasses are known from Amarna (Jackson and Nicholson, 2007a). OX561 has a yellow glass applied which appears to be a later composition from the by-product of litharge practiced in the Ramesside period (Mass, Wypyski and Stone, 2002). Therefore, the three Cu-brown glasses may represent a new colouring strategy at a specialist workshop.

5.8.8 Amber

OX226 is a pale amber hue with no apparent colourant deliberately added, therefore this glass is comparable with published amber/colourless glasses from the LBA (Shortland and Eremin, 2006; Shortland, 2012, p104). Notably, this glass falls within the Lisht compositional criteria.

5.8.9 Purple

The Serabit purple glasses show some variation between the colouring strategies, however all three are comparable with known Egyptian LBA manganese-purple glass compositions (Shortland and Eremin, 2006; Kemp, Brownscombe and Shortland, 2021). Both OX77 and OX444 exhibit a visibly deeper hue than OX85, which contains 0.27% MnO with no additional colourants added. OX77 contains 0.75% MnO, the highest concentration in the Serabit glasses, in addition to an elevated Fe_2O_3 concentration of 0.71%.

OX444 contains 0.21% MnO, 0.80% Fe_2O_3, and interestingly 0.09% CoO which likely contributes to the darker hue. Purple glasses enhanced with cobalt and/or elevated concentrations of Fe have been observed in the LBA, therefore OX444 exhibits a known colouring strategy (Shortland and Eremin, 2006). OX444 contains significantly lower alumina than New Kingdom glasses containing cobalt and has depleted Zn with elevated Ni, therefore comparable with the "Type R" source used during the 19th-20th Dynasty (Abe *et al.*, 2012). This date is consistent with the yellow glass from the same fragment described earlier, and therefore can be confidently dated to the Ramesside period.

5.8.10 Red

OX334, the only red glass from the selected Serabit material, is a standard high magnesia LBA Egyptian red glass coloured with 1.2% CuO and opacified with 0.14% Sb_2O_3 with an associated elevated concentration of Sn (952ppm), As (42ppm) but notably very low lead (46ppm). Red is one of the rarest Egyptian LBA glasses and published compositions from the 18th Dynasty show wide variations in base composition and colouring strategy (Lilyquist *et al.*, 1993; Shortland and Eremin, 2006; Pusch and Rehren, 2007; Kemp, Brownscombe and Shortland, 2021; Lankton, Pulak and Gratuze, 2022). The red glass from Serabit also falls within the Lisht compositional criteria.

5.8.11 White

OX122 is a standard white LBA glass opacified with antimony (Shortland and Eremin, 2006; Kemp, Brownscombe and Shortland, 2021) and applied to a Fe-black vessel, the composition of which indicates a later glass as discussed.

5.8.12 OX641

OX641 is a white core-formed vessel fragment, with a dark blue (possibly garland) pattern applied. The white glass is of standard LBA composition but contains notably high soda, and is low in lime, alumina, and iron oxide, consistent with glasses produced at Lisht (Smirniou, Rehren and Gratuze, 2018). The blue Co+Cu decoration from the same fragment contains 0.49% MgO and 0.91% K_2O, therefore consistent with natron glasses produced in the IA which are characterised by MgO and K_2O concentrations between 0.5-1.5% (Lilyquist *et al.*, 1993, p56). The blue glass contains 2.7% CaO which is significantly lower than the lime content of the other Serabit glasses in addition to containing a high concentration of CuO with low Sn, indicating the use of a pure copper source. The blue OX641 glass also contains 1.0% Al_2O_3 and low levels of nickel, zinc and manganese, therefore compares with "Type N1" cobalt, characterised as having "lack of nickel and depletion of zinc" with low MnO, and used in natron glasses during the Late Period (Abe *et al.*, 2012). Therefore, OX641 represents the first identified example of a vessel composed of a plant ash body with a natron glass decoration.

The OX641 Co+Cu blue glass is similar in composition to those from the tomb of Nesikhons, containing between 0.3-1.2% MgO, 0.4-0.9% K_2O and 1.3-4.8% CaO (Schlick-Nolte and Werthmann, 2003). These glasses are considered to be among the last glass vessels produced in Pharaonic Egypt, manufactured in the early 10th century BCE. OX641, therefore, was the last glass offering made to the temple in the study group and likely corresponds with the culmination of Egyptian presence at Serabit in the 20th Dynasty.

A summary of proposed production dates can be seen in Table 16

As. Number	**Proposed production date**
High Magnesia High Potash glass fragments	
Black	
OX122	Amarna period onwards, from the reign of Akhenaten (1352-1336 BCE) to Rameses VI (1143-1136 BCE).
OX144	
OX299	
Brown	
OX358	Amarna period onwards, from the reign of Akhenaten (1352-1336 BCE) to Rameses VI (1143-1136 BCE).
OX420	
OX561	
Co blue	
OX189	18th Dynasty, between the reigns of Tuthmosis III (1479-1425 BCE) and Akhenaten (1352-1336 BCE).
OX193	
OX414	
OX433	
OX437	
OX669	
Co+Cu blue	
OX107	18th Dynasty, between the reigns of Tuthmosis III (1479-1425 BCE) and Akhenaten (1352-1336 BCE).
OX183	
OX200	
OX481	
OX501	
OX84	

Cu blue	
OX195	Stylistically dated to 18th Dynasty between the reigns of Tuthmosis III (1479-1425 BCE) and Akhenaten (1352-1336 BCE) owing to the fine examples of pattern application.
OX198	
OX235	
OX70	Composition potentially indicates post-Amarna production due to high lead content and basic pattern application. From the reign of Akhenaten (1352-1336 BCE) to Rameses VI (1143-1136 BCE).
OX482	
OX103	Dated to between the reigns of Tuthmosis III (1479-1425 BCE) and Rameses VI (1143-1136 BCE).
OX127	
OX429	
OX442	
OX472	
OX488	
OX897	
Green	
E.4486	Amarna period onwards, from the reign of Akhenaten (1352-1336 BCE) to Rameses VI (1143-1136 BCE).
E.4486.1	
OX140	
OX484	Pomegranate vessel produced between the reigns of Tutankhamen (1336-1327 BCE) and Rameses VI (1151-1143 BCE).
Purple	
OX77	Dated to between the reigns of Tuthmosis III (1479-1425 BCE) and Rameses VI (1143-1136 BCE).
OX85	
OX444	19th-20th Dynasty - Rameses I (1295-1294 BCE) and Rameses VI (1143-1136 BCE).
White	
OX122	Amarna period onwards, from the reign of Akhenaten (1352-1336 BCE) to Rameses VI (1143-1136 BCE).

Yellow	
OX264	Amarna period onwards, from the reign of Akhenaten (1352-1336 BCE) to Rameses VI (1143-1136 BCE).
OX561	
OX444	19th-20th Dynasty - Rameses I (1295-1294 BCE) and Rameses VI (1143-1136 BCE).
Red	
OX334	Dated to between the reigns of Tuthmosis III (1479-1425 BCE) and Rameses VI (1143-1136 BCE).
Amber	
OX226	Dated to between the reigns of Tuthmosis III (1479-1425 BCE) and Rameses VI (1143-1136 BCE).
Low Magnesia Low Potash Co+Cu blue and white glass fragment	
OX641	Likely represents one of the last glass offerings made to the temple, therefore (later) 20th Dynasty.

Table 16: Summary of Serabit glass production periods.

Conclusion

All glasses in the Serabit study group, excluding fragment OX641, are high magnesia plant ash glasses of Egyptian provenance. Excluding OX641, the 12 blue glasses containing cobalt can be confidently dated to the 18th Dynasty by the characteristic cobaltiferous alum, therefore likely produced in the workshops of Malkata and Amarna. Fragment OX444, containing both purple and yellow glass, can also be confidently dated to the 19th-20th Dynasty by the distinctive Type R cobalt signature and likely use of litharge for the lead source. Unlike early compositions of green and black glasses, the Serabit green and black glasses appear to have no deliberate colourant added and therefore compare with later glasses made during the Amarna period and after. The Serabit glass group exhibit differing strategies for producing ‘rarer’ ground colours, which became more commonly used in the Ramesside period, therefore reflective of the increase in activity at Serabit during this time. Where present, the stylistic features of vessel types provided production period ‘milestones’ and were used in conjunction with compositional information to narrow the dates of production; this is exemplified by the green fragment OX484 which is likely a leaf from a pomegranate vessel.

OX641 is a unique example of a vessel using early natron Co+Cu blue glass, coloured with the later N1 cobalt source, to decorate a white vessel made of high magnesia plant ash glass, with both glasses falling clearly within the Egyptian provenance range. That the Co+Cu natron blue glass is applied to a white glass body of standard LBA plant ash glass confirms that the two glass technologies were worked contemporaneously.

Three periods of Egyptian core-formed vessel glassmaking are therefore represented at Serabit: 18th Dynasty plant ash glass, plant ash Ramesside glass and natron Ramesside glass, which corresponds with the known periods of Egyptian activity at Serabit.

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5.9 References

Abe, Y. *et al*. (2012) 'Transition in the use of cobalt-blue colorant in the New Kingdom of Egypt', Journal of Archaeological Science, 39(6), pp. 1793–1808.

Aldred, C. (1971) Jewels of the Pharaohs: Egyptian Jewellery of the Dynastic Period. London: Thames and Hudson Ltd.

Aston, B., Harrell, J. and Shaw, I. (2000) 'Stone', in Nicholson, P. T. and Shaw, I. (eds) Ancient Egyptian materials and technology. Cambridge: Cambridge University Press, pp. 195–226.

Barrois, A. (1932) 'The Mines of Sinai', The Harvard Theological Review. Cambridge University Press, 25(2), pp. 101–121.

Brill, R. H. (1999) Chemical analyses of early glasses: Volume 1 (tables) and 2 (catalogue). Corning, NY: Corning Museum of Glass.

Caelen, V. (2013) Ceramics from the mining site of Serabit el-Khadem, Sinai, stored at the Harvard Semitic Museum - Revisiting of an old collection through petrographic and chemical analysis. KU Leuven.

Eckenstein, L. (1921) A History of Sinai. London ; New York: The Macmillan Co.

Van Elteren, J. T., Tennent, N. H. and Šelih, V. S. (2009) 'Multi-element quantification of ancient/historic glasses by laser ablation inductively coupled plasma mass spectrometry using sum normalization calibration', Analytica Chimica Acta, 644(1–2), pp. 1–9.

Giveon, R. (1978) The impact of Egypt on Canaan: Iconographical and related studies. Freiburg: Vandenhoeck & Ruprecht.

Grimal, N. (1992) A History of Ancient Egypt. Oxford: Blackwell.

Jackson, C. M. and Nicholson, P. T. (2007) Brilliant things for Akhenaten: The Production of Glass, Vitreous Materials and Pottery at Amarna Site O45.1. Edited by P. T. Nicholson. London: Egypt Exploration Society.

Jochum, K. P. *et al*. (2011) 'Determination of reference values for NIST SRM 610-617 glasses following ISO guidelines', Geostandards and Geoanalytical Research, 35(4), pp. 397–429.

Kaczmarczyk, A. (1986) 'The source of cobalt in ancient Egyptian pigments', in Olin, J. S. and Blackman, M. J. (eds) Proceedings of the 24th International Archaeometry Symposium. Washington: Smithsonian, pp. 369–376.

Kaczmarczyk, A. and Hedges, R. E. M. (1983) Ancient Egyptian faience: an analytical survey of Egyptian faience from predynastic to Roman times. Warminster: Aris and Phillips.

Keller, C. A. (1983) 'Problems of dating glass industries of the Egyptian New Kingdom: Examples from Malkata and Lisht', Journal of Glass Studies, 25, pp. 19–28.

Kemp, V., Brownscombe, W. and Shortland, A. J. (2021) 'The investigation and provenance of glass vessel fragments attributed to the tomb of Amenhotep II, KV35, Valley of the Kings', Archaeometry, 64(1), pp. 147–160.

Lankton, J. W., Pulak, C. and Gratuze, B. (2022) 'Glass ingots from the Uluburun shipwreck: Glass by the batch in the Late Bronze Age', Journal of Archaeological Science: Reports. Elsevier Ltd, 42(June 2021), p. 103354. doi: 10.1016/j.jasrep.2022.103354.

Lilyquist, C. *et al*. (1993) ‘Part 2. Glass’, in Lilyquist, C. and Brill, R. H. (eds) Studies in Ancient Egyptian Glass. New York: Metropolitan Museum of Art, pp. 23–58.

Lilyquist, C., Brill, R. H. and Wypyski, M. T. (1993) Studies in Early Egyptian Glass. Metropolitan Museum of Art.

Mass, J. L., Wypyski, M. T. and Stone, R. E. (2002) ‘Malkata and Lisht glassmaking technologies: towards a specific link between second millennium BC metallurgists and glassmakers’, Archaeometry, 44(1), pp. 67–82.

Mumford, G. (2006) ‘Egypt’s New Kingdom Levantine Empire and Serabit el-Khadim, Including a Newly Attested Votive Offering of Horemheb’, Journal of the Society for the Study of Egyptian Antiquities, 33.

Mumford, G. D. (1999) ‘Serabit el-Khadim’, in Bard, K. (ed.) Encyclopedia of the Archaeology of Ancient Egypt. London: Routledge, pp. 722–725.

New, S. (1932) ‘The Temple of Hathor’, The Harvard Theological Review. Cambridge University Press, 25(2), pp. 122–129.

Nolte, B. (1968) Die Glassgefässe im alten Ägypten, Münchner Ägyptologische Studien. Berlin: Verlag Bruno Hessling.

Petrie, W. M. F. (1904) ‘The Sinai Expedition’, Archaeological Report (Egypt Exploration Fund). Egypt Exploration Society, pp. 10–12.

Petrie, W. M. F. (1906) Researches In Sinai. London: John Murray.

Pusch, E. and Rehren, Th (2007) Hochtemperatur-Technologie in der Ramses-Stadt: Rubinglass für den Pharao - Teil 2. Hildesheim: Gerstenburg.

Pusch, E. and Rehren, Th (2007) Hochtemperatur-Technologie in der Ramses Stadt: Rubinglas für den Pharao - Teil 1. Hidesheim: Gerstenburg.

Rademakers, F. W., Rehren, Th. and Pernicka, E. (2017) ‘Copper for the Pharaoh: Identifying multiple metal sources for Ramesses’ workshops from bronze and crucible remains’, Journal of Archaeological Science, 80, pp. 50–73.

Redford, D. (1992) Egypt, Canaan, and Israel in ancient times. Princeton: Princeton University Press.

Rehren, Th. and Pusch, E. (2005) 'Late Bronze Age glass production at Qantir-Piramesses, Egypt', Science, 308, p. 1756.

Rehren, Th., Pusch, E. and Herold, A. (2001) 'Problems and possibilities in workshop reconstruction: Qantir and the organisation of LBA glass workshops', in Shortland, A. J. (ed.) The social context of technological change. Oxford: Oxbow books.

Sayre, E. V and Smith, R. W. (1961) 'Compositional categories of ancient glass', Science 133, pp. 1824–1826.

Sayre, E. V and Smith, R. W. (1974) 'Analytical studies in ancient Egyptian glass', in Bishay, A. (ed.) Recent Advances in the Science and Technology of Materials. New York.

Schlick-Nolte, B. and Werthmann, R. (2003) 'Glass Vessels from the Burial of Nesikhons', Journal of Glass Studies. Corning Museum of Glass, 45, pp. 11–34.

Schreurs, J. W. H. and Brill, R. H. (1984) 'Iron and sulfur related colors in ancient glasses', Archaeometry, 26(2), pp. 199–209.

Shortland, A. J. (2002) 'The use and origin of antimonate colorants in early Egyptian glass', Archaeometry, 44(4), pp. 517–531.

Shortland, A. J. (2012) Lapis Lazuli from the Kiln : Glass and Glassmaking in the Late Bronze Age. Leuven: Leuven University Press.

Shortland, A. J. and Eremin, K. (2006) 'The analysis of second millennium glass from Egypt and Mesopotamia, Part 1: new WDS analyses', Archaeometry, 48(4), pp. 581–605.

Shortland, A. J., Nicholson, P. T. and Jackson, C. M. (2001) 'Glass and Faience at Amarna: different methods of both supply for production, and subsequent distribution.', in Shortland, A. J. (ed.) The Social Context of Technological Change. Oxford: Oxbow Books, pp. 147–160.

Shortland, A. J., Rogers, N. and Eremin, K. (2007) 'Trace element discriminants between Egyptian and Mesopotamian Late Bronze Age glasses', Journal of Archaeological Science, 34(5), pp. 781–789.

Simpson, P. (1990) 'Egyptian Core Glass Vessels from Sinai', The Journal of Egyptian Archaeology. Egypt Exploration Society, 76, pp. 185–186.

Smirniou, M. and Rehren, Th. (2013) 'Shades of blue - cobalt-copper coloured blue glass from New Kingdom Egypt and the Mycenaean world: A matter of production or colourant source?', Journal of Archaeological Science, 40, pp. 4731–4743.

Smirniou, M., Rehren, Th. and Gratuze, B. (2018) 'Lisht as a New Kingdom Glass-Making Site with Its Own Chemical Signature', Archaeometry, 60(3), pp. 502–516.

Turner, W. E. S. (1956) 'Studies in ancient glasses and glass making processes. Part IV. The chemical composition of ancient glasses', Journal of the Society of Glass Technology, 40, pp. 162–184.

Varberg, J. *et al*. (2016) 'Mesopotamian glass from Late Bronze Age Egypt, Romania, Germany, and Denmark', Journal of Archaeological Science, 74, pp. 184–194.

Varberg, J., Gratuze, B. and Kaul, F. (2015) 'Between Egypt, Mesopotamia and Scandinavia: Late Bronze Age glass beads found in Denmark', Journal of Archaeological Science, 54, pp. 168–181.

Vicenzi, E. P. *et al*. (2002) 'Microbeam characterisation of Corning archaeological reference glasses: new additions to the Smithsonian Microbeam standard collection', Journal of Research of the National Institute Standards and Technology, 107, pp. 719–727.

Wagner, B. *et al*. (2012) 'Critical assessment of the elemental composition of Corning archaeological reference glasses by LA-ICP-MS', Analytical and Bioanalytical Chemistry, 402(4), pp. 1667–1677.

Wilkinson, R. H. (2017) The Complete Temples of Ancient Egypt. London: Thames & Hudson Limited.

6 Dating and Provenance of Glass Artefacts Excavated from the Ancient City of Tall Zirāʿa, Jordan

6.1 Abstract

Fourteen glass objects recovered from excavations at the ancient city of Tall Zirāʿa, Jordan, were analysed using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to determine the period and origin of manufacture. The composition of glasses manufactured in the Late Bronze Age (LBA) and Iron Age are distinctly different, therefore major element analysis can be used to distinguish between the groups relatively easily. The LA-ICP-MS analysis provided quantitative trace element data which were used to determine the provenance of those glasses identified as LBA. This research discusses the implications of the presence of both Egyptian and Mesopotamian LBA glasses and examines the varying compositions and colour strategies employed in both the LBA and Iron Age objects. Specifically, glass in the LBA was considered to be one of the highest status items attainable, playing an instrumental role in diplomatic gift-giving. When considered with the archaeological information, the significance of these finds at Tall Zirāʿa indicates that this city was a settlement of high status, not primarily a convenient trading stop on the Transjordan route.

Keywords: Tall Zirāʿa, Glass, Late Bronze Age, Iron Age, LA-ICP-MS, Egypt, Mesopotamia

6.2 Introduction

The first deliberate manufacture of glass occurs in the sixteenth century BC, although the origin of the material is still a focus of debate; Egypt or Mesopotamia being the most likely innovator. The conventional approach is that glass technology first developed in Mesopotamia (Barag, 1970, p131-4; Moorey, 1994, p192; Shortland *et al.*, 2017) and that the subsequent transfer to Egypt could be ascribed to tribute associated with the successful military campaigns in the Levant by the Egyptian king, Tuthmosis III (1479-1425 BC). Although there is textual and iconographic evidence for the production, supply and transport of glass between Egypt, its vassal Levantine states and Mesopotamia, it is very rare to find Egyptian glass in Mesopotamia or vice versa (Walton *et al*., 2009). The exceptions to date are two green glass rods found in Amarna, Egypt, which have trace element compositions consistent with Mesopotamian glass,

and a collection of blue glass beads and a scarab recovered from a tomb in Gurob, Egypt, which also showed compositional consistency with glasses of known Mesopotamian origin (Varberg *et al.*, 2016; Kemp, McDonald, A and Shortland, 2017; Kemp *et al.*, 2019). Although ubiquitous in modern life, glass in the Late Bronze Age (LBA) was meticulously controlled by the Egyptian royal court (Moorey, 2001, p 4). Glass in the LBA denotated high status and had sufficient value and importance to be a gift appropriate for the upper Egyptian elite, therefore playing an instrumental role in the etiquette of diplomatic gift-giving and tribute (Na'aman, 2000; Shortland, Nicholson and Jackson, 2001). To date, no glass of Egyptian trace element composition has been identified in the Levant or Mesopotamia. However, Egyptian glass has been identified in the Uluburun shipwreck, a vessel which sank in the late 14th Century off the southwest Turkish coast with a large consignment of internationally sourced goods including ebony, pottery from several states, elephant and hippopotamus tusks, copper ingots, tin ingots, and 175 glass ingots (Pulak, 2001; Jackson and Nicholson, 2010). Glass of both Egyptian and Mesopotamian compositions has also been identified at Tyrins, Mycenae (Walton *et al.*, 2009; Smirniou and Rehren, 2013; Varberg *et al.*, 2016).

These observations strongly suggest that Egyptian and Mesopotamian glasses were extensively traded outside of their production areas, and this paper attempts to identify such glasses at Tall Zirāʿa. When referring to glasses as "Mesopotamian", it should be noted that the samples analysed by LA-ICP-MS analysis in Shortland *et al*. 2007 were excavated from the sites of Nuzi and Tell Brak specifically, therefore the term Mesopotamia is used in this paper to describe the collective LBA Near Eastern states that ruled the lands near the Euphrates and Tigris, including Assyria and Babylonia (Oppenheim, 1977, p35-48). Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) provides a quantitative analysis of geologically relevant trace elements including, most importantly, Cr, La, Ti and Zr, which form a "compositional fingerprint" that can be used to ascertain the region of manufacture (Shortland, Rogers and Eremin, 2007). Samples analysed from Tall Zirāʿa are compared with glasses from known centres of LBA glass production: Egypt and Mesopotamia.

When considered with the contextual and historical data of the Tall Zirāʿa site, the provenance data of early glass technology is pertinent to key research questions such as exchange mechanisms between foreign states, and relationships between proximate and distant areas of a single state. Therefore, the provenance information can be used to investigate the connections and diplomatic affiliations that this ancient city maintained with both Egypt and Mesopotamia

through the LBA and IA. In addition, the presence of LBA glass would infer that Tall Zirāʿa was more than a convenient stopping point on a trading route, but an important city in its own right which was rewarded with the one of the highest accolades in the LBA.

6.3 The Levant

The Levant became the centre of an LBA international communication system, with long-distance trade routes playing an integral part (Pfälzner, 2012, p770). The relationship between LBA Levantine potentates of the 'city-states' and the Egyptian royal administration can be perceived from the Amarna Letters, cuneiform tablets which contained the diplomatic correspondences between states (Moran, 1992). From the language used in the Amarna Letters, the Levant was considered as a subordinate vassal state and was persistently subjected to the competing, dominating influences of the Egyptians, Mitanni and Hittites, and endured routine military campaigns which maintained Egyptian and then other supremacy over the Levant (Reader, 2003, p 349). However, trade and improved diplomatic relations between Egypt and Mesopotamia provided the Levant with stability, peace and prosperity, with only minor quarrels forming between neighbouring Levantine cities. The political landscape changed in 1350-1200 BC when the Hittites conquered northern Syria by defeating the Mitanni, thereby initiating critical civil and political disorder.

After the battle of Qadesh in 1275 BC between the Egyptian and Hittite armies, and the subsequent collapse of the LBA, the southern Levant endured an extended period of complex social change during the IA; the 'Great Powers' of Egypt and Mesopotamia withdrew, resulting in urban decline. The resulting power vacuum allowed the Levantine elite to re-establish their power and assume positions of rule, subsequently allowing the city-states to assert their independence and expand their international connections (Joffe, 2002). Some central Levantine cities also continued in a contracted state but were quickly reoccupied by the Philistines, Teukrians and incumbent tribal factions that joined to form the states of Israel (Redford, 1992, p289, p298). The Levant accumulated independent wealth and the Egyptian nation rekindled their interest in goods provided by the lucrative Phoenician trade, maintaining relations to secure the supply of imported and luxury commodities (Goedicke, 1975).

6.4 Tall Zirāʿa

Tall Zirāʿa is located in the Wādī al-ʿArab situated in northern Jordan approximately 5km from the ancient Decapolis city of Gadara in modern-day Umm Qēs (fig. 1). Excavations were carried out by the German Protestant Institute of Archaeology, Amman (GPIA), and the Biblical Archaeological Institute in Wuppertal (BAI), University of Wuppertal. The current excavations are supported by the Department of Antiquities of Jordan and financed by the German Archaeological Institute (DAI).

The site is located in the middle of the Wādī al-ʿArab, providing excellent living conditions with its numerous springs, fertile soil and temperate climate (Hanbury-Tenison, 1984). The Tall measures approximately 200m in diameter, with the highest point located 17m below sea level. The significance of the site can be directly attributed to the artesian spring situated in the centre. The advantageous settlement conditions meant that Tall Zirāʿa was consistently occupied from the Early Bronze Age to the Islamic period, providing the singular opportunity to examine an unbroken comparative stratigraphy (Steuernagel, 1926; Vieweger and Häser, 2017, p16-19). Notably, Tall Zirāʿa was located on a LBA and IA trade route, which connected the Jordan Valley with the Mediterranean coast via the Jezreel plain and Tall al-Ḥiṣn (Beth Shean) in the west and with the Jordanian highlands in the east (Figure 27). Owing to this favourable geography as well as to numerous finds that testify the trade between the inhabitants of Tall Zirā'a with neighbouring regions, the excavators infer that the Wādī al-ʿArab was part of an important trade route connecting Egypt with Syria and Mesopotamia (Vieweger and Häser, 2017, p14, p21–22).

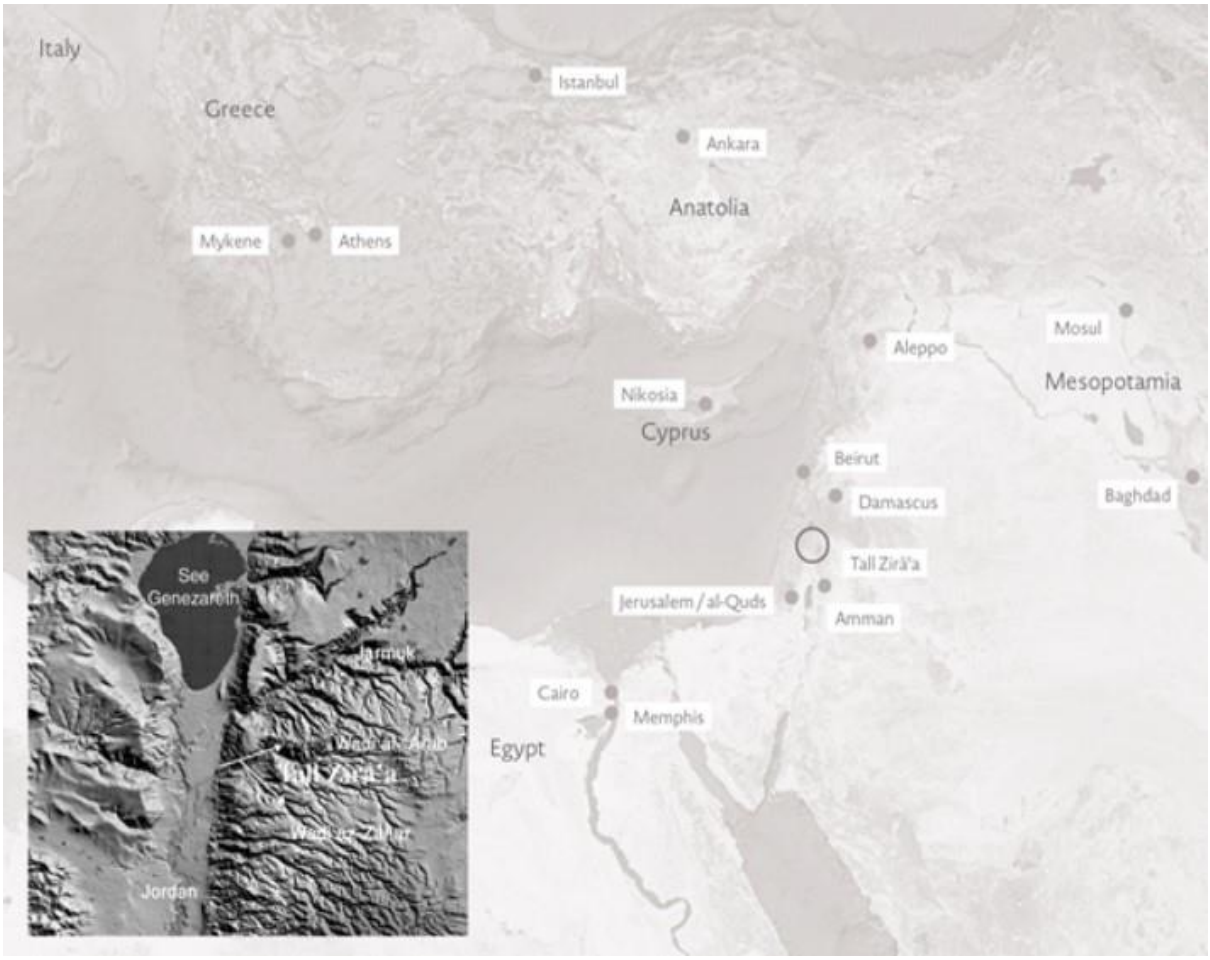


Figure 27: Map showing the location of Tall Zirā'a in the Wādī al-ʿArab (Design after Walter, in Vieweger and Häser, 2019, 29, fig. 1.5).

6.5 Samples and methodology

The glass objects analysed in this paper were excavated from Area I on the western slope of the Tell. Overall, approximately 142 pieces of glass from the LBA (stratum 14, 1500/1450–1200/1150 BC) and approximately 287 pieces from the IA period were recovered: 92 from IA I (stratum 13, 1200/1150–1000/980 BC) and 195 from IA IIA-C (stratum 12–10, 1000/980–520 BC) period.

The LBA settlement (strata 16–14) consists of agglutinating domestic buildings and a casemate wall with an attaching tower. The LBA Temple (complex D) was built on a terrace in the last phase of the LBA period; the radiocarbon samples from the cella of the Temple indicating the date between 1450 and 1300 BC. The discovery in this area of a scarab with the cartouche of the Egyptian king Amenhotep III (1388–1351 BC) confirms this date (Vieweger and Häser,

2019, p57-59). The final LBA phase can be attributed to c. 1200–1150 BC, again according to radiocarbon dating (Soennecken, 2017, p223).

The Temple consists of a rectangular cella (2.15m × 3.40m) with a central column for carrying the roof, a portico, a staircase (numbered D2), a large well-paved courtyard (D4) (150m^2) and four small rooms in the east (D5–8). The solid foundations of the temple, as well as the staircase, indicate that the building had at least two stories (Soennecken, 2017, p171–188, p327; Vieweger and Häser, 2017, p56). Five of the glass objects analysed were found in deposition layers in the Temple cella and one was excavated from the courtyard area, see Table 17.

Unfortunately, many contexts around the temple area which yielded glass finds appear to be disturbed by later building activities, and thus do not provide a precise date, for example: contexts 4674,6343, 2726. Around 1200 BC, the LBA temple together with the entire city was destroyed; shortly after but still during the IA I period the Temple was re-erected but changed its outline. In the IA II period, the temple was abandoned, and residences were built directly on the former IA I Temple using its foundation walls. The two glass finds from the IA II period (stratum 12) were found in a deposition layer (locus 2650) of one of these domestic building complexes, complex B (room B3) (Soennecken, 2017, p588-590).

Sample number	Find number	Object description	Colour	Locus	Context
Iron Age context					
15329	TZ 015329-001	Fragment of a spacer bead	Opaque turquoise	4674	**Stratum 10 (IA IIC)** Deposition layer located in the area above the Late Bronze Age Temple courtyard.
16753	TZ 016753-001	Core formed vessel fragment	Opaque (?) Black/dark blue and white	5410	**Stratum 12 (IA IIA/B)** Deposition layer located in "Complex A", room A3.
10047	TZ 010047-001	Fragment of a spacer bead	Translucent turquoise	2726	**Stratum 12 (IA II A/B)** Deposition layer located west of the large complex B; most probably mixed with earlier layers that belong to the LBA Temple
10048	TZ 010048-001	Fragment of a round bead	Translucent yellow/ brown	2728	**Stratum 13 (IA I)** Round silo in complex G; domestic context with storage facilities and working areas.
18802	TZ 018802-001	Core formed vessel fragment	Translucent dark blue	5942	**Stratum 13 (IA I)** Filling layer located in "Complex C" east of the paved Temple courtyard C1.
16622b	TZ 016622-001	Irregular fragment	Translucent colourless	5105	**Stratum 13 (IA I)**
16622a	TZ 016622-001	Fragment of a hemisphere bead	Translucent yellow	5105	Floor level of area B2, on the outside (north) of the IA I Temple.
Late Bronze Age context					
10779	TZ 010779-001	Fragment of a naked female figurine pendant	Translucent turquoise	2796	**Stratum 14 (LBA)** Deposition layer in the cella of the Temple.
10772	TZ 010772-001	Irregular fragment, probably a piece of raw glass	Opaque white with opaque blue centre	2777	**Stratum 14 d (final LBA)**

10170	TZ 010170-001	Fragment of a disc pendant	Opaque turquoise		Deposition layer in the cella of the Temple.
10762	TZ 010762-001	Fragment of a bead	Translucent dark blue		**Stratum 14 d (final LBA)**
10765	TZ 010765-001	Fragment of a spherical bead	Opaque turquoise		Deposition layer in the cella of the Temple.
16759	TZ 016759-001	Irregular lump	Translucent light green	5520	**Stratum 14 d (final LBA)**
					Deposition layer in courtyard D4 of the LBA Temple complex.
19322	TZ 019322-001	Fragment of a spacer bead	Translucent turquoise	6416	**Stratum 16, 15, 14** (MBA C–LBA)
					"Complex A", room 4, mixed filling layer.
19320	TZ 019320-001	Fragment of a bead	Opaque turquoise	6343	**Stratum 16 (MBA C)**
					Deposition layer in the area of room 9 "Complex B".

Table 17: Summary of objects excavated from Tall Zirāʿa.

The 15 glass or related objects selected for LA-ICP-MS analysis were chosen primarily to represent a range of object types and periods from the site, with the emphasis on the LBA period. Secondly, these objects were selected as they appeared to show a good level of preservation, the criteria of which included no obvious degradation or weathering, strong colour and clarity. Previous experience of work by ICP-MS on glass has shown that weathered, white, powdery glasses (which is often the norm) rarely produce interpretable results and should be avoided.

Small samples around a few millimetres across were clipped from the 15 glass objects and fragments with a pair of wire cutters. The samples were mounted in resin blocks and polished flat. The samples were subjected to LA-ICP-MS analysis at the Natural History Museum, London. The instruments used were an Agilent 7700 ICP-Q-MS mass spectrometer coupled to an ESI NWR193 with laser type ArF excimer with an ablation spot of 50µm, as detailed in the supplementary material.

Each sample was analysed at different 12 spots, avoiding any obvious weathered areas. Rarely, where low sodium values suggested that weathered areas were sampled, these points have been removed to standardise the consistency of the samples and ensure the accuracy of the results.

Corning A standard was run throughout the LA-ICP-MS analysis to check for accuracy and drift. The results are shown in Table 18 where they are compared to established values for the standards. The values for the major elements for Corning A were taken from Vicenzi *et al*. (2002). The results show good agreement for the most elements, with the standards averaging less 10% error on the accuracy. Elements that greatly exceed these values can be split into two groups: elements where the standard only contains parts per billion and it is not well determined (e.g. Au and Cs) and elements where the ICP struggles because of interferences, monoisotopic elements and/or other factors (e.g. P).

			Shortland *et al*. (2007) and Vicenzi *et al*. (2002)		Wagner *et al*. (2012)	
Analyte Measured	Atomic mass	Average Corning A values from Tall Zirāʿa (n=15)	Accepted value mg kg -1	Relative error	Accepted value mg kg -1	Relative error
Na_2O	Na23	14.3	14.3	-0.1	13.4	6.2
MgO	Mg24	2.4	2.7	-11.4	2.5	-4.7
Al_2O_3	Al27	0.9	1.0	-9.0	0.8	10.6
SiO_2	Si29	67.2	66.5	1.1	67.8	-0.8
P_2O_5	P31	0.1	0.1	24.3	0.1	17.6
K_2O	K39	3.0	2.7	8.8	3.5	-15.6
CaO	Ca43	5.2	5.0	2.8	4.9	4.5
MnO	Mn55	1.0	0.9	10.1	1.1	-13.7
FeO	Fe57	0.8	0.8	-1.0	0.9	-5.7
CoO	Co59	0.2	0.2	12.2	0.2	1.3
CuO	Cu65	1.2	1.0	19.4	1.1	9.7
Sb_2O_3	Sb121	1.6	1.3	18.8	1.7	-6.8
PbO	Pb208	0.1	0.1	18.1	0.1	NR
Li	Li7	51.3	46.0	51.0	10.3	0.5
Be	Be9	0.1	0.1	NR	31.8	NR
B	B11	751	537	851	28.5	-13.3
Ti	Ti47	4867	4226	4428	13.2	9.0
V	V51	36.0	34.0	39.0	5.5	-8.4
Cr	Cr52	21.2	18.0	21.0	14.9	0.8
Ni	Ni60	186	160	181	13.8	2.5
Zn	Zn66	413	410	386	0.8	6.6
As	As75	30.7	25.0	NR	18.5	NR

Rb	Rb85	85.8	82.0	82.0	4.5	4.5
Sr	Sr88	935.0	860.0	897.0	8.0	4.1
Zr	Zr90	38.2	40.0	37.0	-4.8	3.1
Nb	Nb93	0.6	0.6	NR	-6.3	NR
Ag	Ag107	17.2	14.0	NR	18.4	NR
Sn	Sn118	1482	1194	1357	19.4	8.4
Sb	Sb121	13109	10649	14002	18.8	-6.8
Cs	Cs133	0.3	0.2	NR	26.4	NR
Ba	Ba137	4651	3905	4122	16.0	11.4
La	La139	0.3	0.3	NR	-6.5	NR
Ce	Ce140	0.2	0.2	NR	19.3	NR
Au	Au197	0.2	0.1	NR	41.4	NR
Bi	Bi209	9.1	7.8	9.0	14.4	1.3
Th	Th232	0.3	0.3	NR	-6.8	NR
U	U238	0.2	0.2	NR	-5.8	NR

Table 18: Average results of the Corning A standard, compared with two sets of reference values (E P Vicenzi *et al.*, 2002; Shortland, Rogers and Eremin, 2007; Wagner *et al.*, 2012). Oxides values in %, elemental values in ppm.

6.6 Results

The average compositions of the major elements in Table 19 show that 14 samples were glasses, and that they fall into three distinct compositional groups: high magnesia/high potash (HMHK), high magnesium/low potash (HMLK) and low magnesia/low potash (LMLK). The remaining sample (16622a) was not glass and is discussed below.

Sample number	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	MnO	FeO	CoO	CuO	Sb_2O_3	PbO
						%							
High Magnesia/High Potash													
10772	15.8	3.9	0.93	58.5	0.19	3.4	9.9	0.03	0.73	0.01	1.04	5.21	0.02
10170	14.1	3.4	0.43	65.3	0.12	2.9	10.4	0.02	0.19	0.00	1.19	1.75	0.02
19322	17.6	3.8	0.54	66.6	0.18	4.4	5.5	0.02	0.35	0.00	0.93	0.00	0.00
10048	19.3	4.8	0.72	65.6	0.19	3.7	5.1	0.05	0.24	0.00	0.00	0.00	0.00
10079	18.2	5.0	0.66	66.8	0.11	3.0	4.7	0.03	0.29	0.00	1.13	0.00	0.00
15329	12.4	3.2	0.39	69.0	0.18	2.4	9.2	0.02	0.16	0.00	1.15	1.72	0.00
19320	12.4	3.1	0.38	69.1	0.18	2.3	9.2	0.02	0.16	0.00	1.16	1.78	0.00
10765	18.2	4.0	1.76	67.2	0.10	2.9	4.1	0.04	0.33	0.00	1.20	0.00	0.00
10047	17.63	5.34	0.70	65.38	0.17	3.48	5.70	0.03	0.19	0.00	1.24	0.00	0.00
Low Magnesia/Low Potash													
18802	17.0	0.6	2.16	65.8	0.11	1.0	8.1	1.20	1.31	0.19	0.32	0.68	1.35
16759	16.5	0.6	2.33	68.7	0.23	1.0	9.0	0.58	0.51	0.00	0.01	0.29	0.02
16622b	11.83	0.94	2.25	72.65	0.06	0.56	11.31	0.01	0.05	0.00	0.00	0.00	0.00
High Magnesia/Low Potash													
16753	18.0	3.5	1.63	66.0	0.12	0.9	8.2	0.16	0.39	0.09	0.10	0.26	0.04
10762	20.6	2.7	2.35	64.6	0.11	1.3	6.2	0.21	0.49	0.14	0.33	0.37	0.02
Non glass													
16622a	0.2	0.0	0.33	99.2	0.00	0.0	0.1	0.00	0.1	0.00	0.00	0.00	0.00

Table 19: Results of the LA-ICP-MS analyses of the major and minor elements of the Tall Zira's samples in wt%.

Sample number	Li	Be	B	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Zr	Nb	Ag	Sn	Sb	Cs	Ba	La	Ce	Au	Pb	Bi	Th	U
	ppm																												
High Magnesia/High Potash																													
10772	15.4	0.2	163	352	11	18	260	5662	48.8	151	8309	78.4	463.7	22.9	554	13.6	1.0	0.9	17.9	43516	0.65	104	2.4	4.6	0.1	209	0.1	0.6	0.3
10170	16.0	0.1	104	163	5	17	167	1466	4.5	35.5	9507	15.7	137.5	10.5	443	5.9	0.4	3.9	31.7	14607	0.41	33.3	1.1	2.1	0.6	147	1.0	0.2	0.1
19322	19.5	0.0	125	198	6	14	166	2756	7.1	18.6	7442	24.4	29.7	15.3	411	7.0	0.5	1.1	3.97	9.3	0.37	43.8	1.4	2.8	0.4	5	0.3	0.3	0.1
10048	26.7	0.1	168	190	6	17	360	1863	1.2	9.2	15.0	16.0	1.18	12.7	501	9.6	0.7	0.1	1.81	0.2	0.31	37.8	1.9	3.8	0.0	5	0.0	0.4	0.2
10079	19.4	0.1	172	249	6	19	229	2293	19.4	14.6	9014	20.2	20.2	6.3	342	7.8	0.7	0.5	2.59	3.3	0.18	33.8	1.9	3.7	0.1	3	0.1	0.4	0.2
15329	16.2	0.0	95	147	4	14	119	1220	1.3	13.8	9227	15.1	82.4	18.4	605	6.5	0.4	1.1	2.44	14408	0.52	42.1	1.2	2.4	0.1	21	0.2	0.2	0.1
19320	14.6	0.1	95	146	4	14	118	1231	1.3	13.7	9310	14.7	81.7	17.7	601	6.4	0.4	1.1	2.48	14868	0.48	41.9	1.2	2.4	0.1	20	0.2	0.2	0.1
10765	24.8	0.4	215	271	8	10	320	2557	7.9	13.9	9628	18.3	19.6	18.7	312	12.1	2.0	0.4	3.75	6.30	0.31	55.0	2.9	5.9	0.1	9	0.3	1.2	0.6
10047	11.9	0.1	119	286	8	23	201	1439	4.2	16.8	9898	24.3	4.5	16.7	337	9.6	0.7	1.8	2.1	32.6	0.3	40.5	1.7	3.5	0.3	9	0.4	0.4	0.2
Low Magnesia/Low Potash																													
18802	5.6	0.3	146	390	17	10	9307	10197	1527	50.3	2575	78.6	36.4	11.6	556	34.8	1.3	1.24	113.5	5707	0.1	255	5.91	10.6	0.11	12496	0.3	0.8	0.8
16759	4.6	0.3	183	528	20	15	4468	3928	5.3	10.7	41.7	29.6	9.9	9.6	459	45.6	1.8	0.09	60.4	2381	0.1	269	6.0	10.8	0.0	206	0.0	0.9	1.1
16622b	24.6	12.9	20.9	272	6	10	47	352	2.5	4.5	7.3	16.9	1130	149	51	247	7.8	0.1	12.9	9.2	11.8	597	8.5	11.5	0.0	41	0.5	6.8	2.7
High Magnesia/Low Potash																													
16753	8.0	1.6	149	589	8	7	1250	3050	735	695	816	2316	10.1	5.7	631	48.3	1.8	0.4	41.5	2176	0.1	64.1	3.5	8.2	0.1	362	0.1	0.9	0.6
10762	11.2	1.4	243	636	11	9	1655	3789	1063	710	2638	1904	27.7	7.5	511	48.9	1.8	0.6	38.2	3102	0.1	63.4	3.4	8.5	0.2	151	0.2	1.0	1.0
Non-Glass																													
16622a	0.0	0.0	67	269	4	1	1	662	0.9	0.4	1.9	5.8	0.0	0.2	8.1	40	0.9	0.0	1.8	0.9	0.0	0.7	0.0	0.2	0.0	0.84	0.0	0.2	0.0

Table 20: Results of the LA-ICP-MS analyses of the trace elements of the Tall Zira's samples in ppm.

6.7 Discussion

LBA glasses found in Egypt and Mesopotamia that date from the middle of the second millennium typically have high soda (15-20%) and significant magnesia (2-5%) and potash (2-4%) (Lilyquist, Brill and Wypyski, 1993, p41; Shortland and Eremin, 2006), suggesting that they were produced using plant ash glass as the principal source of soda, perhaps from the genera *Salicornia* or *Salsola* which are both found in Egypt and the Middle East. Later glasses from the first millennium BC, or Iron Age (IA), used a different source, for example sodium rich evaporite minerals which occur in the Wadi el-Natrun or the Beheira province both located in Egypt (Turner, 1954, 1956b; Henderson, 1985). Natron glasses are characteristically low in both magnesia and potash, with both components at levels of approximately 0.5%, and therefore compositionally distinct from plant ash glasses (Sayre and Smith, 1974). The elemental composition of both plant ash and natron glasses are well published and can be used to distinguish between these glassmaking periods (Sayre and Smith, 1961; Lilyquist, Brill and Wypyski, 1993; Brill, 1999; Henderson, 2000; Shortland and Tite, 2000).

6.8 HMHK and HMLK

The HMHK group is consistent with the typical composition of high magnesia glasses produced in the LBA using a plant ash flux, glasses that are relatively common through Egypt, Mesopotamia and the Greek World. These glasses are low in aluminium, indicating that a relatively pure source of silica was used, such as ground quartz pebbles. The HMHK glasses coloured with copper are relatively low in tin, indicating that an unalloyed source of copper was used. This tin-free copper source is more consistent with Mesopotamian copper coloured glasses from sites such as Nuzi and Tell Brak (Walton *et al.*, 2012), than Egyptian copper coloured glasses which tend to have higher tin contents, although not always (Shortland and Eremin, 2006). Four of the copper coloured glasses contain antimony, which was used to make opaque glasses in this period (Nicholson and Henderson, 2000, p197; Shortland and Eremin, 2006). The addition of an antimony compound creates calcium antimonate crystals in the glass which render it opaque, and at least two different methods of achieving this are known in this period. In Egypt, an antimony compound alone appears to be added to the glass, whereas in Mesopotamia, both a calcium compound and an antimony compound (perhaps combined before addition) are added. This means that whilst in Egyptian sourced glasses the lime content of both the non-opacified and opacified glasses are very similar, in Mesopotamia, the lime

content of antimony opacified glasses tends to be greater than that of the non-opacified glass (A. J. Shortland, 2002; Shortland and Eremin, 2006; Shortland *et al.*, 2017). In the blue glasses from this site, it can clearly be seen that the lime content of the opacified glass (averaging 9.7% CaO) is higher and distinct from the translucent glass (averaging 4.9% CaO). This once again suggests that at least the four opaque blue glasses are more consistent with Mesopotamian technology than Egyptian. The composition of 10765 is consistent with the HMHK group but shows an elevated Al and Nb content.

The single yellow-brown glass, 100488, is the only non-blue glass in the HMHK group. Yellow-brown glasses are relatively rare, but analyses are available from Amarna, Malkata and Lisht (Shortland and Eremin, 2006) and from Nuzi (Kirk, 2009). These glasses range in colour from very pale amber to deep brown due to the presence of relatively low levels of iron in varying oxidisation conditions. The yellow-brown glass in the HMHK group is consistent with the composition of other LBA brown glasses, containing low concentrations of iron (<0.25% FeO) and no other colouring elements in significant concentrations.

Interestingly, two objects of the HMHK group, 15329 and 19320, both spacer-beads, exhibited almost identical compositions for all elements. The compositions are so close that this cannot be mere chance; indeed, the variation is so small as to fall within the range that would be expected if the analysis was carried out on the same piece of glass. It is probable, therefore, that the objects were made from the same glass ingot or glass batch. The contexts in which they were found are different, however, as discussed later. The composition of the HMLK glasses, 16753 and 10762, is consistent with copper-cobalt coloured plant ash glass manufactured in Egypt in the LBA (Shortland and Eremin, 2006). The HMLK group exhibits elevated levels of aluminium, manganese, iron, nickel, and zinc with accompanying low levels of potassium (>1.6% K_2O), which is characteristic of Egyptian cobalt-coloured glasses, made from an Egyptian Oasis sourced cobalt alum-based colourant (Sayre and Smith, 1961; Kaczmarczyk, 1986; Shortland and Eremin, 2006; Walton *et al.*, 2012). The HMLK glasses were also coloured with copper and contained elevated levels of tin, indicating that a tin bearing source of copper was used, such as bronze. Antimony is present once again as an opacifier and at consistent levels to copper/cobalt coloured glasses analysed previously (Shortland and Eremin, 2006).

As mentioned above, concentrations of Cr, La, Ti and Zr can be used to discriminate between glasses produced of Egyptian and Mesopotamian origin (Shortland *et al*., 2007); Egyptian glasses have relatively low Cr and La concentrations with elevated, but varying Zr and Ti concentrations, whereas Mesopotamian glasses have the opposite (Table 20). Figure 28 shows the HMHK and HMLK groups plotted against data from Shortland *et al*. (2007). The HMHK group shows compositional similarities with the glasses from Mesopotamia, whereas the HMLK group showed a strong correlation with Egyptian compositions. This is consistent with the different colouring strategies discussed above and the evidence from the major elemental compositions. The analysis strongly suggests that the nine HMHK glasses, blue and yellow-brown, come from Mesopotamia, whereas the two HMLK cobalt/copper coloured glasses come from Egypt. HMHK glass 10765 exhibits the lowest concentrations of Cr with the highest concentrations of La in the HMHK group, which are comparable with Egyptian composition, however the Ti and Zr levels are consistent with Mesopotamian composition, however this could be an outlier and without a larger sample group, it cannot be said that this sample represents a Levantine glass composition.

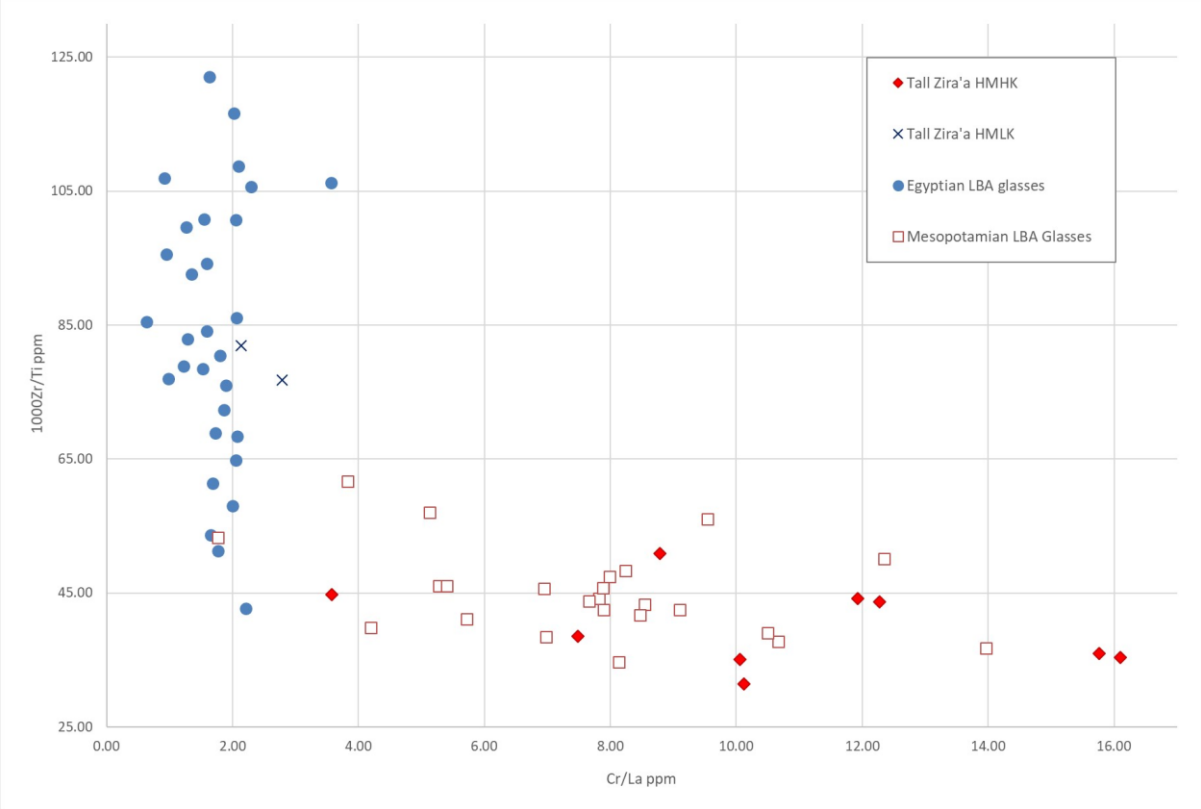


Figure 28: Covariant plot of 1000Zr/Ti with Cr/La of the Tall Zirāʿa HMHK and HMLK groups compared with Egyptian and Mesopotamian glasses of known origin (Shortland, Rogers and Eremin, 2007).

6.9 LMLK

The LMLK group is compositionally consistent with low magnesia glasses produced in the IA and later using natron as an alkali flux and sand as a silica source. The LMLK group has significantly higher levels of aluminium compared with the HMHK group, but comparable with that of the HMLK group (where alumina is introduced with the cobalt colourant). The cobalt-coloured glass (18802) has relatively high levels of a range of elements including cobalt, copper, manganese, iron, lead, antimony, tin and even silver when compared to the other HMLK glasses and such glasses in general. This trace element pattern for the cobalt used to colour the glass has been identified before in other glasses found in Europe from the early IA until the end of the twelfth century (Gratuze, 2013). It is very distinct from the standard; Egyptian Oasis sourced cobalt used in the HMLK glasses and bears compositional similarities with the "Type N" cobalt colourant defined by Abe (2012). Cobalt Type N is recognised as the cobalt colorant that was used after the Late Period, and in distinguished by its relatively low amounts of zinc and a deficiency of nickel. Both levels of zinc and nickel in the cobalt coloured glass 18802 conform with this composition (Abe *et al.*, 2012).

The pale translucent green and colourless translucent glasses appear to have no deliberate colourant added, but in detail they are very different glasses. The translucent green glass (16759) has significant manganese (4469 ppm Mn) and antimony (2381 ppm Sb), suggesting that the glass may have been deliberately decolourised with these elements. The occurrence of both Mn and Sb at intentional levels could also indicate a Roman glass composition. The colourless translucent glass 16622b contains only a tenth of the iron (352 ppm Fe) of 16759 and only trace manganese and antimony. The zirconium content is also high in 16622b. It does, however, contain significant arsenic at 1130 ppm As. The Rb/Sr ratio of the two colourant-free LMLK glasses are very different, with 16759 having a ratio of 0.02 and 16622b much higher at 2.9. 16622b was excavated from an IA context, however the composition is comparable with late 19th Century glasses decolourised with As.

6.10 Archaeological implications

The trace elements of the nine Tall Zirāʿa glasses in the HMHK group match the composition of LBA glasses originating from Mesopotamia, whereas the two HMLK glasses analysed match the composition of LBA glasses originating from Egypt. The pieces belonging to the HMHK group allow good parallels to glass finds from Mesopotamia (e.g., disc pendant, spacer bead)

and partly also from the Levant (e.g., naked female figurine pendant). The findings as well as the analysis show that Tall Zirāʿa was the recipient of glass exports from both Egypt and Mesopotamia. The Egyptian and Mesopotamian origins of the glasses are furthermore also reflected in other finds from the cella, for example: 24 cylinder seals which can be attributed to the Syrian or Syro-Palestinian Style of the Mitanni glyptic (Syro-Palestine), a silver pendant depicting a goddess with parallels in Ugarti, Tall al- ʹAjjul and Megiddo, a scarab with the cartouche of Amenhotep III, and various faience objects (scarabs, vessel fragments) which originate from Egypt.

Only one other LBA site has been identified to contain glasses from both Egypt and Mesopotamia: Mycenae. Beads excavated from the palatial centre of Tiryns, Greece were analysed and identified as coming from both Egypt and Mesopotamia (Walton *et al.*, 2009). No other site in the Levant has yet been identified with a similar pattern, although further work would surely indicate that this was the case. Tall Zirāʿa was on a significant trading route connecting Egypt with Mesopotamia. The trading route started in Egypt, traversed the Sinai Peninsula, diverted north along the Mediterranean further on to Damascus to arrive at the Euphrates in Mesopotamia. Therefore, it can be inferred that high-value items such as glass and other materials were transported via this route and, at least partly, arrived at Tall Zirāʿa as tribute to the Temple.

Seven of the twelve glass objects identified as being LBA plant ash glass were excavated from the LBA stratum 14 and are therefore consistent with the stratigraphy. Five were found in the cella of the Temple or in close proximity: a fragment of a naked female figurine pendant (10779), a disc pendant (10170) (Figure 29), a fragment of a bead (10762), a suspected piece of raw glass (10772), and a spherical bead (10765). These pieces can also be dated according to typological comparisons: for example, 10779 can be identified as the arm of a typically LBA naked female figurine. The best comparable pieces comes from Tall Zirāʿa itself (Schmidt 2019, 46),as well as from Tall al-Fukhar (Jensen, 2015, p331), Lachish (Tufnell, 1958, pl. 27: 3), and Tall al-Ḥiṣn (Beth Shean) (Rowe, 1940, pl. LXVIIIA: 7). In addition, a large number of sites are known to yield naked female figurine pendants (Brill, 1970, appendix II). Due to the thickness and rounded shape, it is credible to identify 10170 as part of disc pendant, as they were similarly found in LBA contexts in Nuzi, where they were decorated with stars (Starr, 1939, pl. 120; Barag, 1970, fig 100, 101). In Nuzi, the star-pendants are connected with the

cult of the goddess Ishtar, a similar function as temple dedication can also be suggested for the piece from Tall Zirāʿa.

Glass beads, amulets and pendants could be purchased by those who could afford them and were eminently tradable as objects of elevated status. Numerous glass fragments identified as parts of disc pendants found at the site supporting the inference that smaller glass objects were transported from Mesopotamia to Tall Zirāʿa.

Figure 29: Fragment of a disc pendant (10170).

According to chemical analysis, four LBA glass objects were primarily classified to have been retrieved from IA deposition layers. However, in each case it was observed by the excavators that probable mixing of the deposition layers had occurred. The production of plant ash glass continued into the IA, however the HMHK glasses excavated from the IA contexts exhibit characteristic LBA composition: the spacer bead fragment 15329 was found in the IA deposition layer in close proximity to fragment 19320, which has an almost identical composition but originates in an adjacent LBA context. The HMHK composition of 15329, typical of a LBA glass, therefore, adds credence to the excavators' interpretation that these contexts were mixed during later construction works. Likewise, another fragment of a spacer bead (10047) of LBA composition was found in IA stratum 12, again thought to be disturbed by the digging of a later pit. The round bead 10048 of LBA plant ash composition was excavated from an IA I stratum, however there is evidence yet again of later works on this area,

including the conversion of the structure into a residence. The core formed vessel fragment (16753) was located north of the former temple (IA II A) and can also be identified as being excavated from a mixed stratum, and has a typical LBA Egyptian cobalt glass composition. Once again, this supports the excavators' interpretation that these contexts were mixed.

The presence of Egyptian composition LBA core formed vessels (16753) at the site also implies that, Tall Zirāʿa was connected with influential individuals, equivalent to the second rank elite of Egypt. Although the Levant was considered as vassal, and subject to the influences of Egypt and Mesopotamia, the presence of core formed vessels indicates that Tall Zirāʿa was considered to be a LBA city of particular significance.

Object 16759, a translucent light green object described as an "irregular lump" is consistent with IA natron glass but was excavated from the deposition layer in the courtyard of the LBA Temple complex. However, stratum 14d is described as being a very late phase of the LBA, therefore it can be inferred that this is an early example of IA glass at Tall Zirāʿa. The natron glass core formed vessel fragment (18802) was excavated from stratum 13 (IA I) which is attributed to the 13-12th century BC, and therefore the composition of this glass is consistent with the date of the phases. The translucent, colourless glass fragment (16622b) was excavated from the north outside area of the temple also from stratum 13 (IA I) however the composition is atypical for LMLK glass.

16622a, a yellowish, translucent hemisphere, likely quartz, and 16622b, a translucent, colourless glass fragment, were found mixed, and in large number on a floor to the north of the IA I temple (stratum 13) of an area identified as a possible workshop. The composition of the translucent, colourless glass fragment 16622b is however atypical for LMLK glass. The area was interpreted as workshop area indicated by the presence of a large number of working stones, slags and fireplaces, but containing no vessels associated with cooking or food preparation. The presence of these numerous glass fragments and quartz pebbles suggest that craftsmen at Tall Zirāʿa may have used these quartz pebbles as raw material and incorporated glass fragments as part of the glass working process. Further evidence for glass working at the site comes from 10772, identified as a piece of raw glass (or part of an ingot) of plant ash composition. This suggests that glassworking may have occurred on site from the LBA and continued into the IA. The continued presence of glass at Tall Zirāʿa during the IA suggests

that the city was affluent enough to sustain the trade of luxury items after the collapse of the LBA and had sufficient resources to support a craft industry encompassing vitreous materials.

6.11 Conclusion

The chronological classification of the glass finds from Tall Zirāʿa shows that glass analyses can be used as a method for dating finds. This is an additional source of information in view of the stratigraphic contexts, which are often difficult to date, as they are often strongly mixed. Of the 14 glass objects analysed in this study, nine plant ash glasses show a positive correlation with the composition of LBA glasses manufactured in Mesopotamia. The remaining two plant ash glasses are consistent with the composition of LBA Egyptian made glasses. Therefore, Tall Zirāʿa represents one of only two LBA sites which are known to have received glass objects from both Egypt and Mesopotamia. This goes hand in hand with the archaeological findings, both with the glass objects themselves as well as with the other finds made in the cella of the LBA Temple. There is also some evidence of glassworking at the site, suggesting that raw glass, possibly in the form of ingots was transported to the city. The presence of a LBA core formed vessel with an Egyptian composition indicates and affiliation directly or indirectly with the upper elite of Egypt. The presence of natron glass confirms that the trade of luxury goods continued at Tall Zirāʿa into the IA after the collapse of the LBA, and that the city was prosperous enough to sustain craftsmen which probably provided glass working. The presence of these three types of glass demonstrates that Tall Zirāʿa was a well-connected settlement of significant social importance during the LBA, maintaining affluence and trade links into the IA.

6.12 References

Abe, Y. *et al*. (2012) ‘Transition in the use of cobalt-blue colorant in the New Kingdom of Egypt’, Journal of Archaeological Science, 39(6), pp. 1793–1808.

Barag, D. (1970) ‘Mesopotamian Core-Formed Glass Vessels (1500-500 BC)’, in Oppenheim, A. L. *et al*. (eds) Glass and glass-making in ancient Mesopotamia. New York: Corning Museum of Glass.

Brill, R. H. (1970) ‘The Chemical Interpretation of the Texts’, in Oppenheim, A. L. *et al*. (eds) Glass and glass-making in ancient Mesopotamia. New York: Corning Museum of Glass.

Brill, R. H. (1999) Chemical analyses of early glasses: Volume 1, the tables. Corning, NY: Corning Museum of Glass.

Goedicke, H. (1975) The report of Wenamun. Johns Hopkins Press (Near Eastern studies).

Gratuze, B. (2013) 'Provenance Analysis of Glass Artefacts', in Jannsens, K. (ed.) Modern Methods for Analysing Archaeological and Historical Glass, Volume I. John Wiley and Sons, pp. 311–343. doi: 10.1002/9781118314234.ch14.

Hanbury-Tenison, J. W. (1984) 'Exploration du Wadi el-Arab', Chronique archéologique, RB, 91, pp. 230–231.

Henderson, J. (1985) 'The raw materials of early glass production', Oxford Journal of Archaeology, 4(3), pp. 267–291.

Henderson, J. (2000) 'Chemical analysis of ancient Egyptian glass and its interpretation', in Nicholson, P. T. and Shaw, I. (eds) Ancient Egyptian materials and technology. Cambridge: Cambridge University Press, pp. 206–224.

Jackson, C. M. and Nicholson, P. T. (2010) 'The provenance of some ingots from the Uluburun shipwreck', Journal of Archaeological Science, 37(2), pp. 295–301.

Jensen, L. W. (2015) 'Basalt and small finds', in Strange, J. and Andersen, F. G. (eds) Tall al-Fukhār. Results from excavations 1990-93 and 2002. Aarhaus: Aarhus University Press, pp. 329–365.

Joffe, A. H. (2002) 'The Rise of Secondary States in the Iron Age Levant', Journal of the Economic and Social History of the Orient. Brill, 45(4), pp. 425–467. Available at: http://www.jstor.org/stable/3632872.

Kaczmarczyk, A. (1986) 'The source of cobalt in ancient Egyptian pigments', in Olin, J. S. and Blackman, M. J. (eds) Proceedings of the 24th International Archaeometry Symposium. Washington: Smithsonian, pp. 369–376.

Kemp, V. *et al*. (2019) 'LA-ICP-MS analysis of Late Bronze Age blue glass beads from Gurob, Egypt', Archaeometry, 62(1), pp. 42–53. doi: 10.1111/arcm.12501.

Kemp, V., McDonald, A and Shortland, A. J. (2017) ‘Ancient Biographies: Trace Element Analysis to Investigate Provenance and Transportation Mechanisms of Late Bronze Age Glass.’, Archaeological and Environmental Forensic Science, 1.2, pp. 161–174.

Kirk, S. (2009) The Vitreous materials from the 2nd Millennium BC City of Nuzi: Their Preservation, Technology and Distribution. Cranfield University.

Lilyquist, C., Brill, R. H. and Wypyski, M. T. (1993) Studies in Early Egyptian Glass. Metropolitan Museum of Art.

Moorey, P. R. S. (1994) Ancient Mesopotamian materials and industries. Oxford: Oxford University Press.

Moorey, P. R. S. (2001) ‘The Mobility of Artisans and Opportunities for Technology Transfer between Western Asia and Egypt in the Late Bronze Age’, in Shortland, A. J. (ed.) The Social Context of Technological Change. Oxford: Oxbow books, pp. 39–58.

Moran, W. L. (1992) The Amarna Letters. Baltimore: The Johns Hopkins Press.

Na’aman, N. (2000) ‘The Egyptian-Canaanite Correspondence’, in Cohen, R. and Westbrook, R. (eds) Amarna Diplomacy: The Beginnings of International Relations. Baltimore: Johns Hopkins University Press, pp. 125–138.

Nicholson, P. T. and Henderson, J. (2000) ‘Glass’, in Nicholson, P. T. and Shaw, I. (eds) Ancient Egyptian materials and technology. Cambridge: Cambridge University Press, pp. 195–226.

Oppenheim, A. L. (1977) Ancient Mesopotamia: portrait of a dead civilization. Revised ed. Edited by Revised by E. Reiner. Chicago: University of Chicago Press.

Pfälzner, P. (2012) ‘Levantine Kingdoms of the Late Bronze Age’, in Potts, D. T. (ed.) A Companion to the Archaeology of the Ancient Near East. Oxford: Blackwell, pp. 770–796.

Pulak, C. (2001) ‘The cargo of the Uluburun ship and evidence for trade with the Aegean and beyond’, in Bonfante, L., Karageorghis, V., and Costakis and Leto Severis Foundation(Nicosia, C. (eds) Italy and Cyprus in antiquity 1500 - 450 BC: proceedings of an international symposium held at the Italian Academy for Advanced Studies in America at Columbia

University, November 16-18, 2000. Nicosia: The Costakis and Leto Severis Foundation, pp. 13–60.

Reader, A. (2003) Near Eastern Archaeology: A Reader. Edited by S. Richard. Pennsylvania State University Press.

Redford, D. (1992) Egypt, Canaan, and Israel in ancient times. Princeton: Princeton University Press.

Rowe, A. (1940) The four Canaanite temples of Beth-Shan. 1. The temples and cult objects. Philadelphia: The University Museum.

Sayre, E. V and Smith, R. W. (1961a) 'Compositional categories of ancient glass', Science 133, pp. 1824–1826.

Sayre, E. V and Smith, R. W. (1961b) 'Compositional categories of ancient glass', Science, 133, pp. 1824–1826.

Sayre, E. V and Smith, R. W. (1974) 'Analytical studies in ancient Egyptian glass', in Bishay, A. (ed.) Recent Advances in the Science and Technology of Materials. New York.

Shortland, A. J. (2002) 'The use and origin of antimonate colorants in early Egyptian glass', Archaeometry, 44(4), pp. 517–531.

Shortland, A. J. *et al*. (2017) 'The analysis of Late Bronze Age glass from Nuzi and the question of the origin of glassmaking', Archaeometry, 60(4), pp. 764–783.

Shortland, A. J. and Eremin, K. (2006) 'The analysis of second millennium glass from Egypt and Mesopotamia, Part 1: new WDS analyses', Archaeometry, 48(4), pp. 581–605.

Shortland, A. J., Nicholson, P. T. and Jackson, C. M. (2001) 'Glass and Faience at Amarna: different methods of both supply for production, and subsequent distribution.', in Shortland, A. J. (ed.) The Social Context of Technological Change. Oxford: Oxbow Books, pp. 147–160.

Shortland, A. J., Rogers, N. and Eremin, K. (2007) 'Trace element discriminants between Egyptian and Mesopotamian Late Bronze Age glasses', Journal of Archaeological Science, 34(5), pp. 781–789.

Shortland, A. J. and Tite, M. S. (2000) ‘Raw materials of glass from Amarna and implications for the origins of Egyptian glass’, Archaeometry, 42(1), pp. 141–153.

Smirniou, M. and Rehren, Th. (2013) ‘Shades of blue - cobalt-copper coloured blue glass from New Kingdom Egypt and the Mycenaean world: A matter of production or colourant source?’, Journal of Archaeological Science, 40, pp. 4731–4743.

Soennecken, K. A. P. (2017) Kulturelle Umbrüche in der südlichen Levante. Der Übergang von der Bronze- zur Eisenzeit unter besonderer Berücksichtigung des Tall Zirāʿa. Universitätsbibliothek Wuppertal.

Starr, R. F. (1939) Nuzi. Report on the excavations at Yorgan Tepa near Kirkuk, Iraq, conducted by Harvard Univ. in conjunction with the American Schools of Oriental Research and the Univ. Museum of Philadelphia 1927-1931. With app. by Ruth Sears Chute and others. Cambridge, MA: Harvard University Press.

Steuernagel, C. (1926) ‘Der ‘Adschlūn.’, Zeitschrift des Deutschen Palästina-Vereins, pp. 1–162.

Tufnell, O. (1958) Lachish (Tell ed-Duweir): The Bronze Age. Text and Plates. London: Oxford University.

Turner, W. E. S. (1954) ‘Studies in ancient glasses and glass making processes. Part I. Crucibles and melting temperatures employed in Ancient Egypt at about 1370 BC’, Journal of the Society of Glass Technology, 38.

Turner, W. E. S. (1956) ‘Studies in ancient glasses and glass making processes. Part IV. The chemical composition of ancient glasses’, Journal of the Society of Glass Technology, 40, pp. 162–184.

Varberg, J. *et al*. (2016) ‘Mesopotamian glass from Late Bronze Age Egypt, Romania, Germany, and Denmark’, Journal of Archaeological Science, 74, pp. 184–194.

Vicenzi, E. P. *et al*. (2002) ‘Microbeam characterisation of Corning archaeological reference glasses: new additions to the Smithsonian Microbeam standard collection’, Journal of Research of the National Institute Standards and Technology, 107, pp. 719–727.

Vieweger, D. and Häser, J. (2017) Tall Zirā‘a The Gadara Region Project (2001–2011) Final Report. Gütersloh.

Vieweger, D. and Häser, J. (2019) ‘Tall Zirāʿa - Mirror of Jordan’s history.’, in Häser, J. and Schmidt, K. (eds) Tall Zirāʿa. Berlin: Wichern Verlag, pp. 12–53.

Wagner, B. *et al*. (2012) ‘Critical assessment of the elemental composition of Corning archaeological reference glasses by LA-ICP-MS’, Analytical and Bioanalytical Chemistry, 402(4), pp. 1667–1677.

Walton, M. *et al*. (2009) ‘Evidence for the trade of Mesopotamian and Egyptian glass to Mycenaean Greece’, Journal of Archaeological Science, 36, pp. 1496–1503.

Walton, M. *et al*. (2012) ‘Analysis of Late Bronze Age Glass Axes from Nippur - A New Cobalt Colourant’, Archaeometry, 54(5), pp. 835–852.

7 Identifying and Evaluating Atypical Traits in Ancient Egyptian Glass Vessels Attributed to the New Kingdom Using Raw Data Analysis and Expert Assessment

7.1 Abstract

The descriptive data pertaining to the remaining, largely intact, glass vessels produced in ancient Egypt between the reigns of Tuthmosis IV (1400-1390 BCE) and Pinudjem II (959-945 BCE) contained in 'Die Glasgefäße im Alten Ägypten' [The Glass Vessels in Ancient Egypt], was extracted and standardised to create a dataset that could be analysed to determine the most typical and atypical features of vessels attributed to the New Kingdom in the corpus. Seven descriptive categories were assessed based on the percentage of incidence to determine if a vessel could be defined as statistically 'atypical'. An expert's evaluation was employed as a second assessment method. The two methods identified 76 vessels from a total number of 320 vessels and agreed on 16 vessels considered as atypical, all of which had little or no provenance information. The resulting 76 vessels identified as 'atypical' by the combined methods were subsequently compared with the respective provenance information and current location to determine patterns of collection and distribution throughout the world. The data showed that the Americas held the largest number of vessels that had little or no provenance data, including those held in private collections. The combined atypical tests identified that the Americas hold the largest proportion of atypical vessels. It is not the intention of this research to undermine the authenticity of vessels but to determine if data methods can be used to identify atypical traits in archaeological collections and to encourage the application of archaeometric testing to provide supporting information on statistically rare objects.

7.2 Introduction

'Die Glasgefäße im Alten Ägypten' [The Glass Vessels in Ancient Egypt], produced by Birgit Schlick-Nolte in 1968, is a catalogue of 344 remaining, largely intact vessels from ancient Egypt produced between the eighteenth and twenty-first Dynasties (between approximately 1550 to 945 BCE). Each vessel is recorded in detail, describing the morphology, colour, decoration, and specific features, such as the handles, feet, neck, and rim. Very few vessels have been added to the corpus since this time, therefore the information contained in Schlick-Nolte's catalogue continues to represent a relevant data set. Although many other vessels were

produced in, and excavated from, ancient Egypt, these vessels cannot be reliably restored from the fragments, however, it is reasonable to expect that the corpus described in *Die Glasgefäße* represents the corpus of vessels that were created overall. Using the Schlick-Nolte catalogue, the descriptive information pertaining to the colour of the body, the shape of the vessel, opacity, colour of the neck rim, handles, pattern colour and pattern design was extracted and standardised to create a data set that could be used to quantify and assess patterns in the attributes of the vessels. The data was used to identify the number of incidences of certain characteristics, thereby distinguishing what could have been the most common usages of colours, preferred shapes, and favoured decorative patterns. Using the same data, vessels that present statistically rare attributes can be identified as 'atypical' and when compared with the provenance information, these vessels can be the subject of further investigation. This study also seeks to compare the current location of the post-study data set vessels with the provenance information and to use the results of the atypical study to examine the distribution of this particular subset of vessels throughout the world.

Although a novel technology in the Late Bronze Age (LBA), glass was rapidly assimilated by the ancient Egyptian elite to become an important symbol of high status. The ensuing production of glass was strictly regulated by the Egyptian royal courts and administered according to a rigid distribution model. Ingots of raw glass were exchanged between royal courts at the highest level, while glass vessels were an exclusive commodity suitable for high-level gift-giving between rulers of LBA states and preferred members of the domestic court (Na'aman, 2000, p130; Shortland, Nicholson and Jackson, 2001, p153). Early vessels were created using the 'cold-working technique' by which glass would be poured into a cast, and then shaped using lapidary techniques (Broschat and Rehren, 2017). The invention of core-forming represented a significant advance in glass vessel production technology (Shortland, 2001, p212), transforming how glass vessels could be created, shaped and decorated. A 'core' made from a mixture of clay and dung was moulded to form the interior shape of the vessel around a long pole called a 'handling piece'. The core was heated and rolled in powdered glass, then worked in the form of a "pasty mass", upon which layer after layer was applied to create the vessel (Nicholson, 1993, p53). The foot, handles and decoration were added before the vessel was left to slowly cool, after which the core and handling piece was removed (Nicholson and Henderson, 2000, p203).

Establishing a reliable timeline for early glass vessels has proven to be problematic: reburials, destruction and transference of goods caused by extensive looting or the actions undertaken by the priests of the necropolis administration to preserve their charges has rendered the context of items in these tombs unreliable in several instances (Reeves and Wilkinson, 2008, p125). Glassworking was undertaken by multiple glass workshops, who based their work on the modes of the time. The workshops of Malkata and Amarna represent the peak of Egyptian glass production, predominantly in the number of vessels produced, the technical accomplishment of the craftsmen and the stylistic uniformity; namely the iconic vessels of blue glass with yellow and white threads applied to create feather or garland patterns (Petrie, 1894, p25). In *Die Glasgefäße*, Schlick-Nolte assigns the vessels into groups and subgroups: The first group comprises of the vessels that can be reliably dated to a specific time of manufacture, having either come from a reliable archaeological context such as the tomb of Amenhotep II, or are stylistically dated with confidence. Even though this group is comparatively small, the author emphasises the archaeological importance of having such pieces recorded from reputable investigations (Nolte 1968, p46). The second, and largest group comprising of 213 vessels, are divided into "*Werkkreis*"; this term is often used to refer to an Old Master artist and his associated assistants and followers - "circle of workshops" is perhaps the nearest translation. The vessels in the *Werkkreis* groups have been approximately dated according to the stylistic features and some are attributed to known workshop locations such as Malkata and Amarna. At the beginning of the 14th Century BCE, a more uniform approach to style was taken for the production of glass vessels, however, subtle changes in features such as the diameter of the neck, the shape of a spout, handles and the shape and size of the feet provided key elements that narrow estimates for the period of production. As such, the *Werkkreis* are divided into six groups, the largest of which, *Werkkreis* 6, contains 43 vessels and dates between the reigns of Tutankhamun (1333-1323 BCE) and Pinudjem II (959-945 BCE), an era of approximately 390 years, thereby making any speculation pertaining to periodical trends somewhat tenuous. Of the vessels contained in the *Werkkreis* groups, only 15% are of known origin, 19% are of unknown origin, 32% are of ambiguous origin and the remaining 35% belong to private collections. Two additional groups are also described: the *Kohlpalmsäulchen*, or kohl palm vessels, that contain 58 vessels and "special shapes" that contain 19 vessels. The vessels in both groups are dated from Amenhotep III (1391-1353 BCE) to the Ramesside period (ending in 1070 BCE), spanning approximately 320 years.

7.3 Methodology

To accurately assess the characteristics that exemplify typical and atypical features of the New Kingdom, this paper concentrates on the vessels that were attributed to between the reigns of Amenhotep II (1427-1400 BCE) and Rameses III (1194-1163 BCE). The 15 early vessels that are reliably dated between the reign of Tuthmosis III (1479-1425 BCE) to Amenhotep II were excluded from the data set as they exhibit unusual shapes, colours and morphology that have been attributed to the experimental phase of early glassmaking[1] (Nolte, 1968, p5). The six vessels that are reliably dated to the 21st Dynasty and the three vessels, recorded as lost, are also excluded from the data set.

The descriptive information of the remaining 320 vessels exactly as reported by Schlick-Nolte was collated into a working database using Microsoft Excel. Seven attributes were chosen to assess typical and atypical features for the purposes of the study: the colour of the body, or 'ground colour', the vessel shape, neck rim colour, handle colour, the pattern colour and the pattern type on the neck and body. The foot colour and foot rim colour were not included in the data as the information did not provide sufficient discrimination between the vessels; over a third of vessels were not made with a foot. The pilgrim flask, for example, is the second most common vessel shape in the corpus, and the majority of the remaining vessel feet were created using the ground colour.

For clarity, colours are standardised into the main colour groups, rather than listing individual hues as described by the author; for example, 'olive green' is noted in the dataset as green. As the most prevalent colour, blue is standardised into three main groups: light blue (which contains the colours described as light blue, sky blue and turquoise), mid blue (blue, bright blue, copper blue, grey-blue and lapis lazuli blue) and dark blue (black blue, cobalt blue, dark blue, deep blue and ultramarine).

[1]These vessels are: 24391, 47620 (British Museum), 19657 (University College London), 23.9, 26.7.1175, 26.7.1179 (Metropolitan Museum of Art), ÄS 630 (Bavarian State Collection of Egyptian Art, Munich), E 2451 (Ashmolean Museum), 24761, 24761 bis, 24768, 24804, 24808, J 33827 (Cairo Museum), E 6201 (Brussels Royal Art and History Museum).

The vessels are categorised into 14 main shape types using the terminology described in *Die Glasgefäße.* The origin of these names are mainly derived from traditional ceramic vessels:

- Krateriskos refers to vessels that have a wide, cylindrical, crater-like neck with a short spherical body, usually with a foot attached.
- The thick walled krateriskoi exhibit a broader neck and have thicker, less defined handles that do not protrude far from the body of the vessel.
- The simple krateriskoi is a basic version of the krateriskos and may not contain handles, feet, or decoration.
- The pilgrim flask has a small cylindrical neck with a round, lenticular body. Pilgrim flasks can be large or small; specifically between 45mm and 145mm tall, with no, or two to three handles attached.
- Kohl tubes are modelled on the Egyptian palm columns and have a rounded or flat base with a long, narrow body and an opening that is fashioned into leaves surrounding the rim.
- Amphoriskos vessels are composed of a cylindrical, narrow, or conical neck with board shoulders and a tapered base.
- Jug-shaped vessels have narrow neck with a wider, oval body with a handle attaching the neck and shoulder.
- The spherical vessel is defined by the orbicular body but can have a long or short neck with various handle types and a stand.
- The flask or bottle type is generally composed of a long and narrow neck with an oval body and rounded base without handles.
- The beaker has no handles or rim applied and tapers to a flat base.
- The pomegranate vessel exhibits a distinctive pomegranate shape with a spherical body, no handles and a narrow, cylindrical neck that opens into several small leaf shapes.
- The lotus beaker is modelled after the lotus flower and contains a small foot and no handles (Loat, 1905 pl 4-30; Nolte, 1968, p149).

One vessel described in *Die Glasgefäße* is identified as ‘pilgrim flask and pomegranate vessel’; this vessel consists of a pilgrim flask and a pomegranate vessel which appears fused at the body, most likely accidentally, and is therefore described as one vessel throughout.

The category of ‘special shapes’ consists of glass objects that cannot be classified into the main shape groups; these include fish-shaped vessels, curved and flat bowls and the alabastron style vessels.

The colour of the neck rim and handles are also described in the main colour groups. Where two or more colours are used, this is described as polychrome. It should be noted that no colour combination in the polychrome group exceeds 5% of instances in the respective category, therefore all polychrome combinations used for the neck, rim and handles are classified as atypical for the study.

The colours of the patterns were assessed by counting the total number of instances that a single colour occurred across the corpus of vessels overall. The colour combinations of patterns used for each vessel were also assessed to determine frequency of colour combinations. The vessel patterns in *Die Glasgefäße* are described in detail to convey information about the style and aesthetic of the vessel, such as: ‘Especially generous, even garlands’ and ‘Garlands turning into a regular feather pattern, irregular feather pattern’. For clarity when comparing the data, the patterns were standardised into basic types: garland, feather, arcades, zigzag, other, unknown and none. Where multiple patterns were used on the body or neck, these were added as a separate category, for example ‘arcades merging into feather pattern’ was described in the data as ‘arcades > feather’. Where the vessel type did not comprise a neck, such as the beaker shape, the kohl tubes, and the special shapes, this was shown in the data as ‘not applicable’. In some instances, more than one type of pattern was applied to the vessel on the body and neck, thereby adding another feature for trend comparison. It was noted whether the patterns on the body and neck were the same pattern, two distinctly different patterns, or had the same pattern on the body and neck with an additional pattern emerging, for example, one vessel (67.1, Toledo Museum of Art) is described as having a feather pattern applied to the body and a feather pattern, that turns into garlands on the neck (Nolte, 1968, p85).

Characteristics that represented less than 5% of the whole category were identified as an atypical trait, for example, yellow represented 3% of vessel ground colour, thereby classifying it as an atypical trait. If a vessel exhibited three or more atypical traits, the vessel as a whole was classified as atypical for the purposes of the study.

Finally, the information pertaining to the provenance and the location of the vessel were reviewed with the post study data set. Four categories were given to describe the origin of each

vessel: ‘Origin known’ describes a vessel that is recorded as being excavated from a specific archaeological context, i.e., a grave or tomb, whereas ‘Origin ambiguous’ indicates that the vessel is recorded as coming from a specific region or town, such as ‘Malkata’, ‘Cairo’ or more generally ‘Egypt’. It is possible (indeed probable in many cases) that the object was bought rather than found there. ‘Origin unknown’ refers to the vessels that have no provenance information, or that the information refers only to the date or location of acquisition. Finally, ‘Private collection’ refers to those vessels where only the collection name is listed, but there is no information regarding the actual origin, such pieces usually having been bought or exchanged through the art market. During the research for this paper, it was apparent that the locations of some vessels have changed, for instance, where vessels have been purchased by museums from private collections. While these locations were updated, no active investigation to confirm the current location of each vessel was undertaken as part of this research. For clarity, the regions of Egypt and the Levant, Europe and the Americas were used to define locations, rather than individual countries, unless pertinent to the information.

In addition to using the raw data approach, a second test method using a ‘connoisseurs’ eye’ was employed. A specialist in the area of ancient Egyptian glass, Professor Andrew Shortland, was asked to use their expert opinion to appraise each vessel using black and white images without context. The specialist was asked to categorise each vessel as typical or atypical based on shape, design, and discernible pattern type. The two methods were designed to provide virtually opposite techniques of assessment; the ‘connoisseurs’ eye’ method was intended to assess the vessels using a minimal amount of visible data, compared with the raw data approach which presented attribute categories, but with no stylistic description. Each method was performed independently.

7.4 Results

Blue was revered above all colours by the ancient Egyptians and utilised extensively in painted reliefs, protective amulets, and jewellery; it symbolised many significant spiritual meanings, including representing the embodiment of divine truth and justice (Birren, 1950, p37). It is unsurprising, therefore, that 80% of the vessels described in *Die Glasgefäße* were produced with a ground colour of either dark, mid, or light blue glass. The next most prevalent colour is black which represents a significantly smaller group of 6% of the vessels. Some ‘black’ vessels are actually very dark blue vessels coloured with cobalt, or very dark purple glasses coloured

by manganese, however as mentioned previously the characteristics of each vessel are reported as described by Schlick-Nolte. The remaining colours used for the body in descending frequency are white, green, yellow, grey, brown, purple, unknown, polychrome, and red, representing between 5% to less than 1% per colour. Also, 86% of vessels in the dataset are described as opaque, rather than translucent, making this by far the most typical trait of ancient Egyptian vessels. However, because the incidences of translucent vessels are above 5%, they are not classified as an atypical trait for this study. It should also be noted that the classification of atypical vessels in this study is performed using the data as unrelated variables and no attempt is made to link stylistic characteristics, however, where it is appropriate, the style and date is considered in the discussion section.

The most common four vessel shapes are the krateriskos, the pilgrim flask, the kohl tube, and the amphora. The remaining vessel shapes accounted for 6% or less per vessel shape type (Figure 30). With the exception of the thick-walled krateriskos, the beaker shape, pomegranate vessels and the unusually merged pilgrim flask and pomegranate vessel, blue is the most predominant colour for all vessel types.

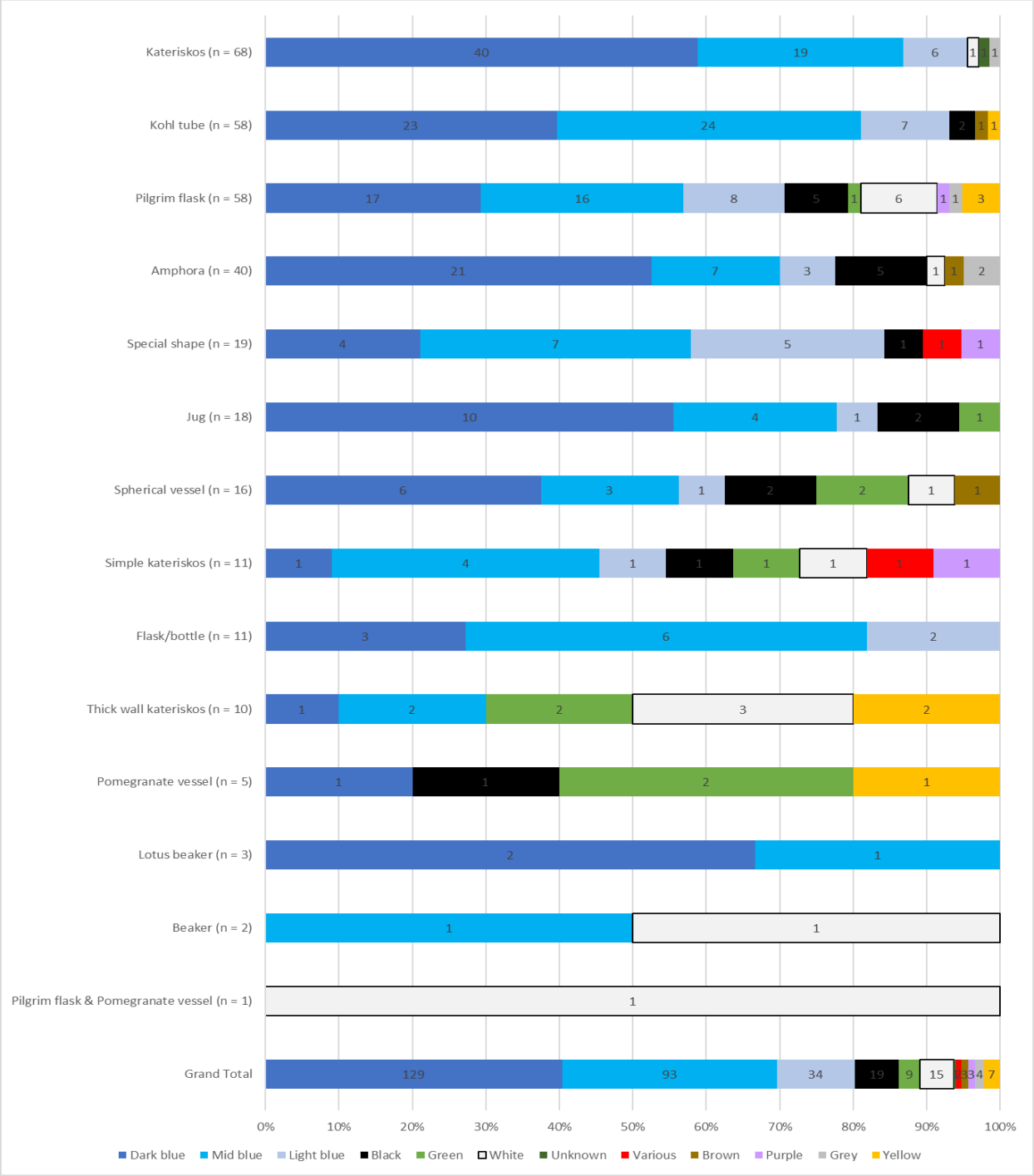


Figure 30: Chart illustrating colour prevalence in each vessel type attributed to the New Kingdom. Centre bar labels indicate number of vessels.

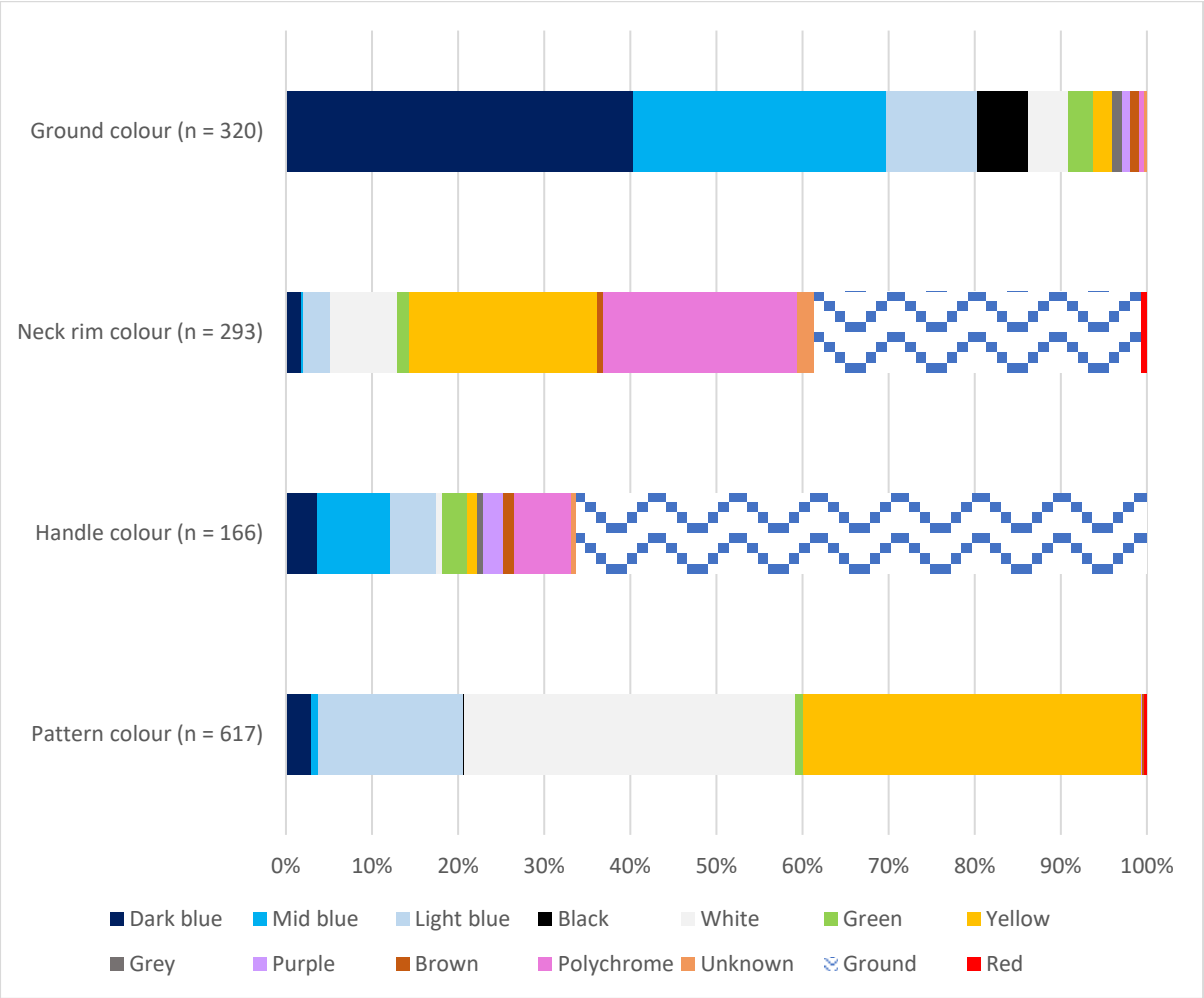


Figure 31: Distribution of colours used in vessels attributed to the New Kingdom to create patterns, handles, neck rim and the vessel body. Where vessels do not contain a neck rim or handles, or are recorded as 'not present', these have been removed from the figure.

Of the 320 vessels observed, 92% of vessels have a rim which is still preserved. 35% of these vessels presented rims created from the same tone as the ground colour, 20% of vessels used yellow and 21% of vessels were recorded as polychrome, exhibiting 22 different colour combinations of two or more colours (Figure 31). The most common polychrome combination being black and white, occurring in 4% of instances. 8% of vessels were observed as having no rim, broken from the body of the vessel.

34% of ancient Egyptian vessels were produced without handles, with the same percentage of vessels exhibiting handles made from the same tone as the ground colour used for the body of the vessel. 14% of vessels are recorded as once having had handles, however, these have been broken and are missing from the vessel thereby preventing colour determination. The remaining 18% of handles equate to 29 different colour combinations; therefore, classified as

atypical. 11 handles are described as translucent and appear to be made in a different colour to the vessel ground colour, making this an unusual trait. However, it should be noted that the translucency of a vessel may be more difficult to discern due to the thickness of the glass used for the body, any weathering of the vessel and any core remaining inside the vessel. The hue of the handles, therefore, may appear optically distinct from the vessel body. As discussed, for the purposes of the study, the colours are reported as stated in *Glasgefäße*.

The three most frequently used colours for pattern application across the corpus of the 320 glass vessels are yellow, white, and light blue. 76% of vessels had a yellow pattern applied, and 74% of vessels had a white pattern applied; light blue is the third most common pattern colour, used on 33% of vessels. However, it is the combination of colours which were the most statistically significant when identifying atypical pattern traits. Patterns applied using yellow and white combined comprised 35% of the vessels in the dataset, with the second most common combination of pattern colours being yellow, white, and light blue at 28%. The third-largest group totalling 20% of vessels have no decoration applied to the body. The remaining pattern colours were mid or dark blue with yellow or white, and the use of green, red, purple, or black in various colour combinations. 13% of vessels exhibited combinations of yellow or white with one or multiple other colours such as green, red, or purple. These 'atypical' colours and combinations presented 18 separate incidences of single and polychrome combinations, comprising the remaining 17% of vessels, hence less than 1% per incidence.

The garland pattern followed by the feather pattern are the two most likely patterns to be applied to both the body and neck of a vessel; the third most common pattern type is 'no pattern' applied. Combinations and fusions of feather, garland, and arcade patterns, zigzag, or other patterns occur in 5% or less of vessels per pattern type. Although not assessed as part of the atypical traits, it was noted that 61% of vessels that are created with the garland pattern have the same pattern on the neck and body, and 63% of vessels created with the feather pattern have the same pattern on the neck and body. 8% of vessels showed a combination of patterns that merged on the neck or body, for example, a vessel that is described as having a feather pattern on the body and a neck pattern that showed both a garland and feather pattern. 22% of vessels from the dataset do not comprise necks and were described as 'not applicable'. 35% of vessel rims were created using the ground colour, followed by 20% of vessels using yellow. 8% of vessels are recorded as the rim not being present, either from damage or because of the vessel design, for example, fish-shaped vessels in the 'special shapes' category, white composed 7%

of rim colours. The remaining 30% of vessels exhibit multiple different single colour or polychrome combinations, less than 1% per incidence.

7.5 Provenance review

From the corpus, 17% of vessels are of known origin, having been excavated from a specific archaeological context such as a tomb or grave. 34% are described as 'Origin ambiguous', 18% are 'Origin unknown' and finally, 32% have been or are still part of a private collection where virtually no information is known about the origin of the vessel (Figure 32). The distribution of vessels was assessed by comparing the region with the provenance category; the vessels of known origin in the post-study group equate to 53 vessels; the country with the largest number of known vessels is the United Kingdom with 15 vessels. Egypt holds the second largest number equating to 13 vessels, followed by Israel with 6 vessels of known origin. The remaining 19 vessels of known origin are distributed throughout 9 different countries.

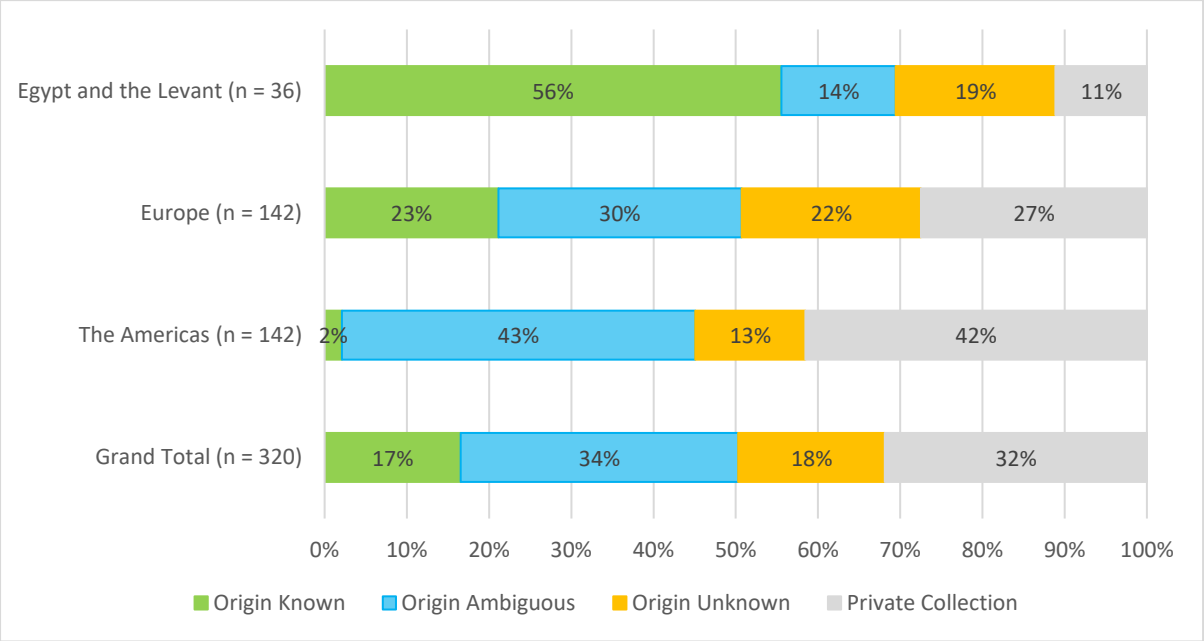


Figure 32: Vessel provenance category by current regional location.

The data also showed that although the Americas contained the same number of ancient Egyptian glass vessels as Europe, 142 vessels each in total, only 3 vessels are of known origin with the remaining 139 vessels having very little or no recorded information about the provenance. Of the vessels located in the Americas, 42%, equating to 59 vessels, are recorded as belonging to private collections, meaning that the Americas have the largest number of

privately owned ancient Egyptian glass vessels in the world, also representing 18% of the total number of vessels in the world. By comparison, the number of vessels in private collections in Egypt and the Levant is 4, equating to 10% of the total number of vessels in this region. Europe has 39 vessels in private collections overall, equating to 27% of the total number of vessels in this region.

7.6 Discussion

Using the raw data approach, 44 vessels were identified as having three or more atypical traits according to the test criteria, thereby classifying them as atypical vessels. The expert identification method distinguished 48 vessels as atypical. Both methods combined identified 76 vessels in total, with 16 vessels being identified as atypical by both methods.

The largest group of shape type distinguished in the raw data atypical test is the pilgrim flask, formerly the third most frequent vessel type in the corpus; the frequency of this vessel increased from 18% to constitute 27% of the atypical vessels. The second most prevalent shape in the atypical group is the spherical vessel, composing 16%, previously it occurred in only 5% of the corpus. The third most frequent is the thick-walled krateriskos, that comprises 11% in the atypical group, but only 3% in the corpus. The amphora shape was the fourth most common vessel shape in the corpus at 13% and occurs in 9% of the raw data atypical group. The most prevalent vessels from the corpus, the krateriskos and the kohl tube represented 21% and 18% respectively, however, in the atypical group they represented 7% and 5% of the vessels identified as atypical. Therefore, the krateriskos and the kohl tube show the largest decreases in frequency in the atypical raw data group, and the pilgrim flask and the spherical vessel show the largest increases in frequency in the atypical raw data group. The only two vessels not detected in the atypical group are the merged pilgrim flask & pomegranate vessel and the lotus beaker shape. The expert assessment differed to the raw data test by identifying the amphora shape, krateriskos, kohl tube and pilgrim flask as being the four most prevalent atypical vessel types (in this order) but did not identify any thick-walled krateriskos shape or beaker shaped vessels as being atypical.

The most prevalent ground colour distinguished by the raw data atypical test is dark blue comprising 27%, compared with the pre-test corpus which comprises 40%. The remaining ground colours distinguished in the atypical test differ in frequency to the corpus order; the second most prevalent ground colour is green, which represents 14% of the ground colour, the

third being white and light blue at 11% each. Therefore, the incidences of green more than triple in the raw data atypical group, white more than doubles in the atypical test, whereas light blue represents almost the same percentage in the atypical group. Mid blue, the second most prevalent corpus ground colour at 29% is seen in only 5% of atypical vessels. The remaining colours ranged from 9% to 2% which included two polychrome vessels and one vessel of unknown colour, meaning that at least one of each colour category is represented in the raw data atypical test. The expert test identified atypical vessels which were primarily dark blue vessels at 54%. The remaining vessels were light blue, mid blue, black, white, green, and yellow: almost identical to the order of prevalence seen in the corpus.

The polychromatic combinations of the neck rim colour in the raw data test were most prevalent at 61%, whereas it accounted for 21% in the corpus; the two most prevalent colour combinations in the polychromatic group being black and white and blue and white in both the corpus, the raw data test and the expert test. By comparison, the ground colour accounted for 11% of the neck rim colour of the raw data atypical test but accounted for 35% in the corpus. Yellow accounted for 20% in the whole corpus but only accounts for 11% in the raw data atypical group. The expert test also identified vessels that had polychrome neck rims (31%), ground colour (27%), yellow (21%) and white (13%) respectively as the most prevalent atypical colours in the neck rim category.

27% of handles in the atypical raw data group are made from the ground colour and are therefore the most prevalent. ‘No handles’ in the atypical group represented the second largest group at 20%. In the corpus, the ‘no handle’ group and the ground colour group were the most frequent at 34% each. Vessels which were recorded as handles ‘not present’, i.e. vessels which showed evidence of comprising handles, but were no longer surviving on the vessel, was the third largest group at 14% in the corpus, however, in the raw data atypical group, only 5% of vessels are recorded as having handles ‘not present’. Dark blue represented 11% in the raw data atypical group, while only comprising 2% in the corpus. The polychrome group represented 18% of the handle occurrence in the raw data test, the most prevalent colour combination was blue and white, comprising of 5% of the handle colour. The most prevalent handle colour of atypical vessels indicated in the expert assessment were made from the ground colour then ‘no handles’ at 35% and 31% respectively, but the remaining nine categories were seen at 6% or less.

The most common pattern colours in the raw data atypical group were the combinations of white, yellow, and light blue occurring in 25% of the atypical vessels, compared with 28% in the corpus. Vessels that were reported with no pattern applied were noted at 23% in the raw data atypical group and 20% in the corpus. The most prevalent colour combination of pattern in the corpus is the combination of white and yellow, which occurred in 35% of the corpus compared with 18% in the raw data atypical group. Patterns applied singly in white or yellow occur in 5% and 2% of the atypical vessels respectively but each occurred in 2% of the whole corpus. The remaining colours and combinations are noted at 6% or below in the atypical group. In the expert assessment, the two most prevalent patterns were yellow and white at 38% and yellow, white, and light blue at 31%. 'No decoration' and yellow, white, and dark blue both accounted for 8% each of the expert pattern identification, the remaining six categories accounting for 4% or less.

The most prevalent body pattern in the raw data atypical group was the feather pattern at 23%, 'other' and 'no pattern' are the second most common representing 18% of the atypical vessels each, with the garland pattern comprising 17% of the atypical group. In comparison the most common three pattern types in the main corpus were garlands (35%), feather (33%) and 'no pattern' (19%); all other pattern types represented 5% or less. Patterns described as 'other' represented 5% in the vessel corpus. The expert test indicated a total of seven body pattern categories in contrast to the raw data method that indicated nine; the three most prevalent patterns in the expert test were garland, feather, and 'other' at 40%, 27% and 13% respectively, with the remaining four categories accounting for 8% or less per pattern type.

The most common neck decoration group in the raw data atypical vessels group was 'no pattern' and garlands at 20% each, and 'other' at 16%. Zig-zag represented 14% of the atypical vessels, with the feather pattern appearing on 11% of atypical vessels. The corpus by comparison showed that the neck pattern fell into four major categories; garlands were most prevalent at 27%, feather 23%, 'no neck' at 22% and 'no pattern' at 19%. All others occurred in under 3% of incidents, including 'merged' patterns. The expert assessment for the neck decoration showed the garland and feather patterns being the most prevalent respectively at 31% and 27%, with 'no neck' accounting for 21% and 'no pattern' accounting for 10%. Only two other pattern types, 'zig-zag' and 'other', were identified by the expert assessment.

The raw data approach identified four vessels of known origin as atypical whereas the connoisseur's eye method identified only one, equating to a total of five vessels identified of known origin. Overall, the raw data approach identified more atypical vessels as being from the 'origin ambiguous' category, whereas the connoisseur's eye method indicated more atypical vessels as being from private collections (Figure 33 and Figure 34).

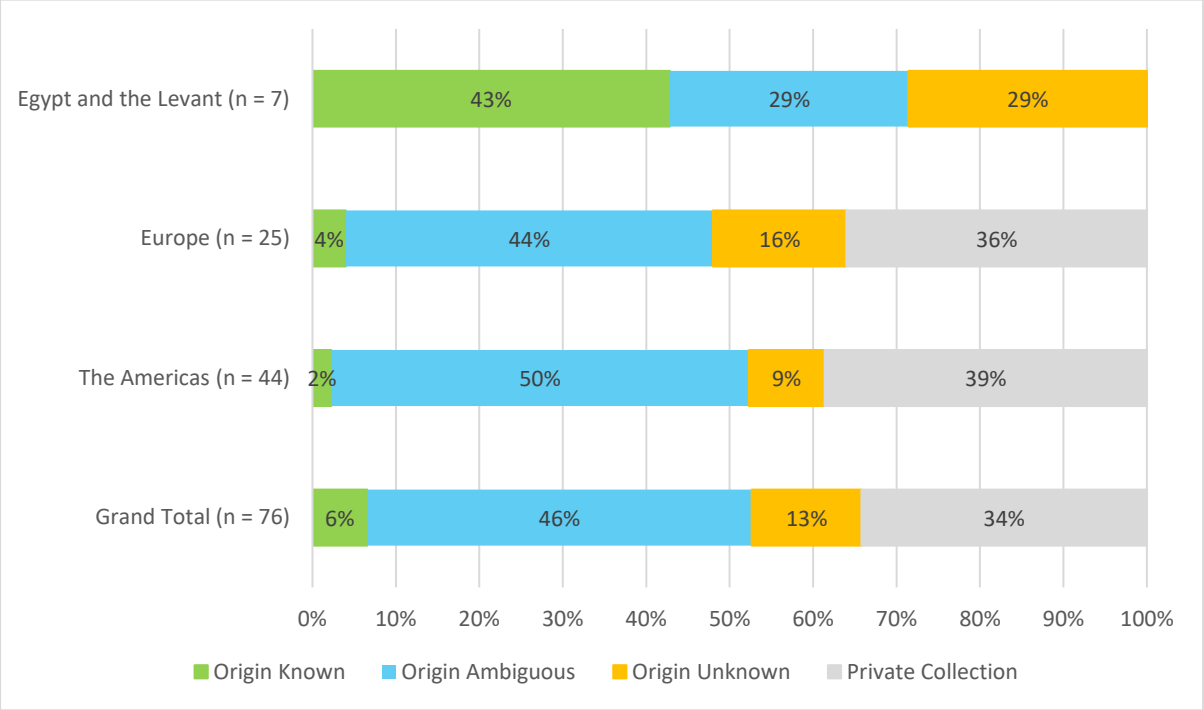


Figure 33: Combined percentages of provenance type by region of atypical vessels using both the raw data method and the connoisseur's eye method.

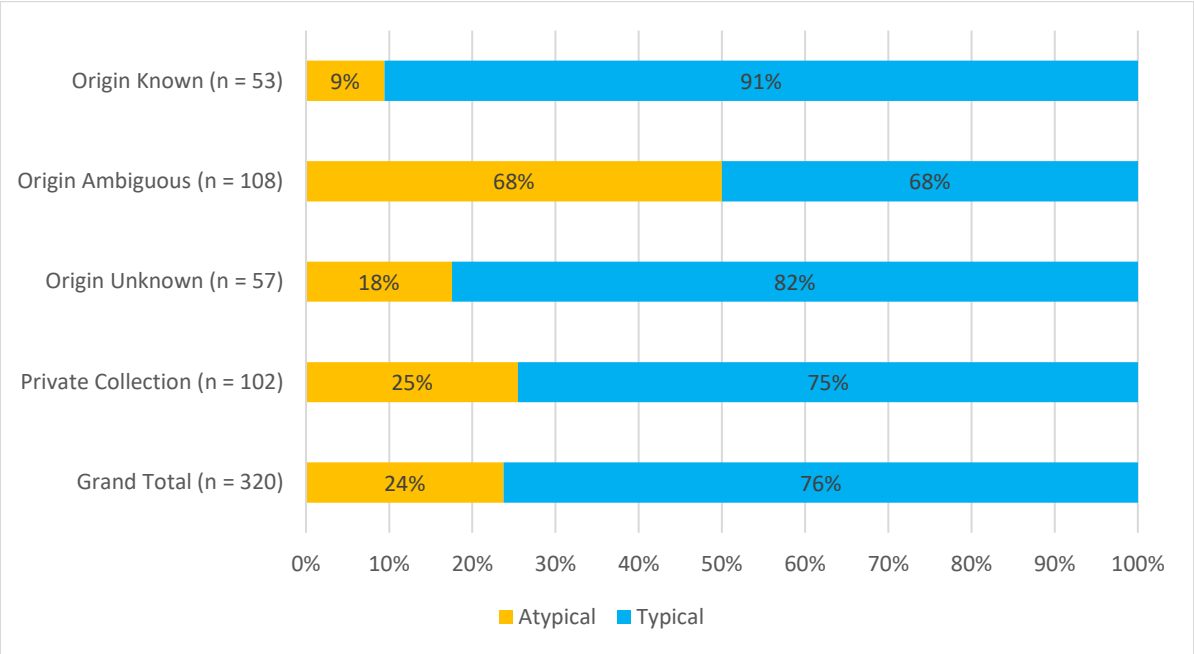


Figure 34: Percentage of provenance category: typical, atypical, and total number of vessels in the experimental group using the connoisseur's eye and raw data methods combined.

Using the combined methods, it was observed that 31% of the total number of vessels reported as being located in the Americas were identified as atypical, constituting 56% of the total number of atypical vessels in the world. Also, 33% of the atypical vessels located in the Americas are of ambiguous or unknown origin. Only 1% of the vessels identified as atypical located in the Americas (constituting one kohl tube vessel), was of known origin, and this was indicated by the connoisseur's eye method. The Americas also has the largest percentage of atypical vessels held in private collections at 22%, compared with the private collections in Europe that hold 10%, and Egypt and the Levant that have only 1% of atypical vessels (Figure 35).

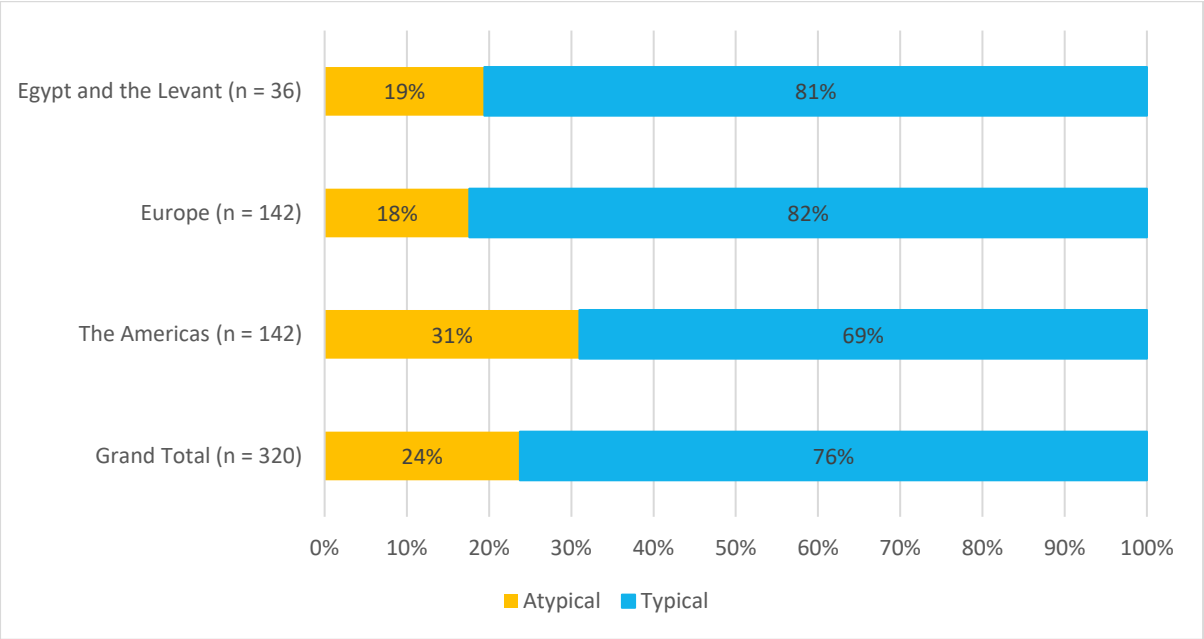


Figure 35: Percentage of atypical and typical vessels by region. Atypical vessels identified by the raw data method and connoisseur's eye method combined.

Egypt has the smallest number of vessels identified as atypical, although three vessels of known origin were indicated by the raw data method. The raw data method identified four vessels of known origin in total: the remaining vessel being located in the United Kingdom, Europe. Three of these vessels have been dated approximately, and are described as having white, brown and polychrome ground colour respectively with two additional atypical features. The remaining vessel of known origin (Cairo museum, 46955) was excavated from the main site of the city of Amarna and is arguably a typical 18th Dynasty style vessel: described as a dark blue jug with trailed decoration in the feather /garland pattern applied in yellow and white. Dated to the reign of Amenhotep IV this vessel was noted as atypical from the three 'atypical' features: the colour combination of yellow, white and blue on the rim and handles and the pattern merging from feather to garlands on the body.

The 16 vessels that were indicated as atypical by both methods were all described as having little or no provenance information: nine vessels being from the origin ambiguous group, four vessels from origin unknown and three vessels from private collections. No vessels from the known origin group were identified from the combined methods. By country, 11 of the atypical vessels indicated by the combined methods are located in the Americas, four in Europe and one in Egypt and the Levant.

7.7 Dating and stylistic trends

This paper seeks to discuss the viability of using datasets to detect and assess atypical characteristics for comparison with the respective provenance of vessels attributed to the New Kingdom period. Taking the example of the thick-walled krateriskos (n = 10) and the pomegranate vessel (n = 5) the most prevalent colours are white and green, respectively. Two of these vessels were reliably dated to between the 19th dynasty and the 20th dynasty, with 13 assigned to *Werkkreis* 4 to 6, spanning a total reign of Tutankhamun to Pinudjem II, therefore it cannot be said if these represent a link between a colour preference for these specific vessel types. Likewise, vessels that exhibit multiple colours in patterns may denote a trend for polychromatic vessels, however, these vessels are relatively evenly distributed over the known reigns of production and *Werkkreis* 1 to 5. The largest group of polychrome patterned vessels belongs to *Werkkreis* 4 that spans the reigns of Tutankhamun (1333-1323 BCE) - Rameses II (1290-1224 BCE), therefore showing little statistical significance. Hence, it can be claimed that these epochs are too broad and span considerable periods of political and social change to reliably assign trends to specific reigns or even Dynasties and may not recognise periods of experimentation as seen in early glass vessel production, of which some vessels are of known origin and can be reliably dated. Therefore, assessing a dataset that spans discrete periods of glassworking institutions and styles, where dating is largely equivocal, is challenging. Including all data prevents cognitive bias that could be introduced by attempting to refine the dataset, however, this presents limitations which should be considered for future study design.

The composition of ancient glass and associated colourants are well documented and analytical techniques have proven extremely effective in determining the period of glass production from their raw materials. Establishing the period of production would help narrow dating epochs of ancient Egyptian glass vessels, specifically the vessels which are categorised in the broader *Werkkreis* groups that span both the Late Bronze Age (LBA) and Iron Age. Where vessels are of known origin and date, elemental analysis could offer new insights regarding raw material trading including colourants and variances in composition, which would be particularly valuable when examining translucent vessels and those with statistically rare colours. Although non-destructive techniques, such as X-ray fluorescence, are currently used, some analytical methods are not sensitive enough to detect trace elements which are used to unequivocally confirm provenance in LBA vessels, however, as non-destructive analysis techniques develop to provide greater sensitivity, compositional data can be obtained with little sample preparation

and with no risk to the vessel. However, analytical analysis may not be a pragmatic solution for items located in countries with strict legislation, such as Egypt, which strictly regulates sampling of artefacts.

7.8 Conclusion

Using the information from *Die Glasgefäße* and applying the raw data test, an ancient Egyptian vessel is statistically more likely to present characteristics typified by vessels produced during the height of the glassmaking industry in the 18th dynasty. However, some vessels of known origin do not conform to this 'statistical ideal' and should be highlighted and investigated as particularly rare stylistic pieces. Overall, the 'connoisseurs' eye' method appeared to be more discriminatory, identifying fewer attributes per category than the raw data atypical test. This was apparent in the higher percentages (>30%) seen in the top two to three most prevalent attributes per vessel, rather than the raw data atypical test that showed a lower percentage (<30%) in the top four to five categories. Therefore, raw data extracted from detailed descriptions can be useful to help define typical and atypical traits, but it does not take into account the aesthetic properties of each vessel or any potential trends throughout the ancient Egyptian glassmaking and glassworking era, therefore, an expert visual analysis should also be used for appraisal. However, the combined methods were by no means conclusive, only 'agreeing' on 16 vessels of the 78 vessels identified as atypical and identifying five vessels of known origin. Therefore, any vessels to be examined should also be subjected to compositional analysis, where appropriate. The Americas were identified as containing the largest number of atypical vessels and the largest proportion of vessels with little or no provenance information, including those vessels that are contained within private collections. Finally, it is not the intention of this research to undermine the authenticity of the vessels identified in this study as atypical, but to articulate the value of the information that has been lost as a result of poor documentation during historical excavations, and how important information may be gained by subjecting these pieces to archaeometric study.

7.9 References

Birren, F. (1950) *Color Psychology and Color Therapy: A Factual Study of the Influence of Color on Human Life*. McGraw-Hill.

Broschat, K. and Rehren, Th. (2017) 'The Glass Headrests of Tutankhamen', *Journal of Glass Studies*. Corning Museum of Glass, 59, pp. 377–380.

Loat, W. L. S. (1905) *Gurob*. London: BSAE/ERA 10.

Na'aman, N. (2000) 'The Egyptian-Canaanite Correspondence', in Cohen, R. and Westbrook, R. (eds) *Amarna Diplomacy: The Beginnings of International Relations*. Baltimore: Johns Hopkins University Press, pp. 125–138.

Nicholson, P. T. (1993) *Egyptian Faience and Glass*. Bloomsbury USA (Shire Egyptology).

Nicholson, P. T. and Henderson, J. (2000) 'Glass', in Nicholson, P. T. and Shaw, I. (eds) *Ancient Egyptian materials and technology*. Cambridge: Cambridge University Press, pp. 195–226.

Nolte, B. (1968) *Die Glassgefässe im alten Ägypten*, *Münchner Ägyptologische Studien*. Berlin: Verlag Bruno Hessling.

Petrie, W. M. F. (1894) *Tell el-Amarna*. London.

Reeves, N. and Wilkinson, R. H. (2008) *The Complete Valley of the Kings: Tombs and Treasures of Egypt's Greatest Pharaohs*. Thames & Hudson.

Shortland, A. J. (2001) 'Social influences on the development and spread of glass and glazing technologies', in Shortland, A. J. (ed.) *The social context of technological change - Egypt and the Near East 1650-1150 BC*. Oxford: Oxbow Books, pp. 211–223.

Shortland, A. J., Nicholson, P. T. and Jackson, C. M. (2001) 'Glass and Faience at Amarna: different methods of both supply for production, and subsequent distribution.', in Shortland, A. J. (ed.) *The Social Context of Technological Change*. Oxford: Oxbow Books, pp. 147–160.

8 Overall Discussion

8.1 Introduction

The final chapter summarises the results of the preceding chapters, examines how the key findings answer the research questions and discusses the findings within the context of the research chapters. The aim of this study was to investigate the development of LBA glass technology from early contexts onwards in conjunction with patterns and methods of transport between Egypt, the Levant and the Near East. The role of women and their impact on the LBA glass system is also discussed in this chapter as part of the research questions.

This thesis proposes that the rapid establishment of a glassmaking industry in Egypt was driven primarily by royal demand, discussed later in section 8.2.3. This research is the first analytical study to examine several polychrome fragments from the tomb of Amenhotep II, thereby contributing significant supporting evidence for an early pre-Malkata Egyptian glassmaking industry. The major, minor, and trace element analysis conducted in chapter 4 provides conclusive evidence to support the theory of an early Egyptian glassmaking workshop by establishing that the provenance of the polychrome fragments from KV35, the tomb of Amenhotep II, were of Egyptian manufacture. In addition to the trace element confirmation, the three dark blue glasses were confirmed as being coloured by cobalt and containing elevated levels of the associated elements Mn, Ni, and Zn therefore characteristic of the Western Oases sources typified in Egyptian cobalt glasses.

In addition to the analytical evidence, this thesis compiled the archaeological evidence which indicates the use of cobalt in the earliest glasses depicted and observed in Egypt. This thesis referenced scenes from the Hall of Annals of Tuthmosis III showing the king dedicating gifts to the temple in celebration of his victories in the Levant; where glass is indicated, the scene has maintained the light blue and dark blue colours, signifying that both copper and cobalt-coloured glasses are represented in this scene. The depiction of dark blue glass is strong evidence suggesting the use of cobalt as a colourant during the reign of Tuthmosis III; as discussed in section 1.2.6.2 and in section 5.8.2, the almost exclusive use of cobalt to colour Egyptian glasses dark blue suggests that these were glasses produced in Egypt. The presence of the king's cartouche next to the depiction of glass has been emphasised as indicating a special royal interest, or as Sherratt terms it "royal lapis lazuli" (Sherratt, 2016) but it could also

indicate royal ownership, i.e., glass produced in Egyptian glassmaking workshops by order of the king, or from the king's workshop. Nicholson states that the fact Tuthmosis III associated his name with glass indicates some personal "excitement" for this new material (Nicholson, 2012). As discussed in section 3.3, the quality of grave goods were a critical part of the Egyptian mortuary cult; the curation of possessions for a tomb were a direct reflection on the social importance of the individual, therefore it is likely that a glassmaking industry was established to provide the king with the highest status goods in this life and for the afterlife.

8.2 Origin of the first glasses

It has been proposed that the invention of glass originated in either Egypt, Mesopotamia or possibly Mycenaean Greece, however identifying the exact region of invention is challenging. As discussed in section 1.5.3.2, to date there has been no definitive archaeological evidence for primary glassmaking workshops in Mycenae and compositional analysis on early glasses from sites in this region show that they are most likely imports from Egypt and Mesopotamia (Walton *et al.*, 2009; Polikreti *et al.*, 2011; Zacharias *et al.*, 2018). Therefore, to date there is little evidence to suggest that Mycenae was the innovator of glass in the LBA, and therefore is not included in this discussion.

The original supposition that Mesopotamia was the original innovator of glass is still largely held today, some suggesting that glassmaking in Mesopotamia potentially predates Egyptian production by centuries (Barag, 1970a, p133). There are several sources of evidence which form the argument for this model: It has been maintained that textual evidence for very early Mesopotamian glassmaking comes from Assyrian glassmaking texts which were translated by Oppenheim and believed to date to the Third Dynasty of Ur, approximately 2112-2004 BCE, therefore pre-dating the earliest finds of glass in Egypt (Oppenheim, 1970, 1977, p336). Archaeological evidence confirming the location of a primary glassmaking or glassworking site in Mesopotamia, as indicated by finds of glass waste products, crucibles or kilns have yet to be discovered, therefore the evidence for glassmaking in Mesopotamia has largely come from the glass finds themselves (Shortland, 2012, p49; Shortland *et al.*, 2017; Reade, 2021, p4). A lump of bubbly blue glass excavated in 1919 from the site of Eridu, in Abu Shahrein in southern Mesopotamia, is believed to be dated to as early as 2000 BCE, hence represent one of the earliest glasses (Beck, 1934; Hall, 2014). However, there appears to be no recent analysis despite the significance of this piece, the last analysis being performed in 1956 (Garner, 1956).

In addition to the texts and the Eridu fragment, a survey of glass objects undertaken by Barag and Von Saldern in 1970 suggested that early glass was being produced in Mesopotamia in a variety of shapes and colours and that glassmaking was conducted at several sites (Barag, 1970; Von Saldern, 1970; Shortland, Rogers and Eremin, 2007; Shortland, 2012; Walton *et al.*, 2012; Shortland *et al.*, 2017). Finally, a re-examination of the finds from Nuzi has identified chunks of glass thought to be part of an ingot, therefore this suggests some limited glassworking was undertaken at Nuzi (Shortland *et al.*, 2017).

This thesis presented the first ever elemental analysis of very early glass objects from a previously undisturbed tomb at the site of Gurob; in total, 38 glass items were analysed from the burial of foreign women and children. The trace element analysis confirms that the glasses analysed from the tomb were all of Mesopotamian manufacture, therefore the research in chapters 2 and 3 provide the first trace element analysis confirmation that early glasses dated to the reign of Amenhotep I to Tuthmosis III were transported from Mesopotamia to the harem palace in Egypt by women. As discussed in section 2.3, 3.4 and 3.6, the transport of glass in the form of personal possessions, such as small items of jewellery and amulets, by women of high status was likely achieved in connection with foreign princesses travelling to Egypt as part of diplomatic marriages. The research in sections 2.6 and 3.10 represent the second instance of Mesopotamian glasses found in Egypt at the time of publishing, in addition to confirming the beads and the scaraboid as some of the earliest glasses ever manufactured. A comparison of the glass goods, specifically personal possessions, transported by women is made between the Tomb of the Foreign Wives and tomb 27 at Gurob, both of which contained multiple bodies of women buried with glass possessions (Lilyquist, 2004).

As discussed in sections 1.5.3.1 and 4.2, recent work at the site of Tell Atchana, ancient Alalakh, has presented archaeological evidence for glassworking including a crucible containing partially fused glass, some associated glassmaking debris and the presence of kilns. The chronology is believed to predate the Egyptian glassmaking sites at Malkata and Amarna and therefore indicates an early glassmaking site outside the core areas of Mesopotamia and Egypt (Dardeniz, 2018; Dardeniz, Henderson and Roe, 2022). Elemental analysis on glasses excavated from Tell Atchana using LA-ICP-MS suggest that these glasses can be distinguished by the vanadium and chromium concentrations when compared with glasses from Nuzi, Tell Brak, Amarna and Malkata (Dardeniz, 2018; Dardeniz, Henderson and Roe, 2022). Work is

ongoing at this site to confirm both the chronology and further evidence of glassmaking, however the evidence to date presents interesting new information to this field.

One of the critical issues to address when discussing physical finds of early glass is the difference in the environmental conditions of both Egypt and Mesopotamia: preservation conditions in the Near East are challenging, with many specimens of glass being degraded to the point where analysis is impossible, if they are recognised as glass at all. Therefore, as discussed in section 3.3, it is the advantageous preservation conditions of Egypt in conjunction with the established chronology which provides the most reliable sources of evidence and dating for early glasses, especially when excavated from a relatively secure context. This is well demonstrated when considering the Mesopotamian glass beads and scaraboid analysed in chapters 2 and 3; all items showed good preservation and were excavated from a secure context. The first identified site in connection with glass production is the palace complex of Malkata, the Theban residence of Amenhotep III (1390-1352 BCE). As discussed in section 1.5.1.1, finds including crucibles, glass slag, waste fragments of vessels, coloured glass rods and an uncoloured piece of partially fired glass supports the proposition that the site of Malkata was engaged in glassworking, however the status of Malkata as a true glassmaking site is contentious as the primary evidence from this site can no longer be examined (Mass *et al*., 2002). The evidence for the first Egyptian LBA glassmaking workshops is discussed in sections 1.5.1 and 5.8.1. Excavations at the New Kingdom sites of Amarna, Lisht and Qantir have shown that glassmaking evidence such as crucibles with partially formed glass, semi fired glass batches, kilns, and glassmaking waste provides firm evidence that glass was being produced at these sites from raw materials (Mass, Wypyski and Stone, 2002; Jackson and Nicholson, 2007a; Pusch and Th Rehren, 2007; Smirniou and Rehren, 2011).

As shown in Table 1 and discussed in section 1.2.6, copper blue is the most prevalent glass colour produced in Mesopotamia (Reade, 2021, p17). Although other colours were produced in Mesopotamia, it is in Egypt where a visible expansion of colouring technology is observed in vessels and objects (Nolte, 1968). The earliest glasses from the reign of Tuthmosis III are primarily blue, but glasses attributed to the reign of Amenhotep II, his son, show a marked progression in the number of colours used to create glass vessels. Vessels created using black, white, purple and yellow in addition to the use of cobalt blue, utilised exclusively in Egypt, are observed in what is believed to be an early experimental phase in Egyptian glassmaking (Nolte, 1968; Lilyquist *et al.*, 1993).

This is also reflected in other vitreous industries: Faience produced before the New Kingdom era was coloured blue using copper and purple/black/brown using manganese. During the New Kingdom this range of colours expanded to include cobalt dark blue, lead antimonate yellow, green by combining copper and lead antimonate and iron oxide red. It has been suggested that the expansion of the faience colour range can be directly attributed to the production of "new" colours in Egyptian glassmaking (Kaczmarczyk and Vandiver, 2008, p57). Therefore, the development of colourant technology demonstrates that upon the establishment of Egyptian glassmaking industry, it is in Egypt where the technology for colour creation and innovation thrived.

To summarise, it has been advocated that the textual evidence and the early finds such as the Eridu fragment indicates that glass was originally invented in Mesopotamia and that the technology was subsequently transferred to Egypt, likely as a result of the military campaigns undertaken by Tuthmosis III. However, the physical evidence for a Mesopotamian glassmaking industry is scarce. As stated in section 8.1, the confirmation of Egyptian manufactured glass in several colours from the tomb of Amenhotep II analysed as part of this thesis proved that an established glassmaking industry was in operation, and potentially more advanced than Mesopotamia in terms of colourant production by the reign of Amenhotep II, thereby pre-dating the archaeological evidence of the Malkata workshop. The glass beads and scaraboid from the site of Gurob are dated by the excavators to the reign of Tuthmosis III at the latest, therefore, this thesis confirmed the presence of very early Mesopotamian glass in Egypt in addition to the evidence for an Egyptian glass industry dating to Amenhotep II, if not earlier.

8.2.1 Evidence for a pre-Malkata Workshop in Egypt

As previously discussed in 8.1 the research undertaken in chapter 4 presented the elemental analysis of several colours from polychrome glass fragments attributed to the tomb of Amenhotep II, KV35. All colours contained on the polychrome fragments were confirmed to have been manufactured using Egyptian raw materials. In addition to the major composition, the dark blue glasses were found to be of typical Egyptian cobalt blue glass, exhibiting the characteristic low potassium content and elevated levels of Al, Ni, Mn and Zn. The copper-blue glasses are also compositionally characteristic of Egyptian turquoise or mid-blue glasses, which contain elevated levels of Sn indicating that the copper colourant was sourced from

bronze. All glasses from KV35 compare well with glasses from the later Malkata palace, indicating that an Egyptian glass industry was established and was capable of producing standard Egyptian glass compositions at this early stage.

This research therefore greatly expanded on the work by Lilyquist *et al.* and Shortland *et al.* by performing major minor and trace element analysis on early glasses to confirm that all colours analysed were of Egyptian provenance (Lilyquist *et al.*, 1993, p36-39; Shortland and Eremin, 2006). In addition to the analysis by Lilyquist *et al.* Section 4.5 describes more recent analysis undertaken on an early vessel fragment connected with Amenhotep II by Nicholson and Jackson; the research performed LA-ICP-MS analysis on three colours from a polychromatic vessel fragment from KV55. Although this tomb is highly disputed it is believed to be connected with Amenhotep II (Nicholson and Jackson, 2013). The work in chapter 4 built and improved on previous works by providing several analyses on a larger range of colours from fragments with secure attribution to Amenhotep II. Therefore, the research in chapter 4 confirms that glass was produced in a variety of colours in an early pre-Malkata Egyptian workshop using domestically sourced raw materials.

Based on the research findings presented in chapter 4 and from early analyses of glass goods from the tomb of the Foreign Wives of Tuthmosis III, this analysis undertaken as part of this thesis supported that although glass may have been introduced to Egypt from Mesopotamia, a glassmaking industry in Egypt was likely established in the reign of Tuthmosis III. Crucial evidence for an early Egyptian glassmaking workshop comes from the SEM-EDS analysis of very early polychrome glass vessel fragments attributed to Tuthmosis III and glass from a headdress and pendant from the tomb of the Three Foreign Wives. The analysis of the items show that cobalt was used as a colourant for blue glasses; furthermore the elevation of associated elements of aluminium, nickel and zinc confirms that the cobalt source used is from the Western desert Oases (Lilyquist *et al.*, 1993, p36-39). As discussed, this distinct cobalt source was exclusively used in the Egyptian New Kingdom to colour dark blue glasses (see section 1.2.6.2). Cobalt blue glasses are virtually absent in Mesopotamia, with only sporadic finds attributed to Egyptian imports and a very rare example of ceremonial axes which use a distinct cobalt source (Walton *et al.*, 2012). It has been proposed that the three foreign wives died in the early to mid-reign of Tuthmosis III, possibly between year 7 and year 22 (Lilyquist, 2004); therefore, the presence of cobalt blue glasses with a distinct Egyptian composition as part of the grave goods suggests that glassmaking workshops were established in Egypt as early

as 1472 BCE. The establishment of a pre-Malkata glassworking site has also been suggested by Shortland, who argues that although raw materials could have been exported, it is more likely that the cobalt blue glass was manufactured in Egypt using domestically sourced raw materials (Shortland, 2001, p218). Lilyquist acknowledges that a pre-Malkata workshop existed but states that the number of factories and their locations are not known (Lilyquist *et al.*, 1993, p41). Lilyquist also proposes that the technology behind Egyptian glass is foreign, citing that the glass beads and inlays from the tomb of the foreign wives were either "made by Canaanites or by Egyptians having learned glass technology from them" and proposes that workmen were transported to make glass (Lilyquist, 2004, p337).

The establishment of an Egyptian glassmaking industry may have been accelerated by the acquisition of foreign glassworkers who brought expertise and knowledge, thereby effecting a rapid technology transfer to Egypt (Moorey, 2001, p6; Shortland, 2001, p218). The mobility of craftsmen are known in the New Kingdom, and it has been contended by Lilyquist *et al*. and Eyre that foreign craftsmen were indeed present in Egypt from an early stage in the New Kingdom (Eyre, 1987; Lilyquist *et al.*, 1993, p43). Textual reports in the Amarna Letters detail requests for skilled workers therefore it was likely common practice for accomplished and valued personnel to be loaned to foreign courts as a gift when required by a brother king (Moran, 1992, p61; Bryce, 2004, p118).

8.2.2 Possible locations for an early glass factory in Egypt

Glass was a high-value item and consequently regulated by the Royal Court, therefore the location of an early glassmaking workshop would have likely been situated at an existing palace or temple workshop with knowledge of pyrotechnology and access to raw materials and kilns (Nicholson and Peltenburg, 2000, p177-196; Nicholson, 2012). There is evidence at Deir el-Medina, the workman's village next to the Valley of the Queens located near Thebes, for existing faience workshops however there is no evidence for glass production at this site (Shortland, 2000, p81). The modern cities of Cairo, Luxor and Karnak are built on top of the ancient capital sites of Memphis and Thebes; therefore, it is likely that any glassmaking sites in this area are now lost. The two early glassmaking sites of Malkata and Amarna are slightly unusual in that the respective kings moved the location of their palaces outside the core capital areas; the sites were subsequently vacated and were not built upon afterwards. The evidence

for an early glassmaking site in Egypt therefore comes from the iconographic and compositional evidence as discussed in the previous sector.

The city of Memphis had declined in preference of Thebes and Karnak in the 18th Dynasty (Bryan, 2000a, p236) and a new burial place for the royal family was established: The Valley of the Kings, the New Kingdom necropolis, is located on the West bank of the Nile directly opposite Thebes, hence a proximate glassmaking workshop would have been well situated to produce vessels and objects for the court and for royal and elite tombs. The results from chapter 4 confirm that there was an established glassmaking industry in Egypt before or during the reign of Amenhotep II, and as discussed in 1.8.1, primary glassmaking sites in Egypt are found in proximity to palatial centres or temples, and finds of glasses such as vessels, jewellery and inlayed furniture and coffins are excavated from high status burials. Therefore a glassmaking centre at the temple of Thebes, a favoured site of Tuthmosis III, would be credible (Nolte, 1968; Nicholson, 1995; Shortland, Nicholson and Jackson, 2001, p153).

8.2.3 Demand for an Egyptian glass industry

It is with certainty that royal demand drove the establishment of the first Egyptian glass industry. When discussing the models of production and control, the evidence suggests that glass was primarily produced and controlled by the elite for the elite. The New Kingdom period was one of affluence, therefore the display of wealth and gift giving, shown by the exchange of gifts detailed in the Amarna Letters, was an important part of international relations (Bryce, 2004). In addition to displaying wealth in life, one of the most important tasks of the elite, especially the king, was the preparation of his tomb. In the New Kingdom, elite burials would contain items made specifically for the tomb, including amulets and jewellery, *shabti*, along with objects used in everyday life (Grajetski, 2003, p66; Ikram, 2015, p95). Therefore, the need to exhibit wealth, power and status in the New Kingdom, and to reciprocate the same value of gifts from the other ‘Great Powers’, in addition to preparing for the afterlife, would have been primary drivers to establish the luxury industry of glassmaking by the king. This research confirmed that glass was produced in Egypt using raw domestic materials from the reign of Amenhotep II, consequently, it is very likely that the royal court would be one of the few organisations able to supply the ample resources required to rapidly establish a complex industry involving the administration and refinement of raw materials, therefore they would hold the monopoly on the glass industry to maintain status.

8.2.4 Control of glass

This thesis redefines the model for the administration of glass in the LBA first proposed by Shortland *et al.* (Shortland, Nicholson and Jackson, 2001, p152), by incorporating the key findings from the research chapters contained in this thesis. Figure 36 incorporates significant sites, such as Serabit, now confirmed as a major consumer of Egyptian glass. The schematic also shows the potential mechanisms for the wider distribution of glass items into the general populace and ultimately transported as part of international trade. Glass vessels and objects (such as jewellery, glass inlayed furniture and sarcophagi) provided the royal family and high-ranking members of the court with grave goods which would reflect their status in this life and the afterlife (Shortland, Nicholson and Jackson, 2001, p152; Kemp, 2006, p308). The giving of high status gifts by the King would be made during a ceremony whereby courtiers and high officials would be led before the "Window of Appearance" and have rewards of gifts and honours bestowed upon them (Kemp, 2006, p276). Therefore, the giving of luxury objects was a ritualised event in the New Kingdom and it is likely that glass objects were part of the gifts, as indicated from the numerous glass goods recovered from tomb of Thuya and Yuya, the parents of Queen Tiye, wife of Amenhotep III; both of who were high members of the court and held many titles (Davis *et al.*, 1907). From the research undertaken on the fragments from Serabit, Sinai, the worth and quantity of votive offerings of Egyptian glass to temples is now established as a significant part of the LBA glass system. The addition of the movement of glass as containers for luxury goods are also represented in this new model.

Glassmaking was a labour-intensive process in addition to requiring the sourcing and refining of raw materials, including colourants such as cobalt which were sourced from the western oases. Therefore, the role that royal courts played in the resourcing of technological developments is highly relevant to this industry; Moorey states that only in such organisations could the necessary resources, workshops and workforce be provided to initiate artistic ventures on the scale required (Moorey, 2001, p4).

Smaller goods such as beads and amulets were clearly obtained by members outside the upper elite of the royal court (Figure 36), however it is questionable if glass was intended to be directly available to the common people as part of the wider Egyptian economy. Kemp, who has written extensively on the economics of ancient Egypt in his seminal book "Ancient Egypt: Anatomy of a Civilization", states that Egypt operated on an administrative, redistribution

system, however there was also a private sector for “trade” (Kemp, 2006, p302-304). Records of workmen from the artisan town of Deir el-Medina indicate that they were employed by the state, but also were free to practice privately, therefore excess or waste materials from glassmaking/glassworking may have been used for smaller items such as beads or amulets and subsequently traded. This thesis supports this concept by presenting the analysis from small items excavated from Tall Zirā’a as discussed in chapter 6; in addition to the core formed vessels from both Egypt and Mesopotamia, many small items such as beads and religion pendants made from glass are present at this significant site. The trace element analysis conducted as part of this research confirmed that small glass objects from both Egypt and Mesopotamia are present from both LBA and IA contexts; many hundreds other glass finds have been recovered from Tall Zirā’a, therefore indicating that there was routine, ongoing trade for these objects manufactured in both states and transported to the city. An alternative mechanism for the entry of glass jewellery into wider circulation could also have been accomplished from looting.

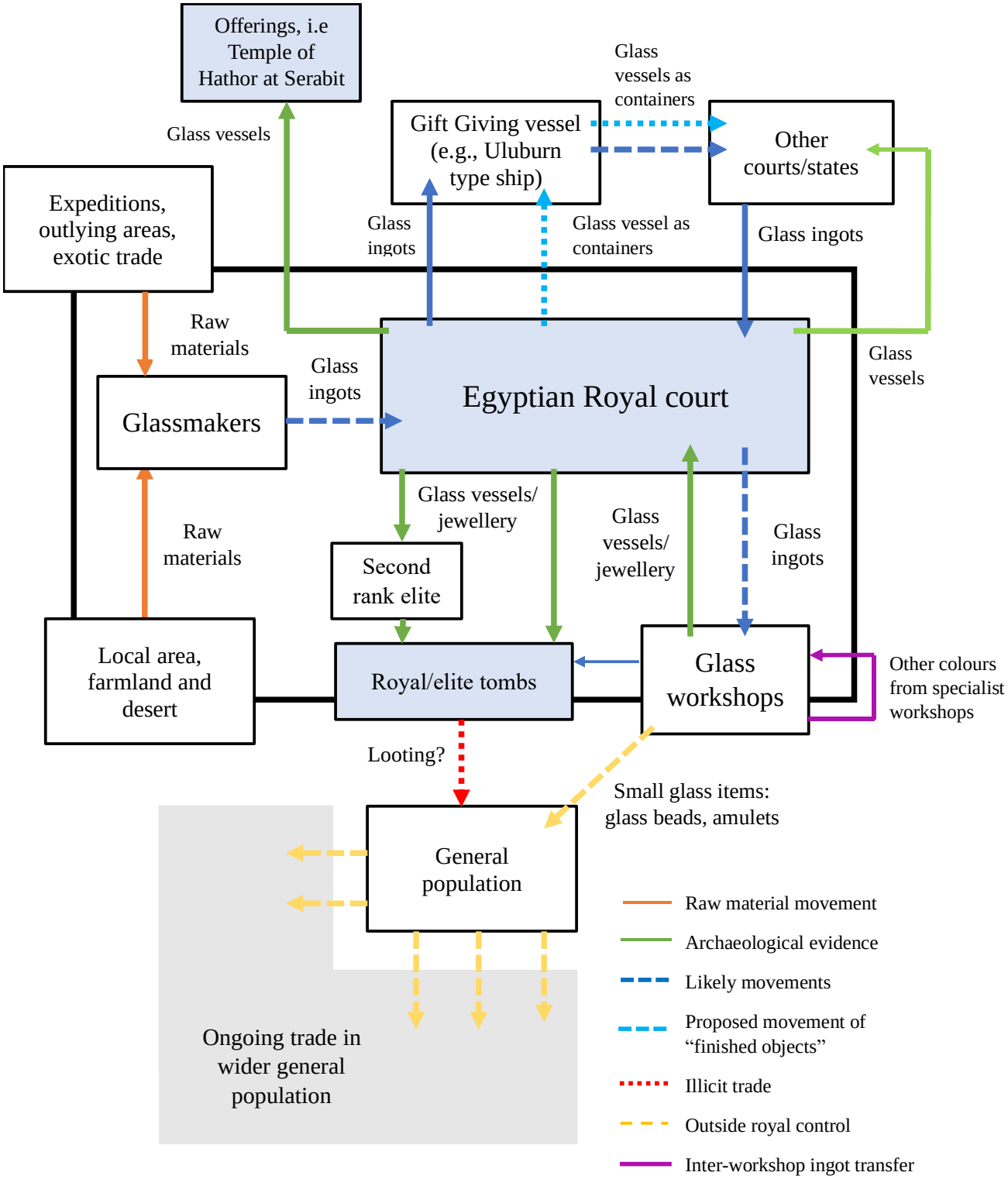


Figure 36: Proposed model for the control and distribution of glasses in the LBA, adapted from Shortland *et al*. 2001 (Shortland, Nicholson and Jackson, 2001, p152).

8.3 The movement of glass

This thesis established that significant amounts of glass from Egypt was transported internationally, specifically large quantities of glass vessels were regularly conveyed to the temple of Hathor, with vessels and beads being transferred to the Levant. Within Egypt, the Nile was the main method of transporting goods, and this also applied to the trade of exotic goods from Nubia which was administered through personnel employed by the temple (Kemp, 2006, p308). Traders were not regarded highly in Egyptian society (Brier and Hobbs, 2008) however, the political stability cemented in the early 18th Dynasty allowed Egypt to prosper through newly formed diplomatic relationships, and as a result the trade of exotic and imported goods increased: scenes from the 18th Dynasty tomb of Ken-Amun, the chief steward of Amenhotep II, depict a fleet of sea-going ships arriving from Syria and the Aegean, laden with goods (de Garis Davies, 1973; Wilkinson, 2010). By the 18th Dynasty, Egypt had also built sea-worthy ships which could transport large quantities of cargo such as raw materials or groups of people; Hatshepsut's mortuary temple at Dier el-Bahri also show depictions of soldiers on boats accompanying a trading expedition for luxury items to Punt. Therefore, the facility to transport large quantities of goods and people nationally and internationally both from and into Egypt by sea-going vessel was well established, as was the practice of using the Egyptian army to ensure the delivery of high-value items (McDermott, 2004, p93). Foreign brides, their goods and retinue were also likely transported by military convoy to the royal harems in Egypt (Lilyquist, 2004, p336; McDermott, 2004, p96).

Alternative methods of transport were by foot and donkey, and military routes were well established with forts and wells dug along the roads which supplied water (McDermott, 2004, p94). One such route was "The Way of Horus" which led out of Egypt into Canaan (Moshier and El-Kalani, 2008). It is very likely that glasses manufactured in Egypt would be transported to Serabit partially along this route to be offered at the temple of Hathor. Valuable trade and military routes were actively protected by the Egyptian army, however the exact routes are difficult to reconstruct based on the shifting geographical landscape and the ancient barriers which have changed over time (Pelletier, 2013). The likely LBA trade routes are shown in figure 38 and as discussed in section 1.8.1, varying routes were used. For example, three routes for transporting lapis lazuli were generally used: one by sea and two by land. The overland routes changed over time as networks were adapted (Huang, 2018). The trade routes followed in connection with the site of Tall Zirā'a are detailed in section 1.5.4.3.1.

Caravans are mentioned multiple times in the Amarna Letters in connection with gift transport; therefore, it is reasonable to suggest that this was the regular method for transporting high value goods between Egypt and Mesopotamia, despite the risks as discussed previously in this section. Once again, the courts could maintain control this way by equipping the caravan with a military presence and performing official checks along the route. The main LBA trade routes in Figure 37 shows that one route follows the coast, while the other follows an inland route which connects with the ancient city of Tall Zirā'a, also the recipient of glass vessels and objects from both Egypt and Mesopotamia as discussed in chapter 6. Although shipment by sea cannot be entirely disregarded when considering the Uluburun shipwreck, shipping by sea may have been the alternative method for transporting glasses where overland routes were not possible. As discussed in the previous section, chapter 6 combines archaeological information and elemental analysis to confirm that both Egypt and Mesopotamia transported high value core-formed vessels in addition to smaller items such as beads and amulets. The frequency of small glass items found at the site across several contexts from the LBA to the IA indicate that there was regular influx of these items into the city.

Based on existing texts, it is highly likely that there was a military presence with supervision by an official element involved with glass transport; overland transportation would have been subjected to regular checks enroute by the Egyptian administration and goods arriving in Egypt were also likely received by an official (Sherratt and Sherratt, 1991; Kemp, 2006, p324; Sherratt, 2016; Huang, 2018). Therefore, enforcing the proposition that all aspects of glass, from production to transport were controlled by the royal court.

The Amarna Letters provide textual evidence that items of high value were transported overland to Egypt, with letters EA7 and EA8 describing the robbing of caravans containing gifts for the Egyptian king (Moran, 1992, p14, p16). Letter EA7 from Burnaburiash, the king of Babylon, states that the caravans bearing gifts including gold and silver for Akhenaten were robbed by the pharaoh's own officials (Moran, 1992, p12-14), therefore it can be assumed that glass was transported overland from Mesopotamia as it ranked below gold and silver in value.

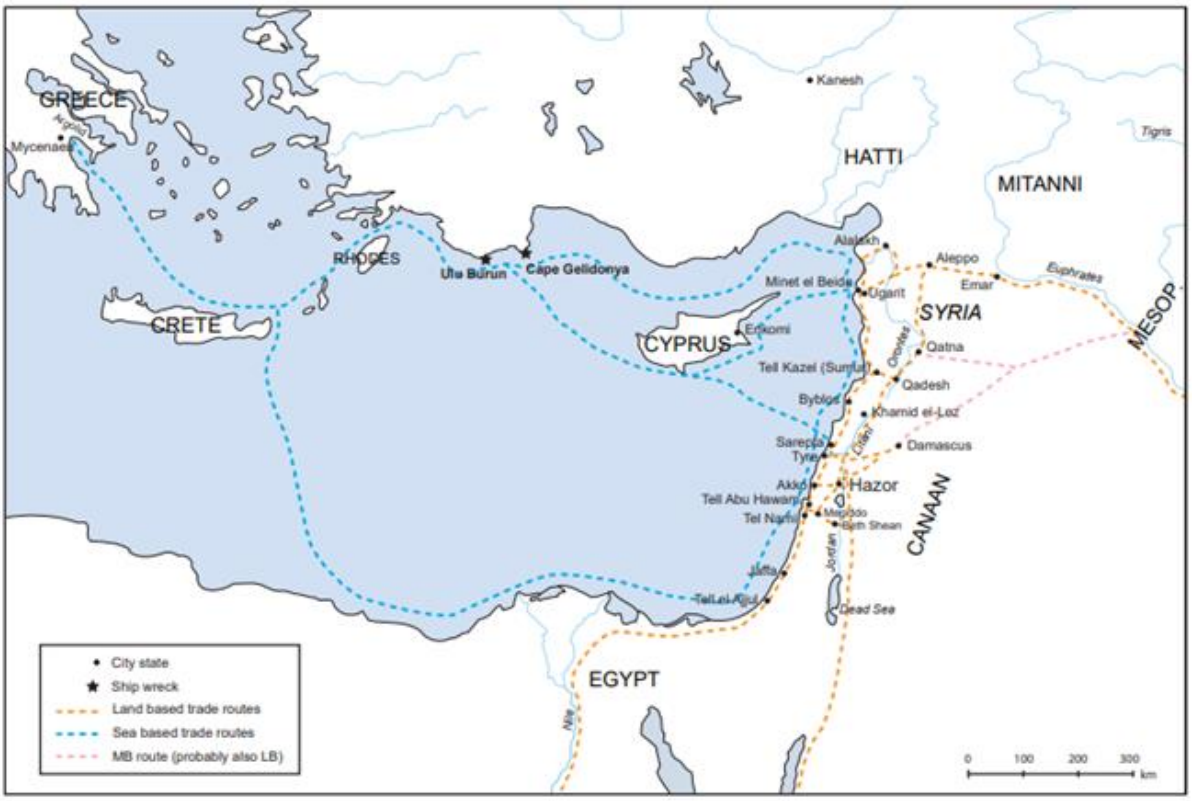


Figure 37: Late Bronze Age trade routes connecting Egypt to Mesopotamia and the Aegean (Josephson Hesse, 2008, p171).

The Uluburun shipwreck is one of the most important archaeological sites connected with the transportation of glass, the details of which are discussed in section 1.5.4.4. It is the primary evidence for transportation of glass by sea and is often referred to as a "trading vessel" or a vessel associated with the trade of goods in the LBA (Bass *et al.*, 1989; Brown and Harrell, 1995; Nicholson, Jackson and Trott, 1997; Pulak, 2001, 2012; Jackson and Nicholson, 2010; Lankton, Pulak and Gratuze, 2022), however based on the similarity of goods described in the Amana Letters it could be argued that this was a vessel containing diplomatic gifts bound for the Aegean, and not a ship containing random items for trade. This is further indicated by evidence of high-ranking Mycenaean officials aboard the vessel; finds of two Aegean swords and "Mycenaean glass pendant beads from at least two separate pectorals" and other functional Mycenaean pottery suggests the element of foreign supervision and therefore of diplomatic purpose (Pulak, 1998; Demand, 2012, p176).

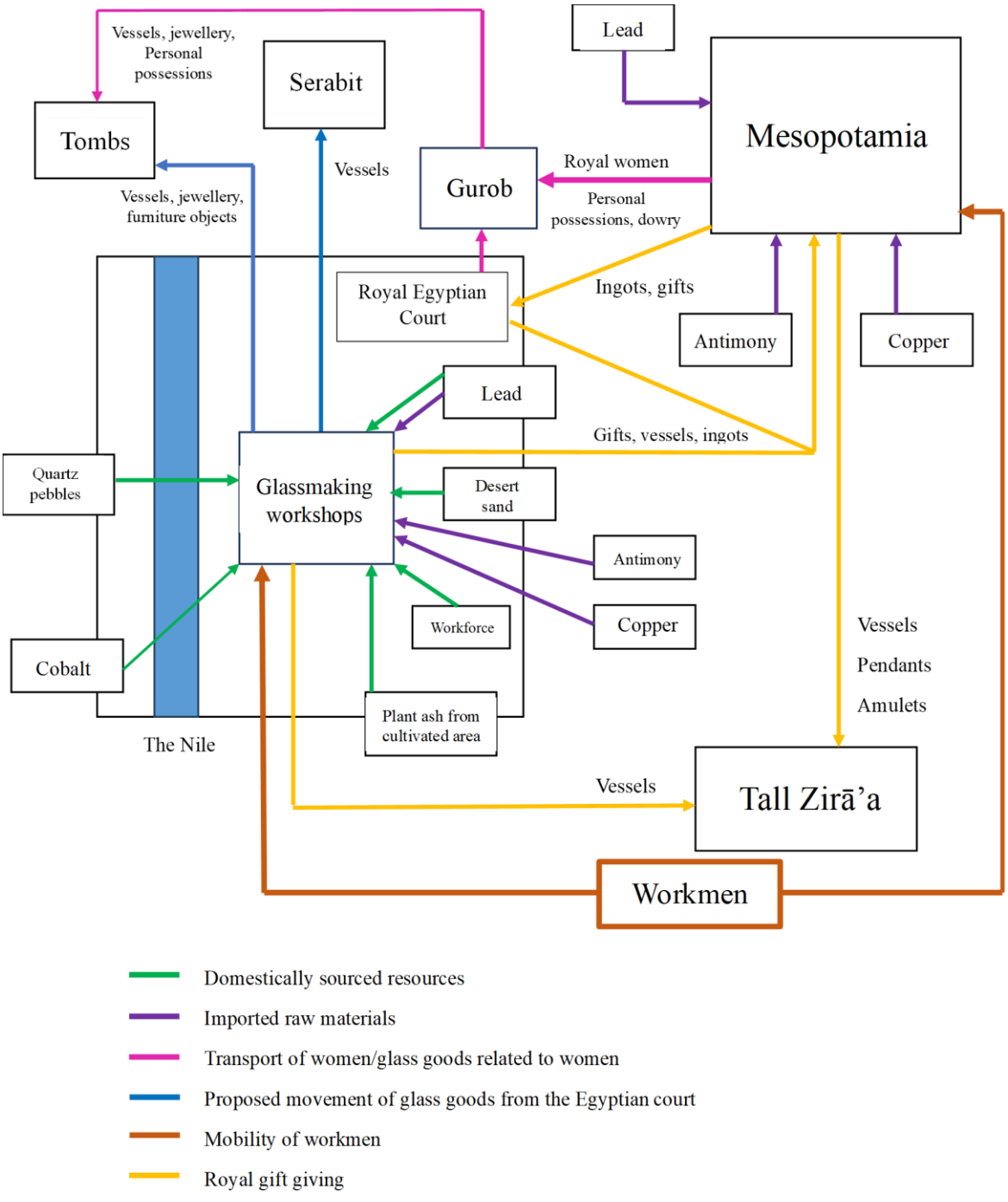
8.3.1 Forms of glass and movement

As discussed in 8.2.4 and shown in figure 36, this research redefines and expands the hierarchical model previously proposed for the control and distribution of glass which associates the value of the glass object to the relevant status in LBA society (Shortland, Nicholson and Jackson, 2001, p152): ingots were exchanged at the highest level between royal courts, and vessels and objects were given to the upper elite and preferred members of the court. Items such as necklaces and jewellery and smaller items such as beads and amulets were also presented as gifts (Moran, 1992, p72-75; Kemp, 2006, p276). This research also advocates a new international model in Figure 38 which incorporates the research from the key sites presented in this thesis, confirming them to be significant parts of the larger international LBA glass system. Specifically, this schematic links the analytical findings from Gurob, KV35, Serabit and Tall Zirā'a to elucidate the movements of glass to consumption sites (palaces, tombs, temples and international cities respectively) in addition to the raw materials required by the Egyptian glassmaking industry. This model also adds greater details to the model by indicating the forms of glass that were moved internationally, such as glass as containers and consumption sites such as tombs and Serabit, as discussed throughout this thesis.

The evidence from the Uluburun shipwreck indicates that official gift giving between courts that required long distance transportation of glass was undertaken in the form of ingots which were relatively robust. Although it could be argued that they are not 'finished' objects, they are coloured glasses, rather than colourless glasses, and may represent a 'diplomatic currency',

never intending to be worked into an object but presented a symbol of wealth to be displayed or circulated between brother kings.

Figure 38: Summary of the supply of raw materials, exchanges and movement of glass in the LBA. Adapted from Shortland (Shortland, 2000, p145).



The Amarna Letters EA17 and EA27 describe bottles of oils and letter EA48 describes jars containing balsam (Moran, 1992, p42, p89, p120). These items may have been presented in glass vessels, therefore evidence of glass vessels recovered from archaeological sites may not tell the whole story, being that the vessel itself does not represent the whole item being gifted, but that they were prestigious containers for another luxury item. The clearest examples for using glass for personal cosmetic items are kohl pots and palm shaped kohl vessels, where traces of remaining contents can confirm the purpose of such items (Nolte, 1968; Ribechini *et al.*, 2011). "Oily substances" and "waxy blue traces" are among descriptions of the remains of contents still present on glass vessels and fragments described in '*Die Glasgefäße im Alten Ägypten';* Nolte confirms that larger glass vessels would be used for precious ointments, smaller vessels for perfumes and pots for cosmetic goods such as eye colours. Nolte also describes evidence of closures likely made from wax, verifying that glass vessels held a functional purpose (Nolte, 1968, p42).

Chapter 5.3 assesses Petrie's assessment that the site of Serabit must have contained many glass vessels (Petrie, 1906, p139); the hundreds of fragments recovered from Serabit indicate that glass vessels as finished objects were therefore routinely transported to the site. The analysis of the fragments in chapter 5 confirms that glass vessels were transported to Serabit over a period of approximately 300 years, from as early as 1450 BCE during the reign of Tuthmosis III as discussed in section 8.2 and culminating with the final offerings made by Rameses VI before the collapse of the LBA as indicated by the fragment of natron glass using a later cobalt source discussed in section 5.8.12. Therefore, this research verified that the Temple of Hathor at Serabit can be considered as a major consumption site for Egyptian glass as votive offerings. The route from Egypt to Serabit, was well established as discussed in section 8.3, serving both the convoys of workers and royal officials and those embarking on the well-travelled route to the turquoise mines and the temple of Hathor, therefore enabling the routine transport of glasses for the temple.

8.3.2 Movement of glass by women

This thesis is the first study to combine elemental analysis and archaeological research to redefine the critical role of women in the international glass system. By confirming the presence of very early Mesopotamian glass in Egypt as part of foreign female burial this thesis presents conclusive evidence for the transport of glasses by women from the reign of Tuthmosis

III. Glasses were transported from Mesopotamia in connection with diplomatic foreign marriages which was accomplished at distinct levels: the highest level being the official gift items as part of the dowry, the high-status personal possessions of the royal bride and finally the personal possessions of those accompanying the foreign princesses. This research conclusively proves that foreign women, likely in connection with the harem palace travelled to Egypt with personal possessions and remained at Gurob as part of the harem community until their death.

Diplomatic marriages in the 18th Dynasty are well known, one of the most significant in the New Kingdom being the marriage of Tuthmosis III to three "Asiatic" princesses. The contents of their tomb are meticulously described in Lilyquist's "The Tomb of the Three Foreign Wives of Tuthmosis III" and indicate that they were buried in Egyptian style by the presence of canopic jars and other Egyptian ritualistic burial materials. Although they were regarded as relatively minor wives, they were buried with rich grave goods of gold, silver, and glass. Interestingly, their grave goods also contained stylistically un-Egyptian items such as a gazelle diadem and a glassy-faience vessel created in a foreign design, suggesting that the princesses were transported to Egypt along with personal possessions from their homeland (Nolte, 1968, p49; Lilyquist, 2004, p337).

Other diplomatic marriages, recorded in the Amarna Letters, meticulously list the gifts sent as the dowry. A notable marriage by Amenhotep III was to Princess Gilukhepa, the daughter of Shuttarna II, King of the Mitanni. According to a commemorative scarab, Princess Gilukhepa was accompanied by 317 ladies in waiting, likely bringing their personal possessions, jewellery, and cosmetic items to Egypt. Another diplomatic marriage made by Amenhotep III was to Tadukhepa, the daughter of Tushratta, King of the Mitanni (and the niece of Gilukhepa). The dowry list includes items of jewellery and other adornments, such as finger rings and ornamental dress pins (Moran, 1992, p72-81). Approximately 270 female and 30 male attendants were mentioned along with many gifts for the attendants themselves, indicating that high ranking personnel were required to be appropriately dressed and decorated as befitting their station (Moran, 1992, p79; Kemp, 2006, p293). This can be seen in grave goods of the foreign female burial at Gurob, having been interred with personal cosmetic items and other items of jewellery.

Upon arrival in Egypt, the foreign princesses were probably settled at the harem palace in Gurob with some, if not all, of their entourage (Lilyquist, 2004, p337). Other than the princesses' names, the identity of the foreign women travelling to Egypt are not recorded in the correspondence, however the gifts which accompany them are always provided in detail. Once the princesses and women reached Egypt it is apparent that they effectively disappear from the archaeological record, however, their role and influence on the LBA glass system is significant, albeit on an undocumented level. It is seen from the Tomb of the Three Foreign Wives, and to a lesser extent tomb 27 from Gurob, that foreign women travelling to Egypt were given burials befitting their status with numerous glass objects and jewellery containing glass, and some items of a foreign style, which were transported from Mesopotamia. It may even be suggested that the desirability of glass objects brought in by foreign women drove the desire for a domestic industry to supply the royal women at the court and at Gurob with glass items.

8.3.2.1 Domestic vs. foreign glasses

As discussed, the availability of the pre-Malkata glasses for LA-ICP-MS analysis are rare, therefore indicators of provenance are determined from the previous analyses available. Although the sample size is conservative, it is interesting to note that all glasses analysed from KV35 in chapter 4 and Serabit in chapter 5 were of Egyptian provenance only, therefore this provides further supporting evidence as established in the analysis of the polychrome fragments from the reign of Amenhotep II that the glass industry in Egypt was fully established and capable of supplying the demand for glass in Egypt. It may also further support the model of strict control by the Egyptian court, i.e. that glasses produced in Egypt were allocated to specific "Egyptian purposes" or considered to be more appropriate for usages connected with religious or high-level votive offerings. As discussed in previous sections, the identification of Mesopotamian glass in Egypt is rare, despite the textual evidence in the Amarna Letters that glass was demanded from foreign sources. This may indicate that ingots were directly traded rather than worked into objects; however, there Hodgkinson has provided evidence that some ingots were worked and distributed among glassmaking workshops at Amarna for processing (Hodgkinson *et al.*, 2019).

8.4 Using compositional development of LBA glass for dating

There are three standard methods for dating glass objects from the LBA: the first is the traditional method of dating by context and the second is dating by the cartouche inscribed on

the object; however, some kings were subject to a mortuary cult and there are examples of New Kingdom tombs containing objects inscribed with the cartouche of a previous ruler that are observed as part of the grave goods. One such instance is a persea fruit inscribed with the cartouche of Tuthmosis III which was excavated from the tomb of Tutankhamun (Lilyquist *et al.*, 1993, p50). The presence of the persea fruit can be interpreted in several ways: that the item was made during the reign of Tuthmosis III and represents an heirloom, that it was made in Tutankhamun's reign reflecting a mortuary cult of Tuthmosis III, or that the item is erroneous and has been introduced from another source. Given that Tutankhamun reigned for a relatively short amount of time and died unexpectedly, research has suggested that many of the grave goods were acquired from the collections intended for other tombs rather than being made specifically for Tutankhamun, therefore it is likely that this item was curated, or an heirloom. As such, cartouches should be considered as *Terminus post quem*, whereas the context of a secure tomb is regarded as *terminus ante quem*.

The third method is the dating of objects stylistically; this method requires considerable expertise and is the most open to interpretation (see section 8.4.3). The stylistic method of dating was used extensively by Nolte in her seminal work '*Die Glasgefäße im Alten Ägypten'* which is used as the primary data source in chapter 7.

This thesis presents a fourth method: dating by composition which is discussed in the next section.

8.4.1 Dating by glass composition

The elemental analysis of LBA glasses is widely published and show that the base composition of the earliest HMHK glasses (which fall within the definition of Peltenburg's Stage 2) are generally consistent throughout the LBA. Therefore, this indicates that the methods of production and the sources of the raw materials used to make glass, such as silica and plant ash flux, remain largely unchanged throughout the LBA (Lilyquist *et al.*, 1993, p41; Shortland and Eremin, 2006; Abe *et al.*, 2012; Lankton, Pulak and Gratuze, 2022). Therefore, our understanding of the compositions and colouring strategies of glass, how glass composition changes and how it is moved allows us to use it for dating purposes.

The elemental examination of colouring strategies provides key information about the development of glass composition during the LBA and beyond. This research is the first major

work to use compositional to identify unknown samples from the significant sites of Serabit in Sinai and Tall Zirā'a in the Levant. This thesis conclusively concludes that the most indicative glasses for discriminating between production periods are blue cobalt glasses. Sections 4.8.3, 5.8.9, 5.8.12 and 6.9 examine one of the most interesting and valuable compositional modifications in these glasses; namely the change in the source of cobalt used for glassmaking in Egypt. Chapters 4, 5 and 6 demonstrate that the three main distinct sources of cobalt used for glassmaking in ancient Egypt, defined by Abe *et al*. as "Type A" used in the 18th Dynasty, "Type R" used in the Ramesside period and "Type N" used in the Late Period, indicate the production era of the glass itself and can also be used to date the related context (Abe *et al.*, 2012).

As discussed in section 5.8.1, in addition to the production dating information provided by the cobalt source, it follows that the use of the cobalt sources can be used to indicate the workshops where the glasses were produced, therefore it is likely that 18th Dynasty cobalt coloured glasses were produced at Malkata or Amarna, or an earlier workshop as proposed in section 8.1, and that Ramesside cobalt blue glasses could have been produced at Qantir (Shortland and Eremin, 2006; Shortland, Rogers and Eremin, 2007; Smirniou, Rehren and Gratuze, 2018; Lankton, Pulak and Gratuze, 2022). The use of cobalt as a dating indicator is particularly valuable for polychromatic fragments, where the cobalt type can be used to indicate the production era for the overall fragment, and the other colours can be considered for potential compositional characteristics. It is noteworthy that a purple fragment, OX444, from Serabit and discussed in section 5.8.9 contains "Type R" cobalt, therefore this research identifies a very rare example of cobalt being used to colour LBA purple glasses, one earlier example is from Malkata which shows similar concentrations of cobalt from the Type A source, but much higher concentrations of manganese of 2.62% (Shortland and Eremin, 2006; Abe *et al.*, 2012; Lankton, Pulak and Gratuze, 2022). As discussed in section 1.2.6.9, purple glasses are relatively rare in the LBA and the source of the main colourant, manganese, has not been definitively confirmed due to the lack of associated elements which would indicate the ore type.

The change in cobalt source from 'Type A' from the Western Desert to 'Type R' coincides with the relocation of glass factories from the south of Egypt to the North. This implies that the movement of raw materials for glassmaking was impractical, and therefore may have directed Egyptian glassmakers to change raw material supply and strategies. This is further indicated by the Serabit glasses which show notable changes in the colouring strategies for green and

black coloured glasses compared with earlier glasses from Malkata (Shortland and Eremin, 2006). Green glasses produced before the Ramesside period are relatively rare, but as discussed in section 5.8.7, the four green glasses from Serabit are coloured by iron rather than a combination of copper and lead antimonate, as observed with all 25 samples in the Shortland and Lankton studies (Shortland and Eremin, 2006; Lankton, Pulak and Gratuze, 2022). The black glasses from Serabit also demonstrate a change in strategy from adding an excess or combining several transition metal colourants to using iron as discussed in section 5.8.6, a practice which is more commonly observed in Mesopotamian glassmaking (Reade, 2021, p228-236).The LA-ICP-MS analysis of Egyptian copper-blue glasses in this research show that the major, minor and trace element composition remains relatively consistent therefore indicating that the LBA copper blue glass recipe remained largely unchanged (Shortland and Eremin, 2006; Lankton, Pulak and Gratuze, 2022). Therefore, narrowing the production window for copper blue glasses using elemental analysis is challenging: chapter 5.8.1 highlights the exception that five out of seven copper-blue glasses from Lisht contained lower levels of tin, however this may not be a consistent or reliable indicator of detecting later Ramesside copper blue glasses (Smirniou, Rehren and Gratuze, 2018). White Egyptian glasses are another example of LBA glass which maintains a standard composition in the LBA. Changes in the colour preference for glass vessels comes after the end of the Amarna period; although blue is still a favoured colour in LBA Egypt, section 7.7 discusses the significance of other colours becoming more prevalent in the 19th-20th Dynasties. The analysis of the Serabit glasses discussed in chapter 6 identify changes in the compositions of specific colours of glasses from Serabit and compares them with known compositions from other LBA sites.

The presence of both copper and iron-green glasses at Amarna were identified in the Varberg study, in addition to the presence of Egyptian and Mesopotamian green glasses (Varberg *et al.*, 2016). The presence of both green colouring strategies may indicate that glassmakers at Amarna were effecting a period of technology transfer and experimentation. The use of iron as a colourant may have been adopted at Amarna to reduce the importation and processing of colourants, thereby optimising the process. These successful strategies were continued into the Ramesside period, as can be confirmed from the iron-green fragment of a pomegranate vessel, known to have been introduced after the Amarna period (see Figure 39).

Figure 39: (Left) A green glass pomegranate vessel dated to 1295–1070 BCE. Find site: "Egypt". Metropolitan Museum of Art 44.4.52 (https://www.metmuseum.org/art/collection/search/590955) compared with a green glass fragment OX484 from Serabit (Right). The fragment from Serabit is likely a "leaf" from a pomegranate vessel as it is very similar to an intact example from the MMA.

8.4.2 Identification of later glasses (Late LBA and IA)

The use of compositional analysis is well established in the archaeometric field. The composition of both LBA and IA glasses is well published, therefore analysis using analytical techniques which detect major and minor elements are sufficient for distinguishing between standard LBA and IA compositions (Figure 1).

This thesis discusses the distinction between LBA and IA glasses using major composition: section 5.8.12 discusses the composition of a unique example of an early natron glass discussed as part of the research undertaken in chapter 5. Fragment OX641, is a polychromatic fragment of a white body vessel with blue decoration applied. Minor element analysis showed that the blue glass contains the low concentrations of magnesia and potash (see Figure 1) and was likely coloured using type N1 cobalt, therefore can be classified as a later glass.

Another analysis comes from the polychromatic fragment discussed in section 4.8.3, EA64163 (see Figure 40); the piece was marked as coming from "Thebes" and had been stylistically dated to grouped with the Amenhotep II fragments. Fragment EA64163 contains red, blue and white glasses and the analysis showed that all three colours contained low concentrations of both magnesia and potash (less than 1.9% for each value) thereby indicating the fragment was natron glass, and consistent with later glasses produced in the IA. The blue glass coloured by cobalt also indicates this was from the N2 source, therefore confirming a later date of production.

Figure 40: Left image showing fragment from the tomb of Amenhotep II, Metropolitan Museum of Art. Right image showing the fragment EA64163 analysed in section 4.8.3, labelled as find site "Thebes" and attributed to the reign of Amenhotep II, later determined to be a later IA natron glass. British Museum.

In addition to the identification of individual glasses as being produced in the LBA or IA, this research demonstrates that the major composition of glasses can be used to provide supporting information for the dating of the strata from which they were excavated. The research presented in chapter 6 from the site of Tall Zirā'a show that the major composition of glasses from both the LBA and the IA can be used to date the strata at archaeological sites, in addition to verifying the archaeological evidence for mixed contexts.

8.4.3 Authentication of glass

Chapter 7 presents the findings from the first ever large data study relating to Ancient Egyptian vessels. This chapter demonstrates how morphological data can be used to highlight atypical

glass vessels from ancient Egypt using raw data extracted from Nolte's catalogue in conjunction with expert appraisal. The research presented in chapter 7 indicates that there are a higher number of vessels from private collections which show atypical features, and that are excavated from unknown contexts, or where the context provided is from a general area, rather than a specific tomb or site. The "*Werkkreis*" system employed to date vessels by stylistic features is used by Nolte in '*Die Glassgefässe im alten Ägypte'*, meaning that 284 vessels were given broad production windows, ranging from 54 to 360 years. The reason for this phenomenon is unclear. It may be that collectors have acquired items that appear unique but are unaware of the standard style and form of ancient Egyptian vessels and therefore have consequently acquired mis-dated objects or imitations.

9 Conclusion

In section 1.10 the research questions were outlined clearly; chapter 9 now considers each in turn and shows how they are answered by the discussion in chapter 8.

This thesis concurs with the accepted convention that glass was invented in Mesopotamia and subsequently introduced to Egypt following military campaigns during the reign of Tuthmosis III. Previous research has posited that Egypt was reliant on the supply of glass from Mesopotamia, however the findings from this thesis confirm conclusively that craftsmen were able to produce glass in several colours using Egyptian raw materials from the earliest stages of glassmaking in the LBA. Therefore, this research definitively proves that an established Egyptian glassmaking industry was in operation by the reign of Amenhotep II, if not earlier, hence proving that Egypt was one of the very first manufacturers of LBA glass. Consequently, this evidence also proves the existence of a pre-Malkata workshop in Egypt, one which was technologically advanced enough to create polychrome core formed vessels, pertaining to the question of where the first glasses were produced and what the context and analysis shows about the first glasses (research question 1). This thesis provided analytical evidence to further answer this research question by examining the iconographic and analytical evidence to propose that an Egyptian glass industry was very likely to have been established between years 7 and 22 of the reign of Tuthmosis III. Therefore, the research presented in this thesis proves irrefutably that the very first glasses were produced in both Egypt and Mesopotamia; although previous researchers have insinuated earlier workshops, this thesis definitively proposes and provides evidence for a fully functional early glassmaking site in Egypt. In addition, this thesis

also considers the analytical results from the Harem Palace site in Gurob (chapters 2 and 3); the Harem palace was established in the reign of Tuthmosis III so it is feasible that glass was being manufactured in Egypt at this time in parallel with the transport of glass by foreign women of high status from Mesopotamia.

This research answers the question of how production and transport of glass was controlled in Egypt and across the Near East by presenting the analytical data from early glasses in connection with historically important tombs, temples, and sites. Using the evidence from the analytical data in conjunction with the research findings, this research establishes that glasses were transported at several levels: as personal items, dowry gifts, diplomatic gifts, as votive offerings and as likely containers for other luxury items such as oils and perfumes. In the case of Serabit, the analysis and context tells us that significantly large quantities of glass manufactured using raw materials from Egypt were consistently moved from Egypt to Serabit over the course of up to 300 years, thereby not only showing the scale of the Egyptian glass industry but also conclusively proving for the first time that the temple of Hathor at Serabit is to date one of the largest confirmed consumers of Egyptian glass in the LBA.

This research presented the first ever compositional and provenance analysis from the significant Levantine site of Tall Zirā'a and is the first study to confirm the presence of Egyptian and Mesopotamian glass at any site in the Levant. This context tells us that glass was routinely moved from both Mesopotamia and Egypt, likely overland in caravans travelling the established LBA trade routes. The presence of natron glass indicates that Tall Zirā'a maintained its status after the collapse of the LBA and was able to support the trade of luxury goods into the IA, further confirming the importance of this site in the LBA and wider glass system.

One of the major outputs of this thesis are two novel schematics showing for the first time the proposed model for the control and distribution of LBA glass, from an Egyptian domestic perspective and from the wider international LBA glass network which specifically incorporate the significant findings and key sites from this research. Integrating the evidence from this research, figure 36 shows how glass was administered, controlled, and distributed, by encompassing the key Egyptian sites studied in this thesis: Gurob, the Valley of the Kings and the Egyptian-controlled site of Serabit. For the first time in a glass system schematic, this figure includes the mechanism for the distribution to the general populace, broader trade and ultimately the international market. Figure 38 expands the model to demonstrate the wider

international system of LBA glass by incorporating the first archaeometric data from significant site of Tall Zirā'a in the Levant, and Mesopotamia. Figure 38 therefore represents the first proposed international model for LBA glass, showing the central mechanisms of glass transport and the links between all sites studied in this thesis.

This thesis represents the first ever archaeometric research to confirm the primary role of women as mechanisms for glass transport and in the larger international LBA glass system (research question 2). Women are largely missing from the archaeological record however the analysis conducted in this research establishing the presence of Mesopotamian glass in Egypt substantiates the importance women played in the transport and distribution of glasses at the undocumented level. This thesis described how diplomatic marriages created a practice whereby foreign women of high status were systematically transported to Egypt, and that they were customarily accompanied by high value gifts as dictated by the protocol of the "Great Powers". In addition to the foreign princesses, the textual records state that the princesses travelled with many other members of their court, therefore, it is very likely that royal women and their retinue, whose personal possessions would have included jewellery, cosmetics, oils, and perfumes, would have also brought their glass belongings to Egypt. These possessions represent not only the earliest glasses but some of the earliest imports of glass from Mesopotamia. Although previous research has discussed the subject of foreign women in connection with glass, the topics relate to prestigious objects in connection with the Tomb of the Three Foreign Wives of Tuthmosis III, or in research relating to the Amarna Letters. However, this thesis focuses on the principle that large quantities of lesser-status glass, employed as everyday items, used, or worn routinely by women, were introduced to Egypt on a level largely undocumented by history, therefore, that women were instrumental in the LBA glass system by transporting and ultimately distributing many types of glass objects, especially items such beads which have been discovered in as part of LBA burials in Romania, Denmark and Germany.

Research investigating the analysis of glass to determine composition and provenance has expanded considerably over the last few decades. However, the work undertaken in chapter 5 is the first study to present compositional and provenance analysis from the highly significant site of Serabit, Sinai, now identified as a major consumer of Egyptian manufactured glass from the 18th to the 20th Dynasties as a major impact of this research. This thesis examined a curated selection of fragments from this discrete site to establish elemental and stylistic indicators for

compositional dating. Therefore, the question of if the examination of compositional changes in glass from the 18th Dynasty can be used for dating (research question 3) is answered by the research presented in chapters 5 and 6, which demonstrates that the major, minor and trace elements from the analysis of LBA glass can be used for three types of dating:

1. To indicate the era of production of the glasses themselves.
2. To provide supporting evidence for dating the context from which they were recovered.
3. To verify the textual evidence of presence or periods of activity at a site.

To conclude, this research significantly contributes to LBA glass research by adding substantial new information from previously unanalysed objects from significant and highly relevant sites associate with the larger LBA glass system. In addition, this thesis presents new analytical data of glasses to prove the existence of an early Egyptian glassmaking workshop. The discussions pertaining to production and control throughout this thesis support the model that raw glass produced in the glassmaking workshops, and the objects produced in the glassworking sites, would have been tightly controlled by the royal court. This thesis proposes that vessels and jewellery were gifted to the high elite, not just as solitary objects, but likely containing cosmetics, precious oils and perfumes. Glass vessels, along with other gifts, would have been shipped long distances overland in caravans using the established LBA trade or military routes and likely with a military presence, thereby answering the question of the control of glass in the LBA and addressing how glass was moved from the production site to the place it was used (research question 4). Trade routes in and out of Egypt were actively policed by the Egyptian army and caravans were subject to official checks along the route, consequently maintaining the element of control. Two detailed schematics have been produced incorporating this research to demonstrate the positioning of these significant glass-related sites examined in Egypt, Sinai and the Levant as part of the wider international LBA glass system. Research question 2, which discussed the role of women in the LBA glass system, also links to research question 4 which discusses the transport of glass. Overall, this thesis suggests that women were a significant part of the glass system and were instrumental in transporting large quantities of glass goods as their personal possessions.

9.1 Future work

This section identifies and discusses future areas of work which could enhance the research discussed in this thesis and the field of LBA glass study.

The work presented in chapter 7 is a data exercise, therefore the use of non-destructive techniques, such as hand-held X-ray Fluorescence (XRF) on a selection of the more accessible objects mentioned in *'Die Glasgefäße im Alten Ägypten'* and highlighted as being atypical would determine the major composition and provide further information about the colouring strategy, thereby narrowing the window of production.

The same non-destructive technique could also be used to triage a wider sample selection of the glass fragments from Serabit. An initial selection of fragments which contained identifying features would provide the more information which could be used in conjunction with the XRF data. Other fragments which exhibited unusual colours or patterns should also be investigated.

As discussed in chapter 5, characteristic compositions which can determine the production windows of copper-coloured glasses are difficult to distinguish, therefore a wider study of these glasses using lead isotope analysis in conjunction with the elemental analysis my provide indicative patterns.

Overall, more analytical work which provides elemental data in conjunction with firm early contexts would establish the number of imports or confirm the composition of the earliest vessels and glasses ever produced. This could also include analysis on the Eridu fragment and a reanalysis of the glasses studies by Lilyquist in 1993 with XRF, as more recent handheld XRF models have shown to be sensitive enough to detect some trace elements capable of distinguishing between Egyptian and Mesopotamian glasses (Hodgkinson *et al.*, 2019). The work by Lankton in 2022 provides 373 analyses of LBA glasses with the colour, description, country, site and approximate date, however these analyses are not discussed in context with the archaeological data. They are, however, very useful for comparing general compositions.

10 References

Abe, Y., Harimoto, R., Kikugawa, T., Yazawa, K., Nishisaka, A., Kawai, N., Yoshimura, S. and Nakai, I., (2012) 'Transition in the use of cobalt-blue colorant in the New Kingdom of Egypt', *Journal of Archaeological Science*, 39(6), pp. 1793–1808.

Adan-Bajewitz, D., Biedermann, D., Bongartz, G., Bülow, G., Große Frericks, J.,Häser, J.,Hoss, St., Keller, D., Kenkel, F., Leiverkus, P., Olsvig-Whittaker, L., Rassmann, K., Rauen, A., Reiter, S., Soennecken, K., Vieweger, D. (2017) *Tall Zirā'a Gadara Region Project 2001–2011 Final Report. Volume 1: Introduction.* Jerusalem/Amman/Wuppertal.

Ahituv, S. (1999) 'Canaanites', in Bard, K. (ed.) *Encyclopedia of the Archaeology of Ancient Egypt*. Oxford: Routledge, pp. 186–189.

Aldred, C. (1971) *Jewels of the Pharaohs: Egyptian Jewellery of the Dynastic Period*. London: Thames and Hudson Ltd.

Allan, J. W. (1973) *Abu'l-Qasim's treatise on ceramics*. Oxford: Ashmolean Museum.

Andrews, R. W. (1962) *Cobalt*. London: Overseas Geological Survey, Mineral Resources Division, HMSO.

Aruz, J., Benzel, K. and Evans, J. M. (eds) (2008) *Beyond Babylon: art, trade, and diplomacy in the second millennium B.C.* New York: Yale University Press (Metropolitan Museum of Art).

Aston, B., Harrell, J. and Shaw, I. (2000) 'Stone', in Nicholson, P. T. and Shaw, I. (eds) *Ancient Egyptian materials and technology*. Cambridge: Cambridge University Press, pp. 195–226.

Baikie, J. (1932) *Egyptian Antiquities in the Nile Valley: A Descriptive Handbook*. London: Routledge.

Bandiera, M., Verità, M., Lehuédé, P., Vilarigues, M. (2020) 'The technology of copper-based red glass sectilia from the 2nd century AD Lucius Verus villa in Rome', *Minerals*. MDPI, 10(10), p. 875.

Barag, D. (1970) 'Mesopotamian Core-Formed Glass Vessels (1500-500 BC)', in Oppenheim, A. L. *et al*. (eds) *Glass and glass-making in ancient Mesopotamia*. New York:

Corning Museum of Glass.

Barrois, A. (1932) ‘The Mines of Sinai’, *The Harvard Theological Review*. Cambridge University Press, 25(2), pp. 101–121.

Bass, G. F. (1987) ‘Oldest known shipwreck reveals splendours of the Bronze Age’, *National Geographic*, 172, pp. 692–733.

Bass, G. F., Pulak, C., Collon, D., Weinstein, J. (1989) ‘The Bronze Age Shipwreck at Ulu Burun: 1986 Campaign’, *American Journal of Archaeology*. Archaeological Institute of America, 93(1), pp. 1–29. Available at: http://www.jstor.org/stable/505396 (Accessed: 30 April 2023).

Beck, H. (1934) ‘Glass before 1500 BC’, *Ancient Egypt*, pp. 7–21.

Bietak, M. (1999) ‘Hyksos’, in Bard, K. (ed.) *Encyclopedia of the Archaeology of Ancient Egypt*. Abingdon: Routledge, pp. 377–379.

Bimson, M. and Werner, A. E. (1969a) ‘Problems in Egyptian Core Glasses’, in Charleston, R. J., Evans, W., and Werner, A. E. (eds) *Studies in Glass History and Design*. Sheffield: Socienty for Glass Technology, pp. 121–122.

Bimson, M. and Werner, A. E. (1969b) ‘Two problems in ancient glass: opacifiers and Egyptian core material’, in *Congrès International d’Étude historique du verre, 4e. Ravenne-Venise, 13-20 mai 1967. Annales*, pp. 262–266.

Le Bourhis, E. (2014) *Glass: mechanics and technology*. 2nd edn. Weinheim: John Wiley & Sons.

Bourriau, J. (2000) ‘The Second Intermediate Period (c.1650-1550 BC)’, in Shaw, I. (ed.) *The Oxford History of Ancient Egypt*. Oxford: Oxford University Press, pp. 172–206.

Boyce, A. (1995) ‘Collar and necklace designs at Amarna: A preliminary study of faience pendants’, in Kemp, B. J. (ed.) *Amarna Reports*. London, pp. 336–371.

Brier, B. M. and Hobbs, H. (2008) *Daily life of the ancient Egyptians*. Bloomsbury Publishing USA.

Brill, R. H. (1962) ‘A note on the scientist’s definition of glass’, *Journal of Glass Studies*, 4, pp. 127–138.

Brill, R. H. (1963) ‘Ancient glass’, *Scientific American*. JSTOR, 209(5), pp. 120–131.

Brill, R. H. (1970) ‘The Chemical Interpretation of the Texts’, in Oppenheim, A. L. *et al*. (eds) *Glass and glass-making in ancient Mesopotamia*. New York: Corning Museum of Glass.

Brill, R. H. (1999a) *Chemical analyses of early glasses: Volume 1, the tables*. Corning, NY: Corning Museum of Glass.

Brill, R. H. (1999b) *Chemical analyses of early glasses: Volume 1 (tables) and 2 (catalogue)*. Corning, NY: Corning Museum of Glass.

Brochat, K. and Rehren, Th. (2017) ‘The Glass Headrests of Tutankhamen’, *Journal of Glass Studies*, 59, pp. 377–380.

Brown, V. M. and Harrell, J. A. (1995) ‘Topographical and petrological study of ancient Roman quarries in the Eastern Desert of Egypt’, in Maniatis, Y., Herz, N., and Bassiakis, Y. (eds) *The study of marble and other stones used in antiquity - ASMOSIA III, Ahtens. Transactions ffo teh third international symposium of the Associations for the Study of Marble and Other Stones used In Antiquity*. London: Archetype.

Brunton, G. Engelbach, R. (1927) *British School of Archaeology in Egypt and Egyptian Research Account, Twenty Fourth Year, 1918 - Gurob*. British School of Archaeology.

Brunton, G. and Engelbach, R. (1927) *British School of Archaeology in Egypt and Egyptian Research Account, Twenty Fourth Year, 1918 - Gurob*. London: British School of Archaeology in Egypt.

Bryan, B. M. (2000a) ‘The 18th Dynasty before the Amarna Period (c.1550-1352 BC)’, in Shaw, I. (ed.) *The Oxford History of Ancient Egypt*. Oxford: Oxford University Press, pp. 207–264.

Bryan, B. M. (2000b) ‘The Egyptian Perspective on Mittani’, in Cohen, R. and Westbrook, R. (eds) *Amarna Relations: The Beginnings of International Relations*. Baltimore: Johns Hopkins University Press, pp. 71–84.

Bryce, T. (2004) *Letters of the great kings of the ancient Near East: The royal correspondence of the late Bronze Age*. Routledge.

Cable, M. and Smedley, J. W. (1987) ‘The replication of an opaque red glass from Nimrud’,

in Bimson, M. and Freestone, I. C. (eds) *Early vitreous materials*. London: British Museum.

Caelen, V. (2013) *Ceramics from the mining site of Serabit el-Khadem, Sinai, stored at the Harvard Semitic Museum - Revisiting of an old collection through petrographic and chemical analysis*. KU Leuven.

Castel, G., Pouit, G. and Soukiassian, G. (1988) 'Les mines de galene pharaonique du Gebel Zeit (Egypte), dans le Miocène du rift de la Mer Rouge', *Chronique de la Recherche Minière*, 492, pp. 19–32.

Chernykh, E. (1992) *Ancient metallurgy in the USSR*. Cambridge: Cambridge University Press.

Cohen, A. C. (2005) *Death rituals, ideology, and the development of early Mesopotamian kingship: towards a new understanding of Iraq's royal cemetery of Ur*. Brill Academic Publishers (Ancient Magic and Divination).

Cohen, R. and Westbrook, R. (2000) 'Introduction: The Amarna System', in Cohen, R. and Westbrook, R. (eds) *Amarna Diplomacy: The Beginnings of International Relations*. Baltimore: The Johns Hopkins University Press, pp. 1–12.

Cooney, J. D. (1976) *Catalogue of the Egyptian antiquities of the British Museum: Volume IV, Glass*. London: British Museum.

Cox, K. G., Bell, J. D. and Pankhurst, R. J. (1979) *The interpretation of the igneous rocks*. London: George Allen and Unwin.

Dardeniz, G. (2016) 'Vitreous material crafting in the second millennium BC: Glass, faience, and frit production at Tell Atchana, Ancient Alalakh'. Sosyal Bilimler Enstitüsü.

Dardeniz, G. (2018) 'The Preliminary Archaeological and Scientific Evidence for Glass Making at Tell Atchana/Alalakh, Hatay (Turkey)', *Anatolian Archaeological Studies, Japanese Institute of Anatolian Archaeology*, (Proceedings of JIAA Late Bronze Age Glass Workshop held at 27th-28th September, 2014 in Kaman, Turkey).

Dardeniz, G., Henderson, J. and Roe, M. (2022) 'Primary Evidence for Glassmaking in Late Bronze Age Alalakh/Tell Atchana (Amuq Valley, Turkey)', *Journal of Glass Studies*. Corning Museum of Glass, 64, pp. 11–32. Available at: https://www.jstor.org/stable/48703400.

Davis, T. M., Maspero, P., Newberry, P.E., Carter, H. (1907) *The Tomb of Iouiya and Touiyou: The Finding of the Tomb*. A. Constable and Company, Limited (Excavations, Theodore M. Davis': Bibân el Molûk).

Dayton, J. E. and Lamberg-Karlovsky, C. C. (1993) *The discovery of glass: experiments in the smelting of rich, dry silver ores, and the reproduction of Bronze Age-type cobalt blue glass as a slag*. Peabody Museum of Archaeology and Ethnology, Harvard University.

Degryse, P., Shortland, A., De Muynck, D., Van Heghe, L., Scott, R., Neyt, B., Vanhaecke, F. (2010) 'Considerations on the provenance determination of plant ash glasses using strontium isotopes', *Journal of Archaeological Science*, 37(12), pp. 3129–3135.

Degryse, P., Lobo, L., Shortland, A., Vanhaecke, F., Blomme, A., Painter, J., Gimeno, D., Eremin, K., Greene, J., Kirk, S., Walton, M. (2015) 'Isotopic investigation into the raw materials of Late Bronze Age glass making', *Journal of Archaeological Science*. Elsevier Ltd, 62, pp. 153–160. doi: 10.1016/j.jas.2015.08.004.

Degryse, P., Shortland, A. J., Dillis, S., van Ham-Meert, A., Vanhaecke, F., Leeming, P. (2020) 'Isotopic evidence for the use of Caucasian antimony in Late Bronze Age glass making', *Journal of Archaeological Science*, 120, p. 105195. doi: https://doi.org/10.1016/j.jas.2020.105195.

Demand, N. H. (2012) *The Mediterranean context of early Greek history*. Chichester: John Wiley & Sons.

Dériano, S. (2002) *Chemical design of silicate glasses with high mechanical performance*. Rennes.

Van Dijk, J. (2000) 'The Amarna period and later New Kingdom', in Shaw, I. (ed.) *The Oxford History of Ancient Egypt*. Oxford: Oxford University Press, pp. 265–307.

Doremus, R. H. (1994) *Glass Science*. New York: John Wiley.

Dyre, J. C. (2006) 'Colloquium: The glass transition and elastic models of glass-forming liquids', *Reviews of Modern Physics*. American Physical Society, 78(3), pp. 953–972. doi: 10.1103/RevModPhys.78.953.

Eckenstein, L. (1921) *A History of Sinai*. London ; New York: The Macmillan Co.

Van Elteren, J. T., Tennent, N. H. and Šelih, V. S. (2009) 'Multi-element quantification of ancient/historic glasses by laser ablation inductively coupled plasma mass spectrometry using sum normalization calibration', *Analytica Chimica Acta*, 644(1–2), pp. 1–9.

Eyre, C. J. (1987) 'Work and the organisation of work" in MA Powell', *Labour in the Ancient Near East*, pp. 5–48.

Feucht, E. (1999) 'Jewelry', in Bard, K. (ed.) *Encyclopedia of the Archaeology of Ancient Egypt*. Oxford: Routledge, pp. 385–387.

Freestone, I. C. (1991) 'Looking into Glass', in Bowman, S. (ed.) *Science and the Past*. London: British Museum Press, pp. 37–56.

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

Friedman, F. D. (1998) *Gifts of the Nile - Ancient Egyptian faience*. London: Thames and Hudson.

de Garis Davies, N. (1973) *The Tomb of Ken-Amun at Thebes*. With plate. New York: Arno Press.

Garner, H. (1956) 'An early piece of glass from Eridu', *Iraq*, 18, pp. 147–149.

Giannini, R., Freestone, I. C. and Shortland, A. J. (2017) 'European cobalt sources identified in the production of Chinese famille rose porcelain', *Journal of Archaeological Science*, 80, pp. 27–36.

Giveon, R. (1978) *The impact of Egypt on Canaan: Iconographical and related studies*. Freiburg: Vandenhoeck & Ruprecht.

Goedicke, H. (1975) *The report of Wenamun*. Johns Hopkins Press (Near Eastern studies).

Grajetski, W. (2003) *Burial Customs in Ancient Egypt: Life in Death for Rich and Poor*. Bloomsbury Academic.

Gratuze, B. (2013) 'Provenance Analysis of Glass Artefacts', in Jannsens, K. (ed.) *Modern Methods for Analysing Archaeological and Historical Glass, Volume I*. Chichester: John Wiley and Sons, pp. 311–343.

Gratuze, B., Blet-Lemarquand, M. and Barrandon, J.-N. (2001) 'Mass spectrometry with laser sampling: a new tool to characterize archaeological materials', *Journal of Radioanalytical and Nuclear Chemistry*. Akadémiai Kiadó, co-published with Springer Science+ Business Media BV …, 247(3), pp. 645–656.

Grimal, N. (1992) *A History of Ancient Egypt*. Oxford: Blackwell.

Hall, H. R. (2014) *A Season's Work at Ur, Al-'Ubaid, Abu Shahrain-Eridu-and Elsewhere: Being an Unofficial Account of the British Museum Archaeological Mission to Babylonia, 1919*. Routledge.

Hanbury-Tenison, J. W. (1984) 'Exploration du Wadi el-Arab', *Chronique archéologique*, RB, 91, pp. 230–231.

Hench, L. L. and Clark, D. E. (1978) 'Physical chemistry of glass surfaces', *Journal of Non-Crystalline Solids*, 28(1), pp. 83–105. doi: https://doi.org/10.1016/0022-3093(78)90077-7.

Henderson, J. (1985) 'The raw materials of early glass production', *Oxford Journal of Archaeology*, 4(3), pp. 267–291.

Henderson, J. (1988) 'Electron microprobe analysis of mixed alkali glasses', *Archaeometry*, 30(1), pp. 77–91.

Henderson, J. (1989) *Scientific analysis in archaeology and its interpretation*. Oxford: Oxford Committee for Archaeology.

Henderson, J. (1998) 'Scientific analysis of glass and glaze from Tell Brak and its archaeological implications', in Oates, D., Oates, J., and McDonald, H. (eds) *Excavations at Tell Brak, Volume 1: The Mitanni and Old Babylonian periods*. Cambridge: McDonald Institute Monographs, pp. 94–98.

Henderson, J. (2000) 'Chemical analysis of ancient Egyptian glass and its interpretation', in Nicholson, P. T. and Shaw, I. (eds) *Ancient Egyptian materials and technology*. Cambridge: Cambridge University Press, pp. 206–224.

Henderson, J. (2013) 'Glass as a Material: A Technological Background in Faience, Pottery and Metal?', in *Ancient Glass: An Interdisciplinary Exploration*. Cambridge University Press, pp. 1–21. doi: 10.1017/CBO9781139021883.002.

Henderson, J., Evans, J. and Nikita, K. (2010) 'Isotopic evidence for the primary production,

provenance and trade of Late Bronze Age glass in the Mediterranean', *Mediterranean Archaeology*, 10(1), pp. 1–24.

Hodgkinson, A. K. (2015) 'Archaeological Excavations of a Bead Workshop in the Main City at Tell el-Amarna', *Journal of Glass Studies*, 57, pp. 279–284.

Hodgkinson, A. K. (2017) *Technology and Urbanism in Late Bronze Age Egypt (Oxford Studies In Egyptian Archaeology)*. Oxford: Oxford University Press.

Hodgkinson, A. K. *et al.* (2019) 'The use of Cobalt in 18th Dynasty Blue Glass from Amarna: the results from an on-site analysis using portable XRF technology', *STAR: Science & Technology of Archaeological Research*, 5(2), pp. 36–52.

Huang, H. (2018) 'The Route of Lapis Lazuli: Lapis Lazuli Trade From Afghanistan to Egypt During Mid-late Bronze Age', in. doi: 10.2991/mess-18.2018.73.

Ikram, S. (2015) *Death and Burial in Ancient Egypt*. American University in Cairo Press (American University in Cairo Press Series).

Jackson, C. M. (2005) 'Glassmaking in Bronze Age Egypt', *Science*, 308, pp. 1750–1752.

Jackson, C. M. and Nicholson, P. T. (2010) 'The provenance of some ingots from the Uluburun shipwreck', *Journal of Archaeological Science*, 37(2), pp. 295–301.

Jackson, C. M. and Nicholson, P. T. (2023) 'Simply red: a late bronze age glass ingot from Amarna', *Journal of Archaeological Science: Reports*. Elsevier, 47, p. 103793.

Jackson, C. and Nicholson, P. (2007a) *Brilliant things for Akhenaten: The Production of Glass, Vitreous Materials and Pottery at Amarna Site O45.1*. Edited by P. T. Nicholson. London: Egypt Exploration Society.

Jackson, C. and Nicholson, P. (2007b) 'Compositional analysis of the vitreous materials found at Amarna', *Brilliant Things for Akhenaten: The Production of Glass, Vitreous Materials and Pottery at Amarna Site O*, 45, pp. 101–116.

Janssen, J. J. (1975) *Commodity prices from the Ramesside Period: An economic study of the village of necropolis workmen at Thebes*. Leiden.

Jensen, L. W. (2015) 'Basalt and small finds', in Strange, J. and Andersen, F. G. (eds) *Tall al-Fukhār. Results from excavations 1990-93 and 2002*. Aarhaus: Aarhus University Press, pp. 329–365.

Jochum, K. P. *et al.* (2011) 'Determination of reference values for NIST SRM 610-617 glasses following ISO guidelines', *Geostandards and Geoanalytical Research*, 35(4), pp. 397–429.

Joffe, A. H. (2002) 'The Rise of Secondary States in the Iron Age Levant', *Journal of the Economic and Social History of the Orient*. Brill, 45(4), pp. 425–467.

Josephson Hesse, K. (2008) 'Contacts and trade at Late Bronze Age Hazor: aspects of intercultural relationships and identity in the Eastern Mediterranean'. Institutionen för idé- och samhällsstudier, Umeå universitet.

Kaczmarczyk, A. (1986) 'The source of cobalt in ancient Egyptian pigments', in Olin, J. S. and Blackman, M. J. (eds) *Proceedings of the 24th International Archaeometry Symposium*. Washington: Smithsonian, pp. 369–376.

Kaczmarczyk, A. and Hedges, R. E. M. (1983) *Ancient Egyptian faience: an analytical survey of Egyptian faience from predynastic to Roman times*. Warminster: Aris and Phillips.

Kaczmarczyk, A. and Vandiver, P. B. (2008) 'Faience Production in Egypt', in *Production Technology of Faience and Related Early Vitreous Materials*. Oxford: School of Archaeology, pp. 57–91.

Keller, C. A. (1983) 'Problems of dating glass industries of the Egyptian New Kingdom: Examples from Malkata and Lisht', *Journal of Glass Studies*, 25, pp. 19–28.

Kemp, B. J. (2006) *Ancient Egypt: Anatomy of a civilization*. 2nd edn. London: Routledge.

Kemp, V. *et al.* (2019) 'LA-ICP-MS analysis of Late Bronze Age blue glass beads from Gurob, Egypt', *Archaeometry*, 62(1), pp. 42–53.

Kemp, V. *et al.* (2020) 'Dating and provenance of glass artefacts excavated from the ancient city of Tall Zirāʿa, Jordan', *Archaeometry*, 62(6), pp. 1164–1181.

Kemp, V., Brownscombe, W. and Shortland, A. J. (2021) 'The investigation and provenance of glass vessel fragments attributed to the tomb of Amenhotep II, KV35, Valley of the Kings', *Archaeometry*, 64(1), pp. 147–160.

Kemp, V., McDonald, A and Shortland, A. J. (2017) 'Ancient Biographies: Trace Element Analysis to Investigate Provenance and Transportation Mechanisms of Late Bronze Age Glass.', *Archaeological and Environmental Forensic Science*, 1.2, pp. 161–174.

Kirk, S. (2009) *The Vitreous materials from the 2nd Millennium BC City of Nuzi: Their Preservation, Technology and Distribution*. Cranfield University.

Koch, I. (2017) 'Revisiting the Fosse Temple at Tel Lachish', *Journal of Ancient Near Eastern Religions*, 17, pp. 64–75. doi: 10.1163/15692124-12341286.

Kozloff, A. P. and Bryan, B. M. (1992) *Egypt's Dazzling Sun: Amenhotep III and his World*. Cleveland: Cleveland Museum of Art.

Kurkjian, C. R. and Prindle, W. R. (1998) 'Perspectives on the history of glass composition', *Journal of the American ceramic society*. Wiley Online Library, 81(4), pp. 795–813.

Labino, D. (1966) 'The Egyptian sand-core technique: a new interpretation', *Journal of Glass Studies*, 8, pp. 124–127.

Lacovara, P. (2022) 'The Treasure of Ahhotep in Archaeological Context', in Miniaci, G. (ed.) *The Treasure of the Egyptian Queen Ahhotep and international Relations at the turn of the Middle Bronze Age (1600-1500 BCE)*. Croydon: Golden House Publications, pp. 153–161.

Lankton, J. *et al.* (2016) 'Scientific Analysis of Ancient Glass: Answering the Questions and Questioning the Answers', in Gan, F., Li, Q, and Henderson, J. (eds) *Recent Progress of Scientific Research on Ancient Glass and Glaze*. World Scientific Publishing Company, pp. 267–302.

Lankton, J. W., Pulak, C. and Gratuze, B. (2022) 'Glass ingots from the Uluburun shipwreck: Glass by the batch in the Late Bronze Age', *Journal of Archaeological Science: Reports*. Elsevier Ltd, 42(June 2021).

Legrain, G. (1929) *Les Temples de Karnak*. Brussels: Vromant.

Lilyquist, C. *et al.* (1993) 'Part 2. Glass', in Lilyquist, C. and Brill, R. H. (eds) *Studies in Ancient Egyptian Glass*. New York: Metropolitan Museum of Art, pp. 23–58.

Lilyquist, C. (2004) *The Tomb of Three Foreign Wives of Tuthmosis III*. New York: Yale University Press.

Lilyquist, C., Brill, R. H. and Wypyski, M. T. (1993) *Studies in Early Egyptian Glass*. Metropolitan Museum of Art.

Liverani, M. (1999) 'Amarna Letters', in Bard, K. (ed.) *Encyclopedia of the Archaeology of*

Ancient Egypt. Abingdon: Routledge, pp. 133–135.

Liverani, M. (2000) 'The Great Powers' Club', in Cohen, R. and Westbrook, R. (eds) *Amarna Relations: The Beginnings of International Relations*. Baltimore: The Johns Hopkins University Press, pp. 15–27.

Lucas, A. and Harris, J. R. (1962) *Ancient Egyptian Materials and Industries*. 3rd edn. London: Edward Arnold & Co.

Mace, A. C. (1911) 'The Murch Collection of Egyptian Antiquities', *The Metropolitan Museum of Art Bulletin*. JSTOR, 6(1), pp. 1–28.

Manning, S. W. *et al.* (2009) 'Absolute age of the Uluburun shipwreck: a key Late Bronze Age time-capsule for the East Mediterranean', in *Tree-rings, kings and Old World archaeology and environment: papers presented in honor of Peter Ian Kuniholm*. Oxbow Books, pp. 163–188.

Mass, J. L., Wypyski, M. T. and Stone, R. E. (2002) 'Malkata and Lisht glassmaking technologies: towards a specific link between second millennium BC metallurgists and glassmakers', *Archaeometry*, 44(1), pp. 67–82.

McDermott, B. (2004) *Warfare in Ancient Egypt*. Stroud: Sutton (Sutton Series). Available at: https://books.google.co.uk/books?id=flFuQgAACAAJ.

Merkel, S. and Rehren, Th. (2007) 'Parting layers, ash trays and Ramesside glassmaking: an experimental study', in *Hochtemperatur-Technologie in der Ramses-Stadt: Rubinglas für den Pharao.* Hildesheim: Verlag Gebrüder Gerstenberg, pp. 201–220.

Van De Mieroop, M. (1997) *The Ancient Mesopotamian City*. Oxford: Oxford University Press.

Miniaci, G. (2022) 'The Discovery of Queen Ahhotep's Burial ar Dra Abu el-Naga (Thebes) in the Nineteeth Centruy AD: Between Tale and Archaeological Evidence', in Lacovara, P. (ed.) *The Treasure of the Egyptian Queen Ahhotep and international Relations at the turn of the Middle Bronze Age (1600-1500 BCE)*. 1st edn. London: Golden House Publications, pp. 27–69.

Molina, G. *et al.* (2014) 'Production technology and replication of lead antimonate yellow glass from New Kingdom Egypt and the Roman Empire', *Journal of Archaeological Science*.

Elsevier, 41, pp. 171–184.

Moorey, P. R. S. (1999) *Ancient Mesopotamian Materials and Industries: The Archaeological Evidence*. Oxford: Oxford University Press.

Moorey, P. R. S. (2001) 'The Mobility of Artisans and Opportunities for Technology Transfer between Western Asia and Egypt in the Late Bronze Age', in Shortland, A. J. (ed.) *The Social Context of Technological Change*. Oxford: Oxbow books, pp. 39–58.

Moran, W. L. (1992) *The Amarna Letters*. Baltimore: The Johns Hopkins Press.

Moshier, S. O. and El-Kalani, A. (2008) 'Late Bronze Age paleogeography along the ancient ways of Horus in Northwest Sinai, Egypt', *Geoarchaeology: An International Journal*. Wiley Online Library, 23(4), pp. 450–473.

Mumford, G. (2006) 'Egypt's New Kingdom Levantine Empire and Serabit El-khadim , Including a Newly Attested Votive Offering of Horemheb', *Journal of the Society for the Study of Egyptian Antiquities*, 33.

Mumford, G. D. (1999) 'Serabit el-Khadim', in Bard, K. (ed.) *Encyclopedia of the Archaeology of Ancient Egypt*. London: Routledge, pp. 722–725.

Mynářová, J. (2007) *The Region and the Language*, *Language of Amarna--language of diplomacy: perspectives on the Amarna Letters*. Prague: Czech Institute of Egyptology.

Na'aman, N. (2000) 'The Egyptian-Canaanite Correspondence', in Cohen, R. and Westbrook, R. (eds) *Amarna Diplomacy: The Beginnings of International Relations*. Baltimore: Johns Hopkins University Press, pp. 125–138.

New, S. (1932) 'The Temple of Hathor', *The Harvard Theological Review*. Cambridge University Press, 25(2), pp. 122–129.

Newberry, P. E. (1900) *Extracts from My Note-books (III)*. PSBA 22.

Newberry, P. E. (1902) *Extracts from My Note-books (V)*. PBSA 24.

Newton, R. G. and Davison, S. (1989) *Conservation of glass*. Oxford: Butterworth-Heinemann.

Nicholson, P. T. (1993) *Egyptian Faience and Glass*. Buckinghamshire: Shire Publications Ltd (Shire Egyptology).

Nicholson, P. T. (1995) ‘Recent excavations at an ancient Egyptian glassworks: Tell el-Amarna 1993’, *Glass Technology*, 36(4), pp. 125–128.

Nicholson, P. T. (2006) ‘Glass Vessels from the Reign of Thutmose III and a Hitherto Unknown Glass Chalice’, *Journal of Glass Studies*. Corning Museum of Glass, 48, pp. 11–21.

Nicholson, P. T. (2012) ‘“Stone... That Flows”: Faience and Glass as Man-Made Stones in Egypt’, *Journal of Glass Studies*. Corning Museum of Glass, 54, pp. 11–23. Available at: http://www.jstor.org/stable/24191269.

Nicholson, P. T. and Henderson, J. (2000) ‘Glass’, in Nicholson, P. T. and Shaw, I. (eds) *Ancient Egyptian materials and technology*. Cambridge: Cambridge University Press, pp. 195–226.

Nicholson, P. T. and Jackson, C. (2013) ‘Glass of Amenhotep II from Tomb KV55 in the Valley of the Kings’, *The Journal of Egyptian Archaeology*, 99, pp. 85–99.

Nicholson, P. T. and Jackson, C. M. (1998) ‘“Kind of blue” - glass of the Amarna period replicated’, in McCray, P. and Kingery, W. D. (eds) *The Prehistory and History of Glassmaking Technology*. The American Ceramics Society, USA, pp. 251–268.

Nicholson, P. T., Jackson, C. M. and Trott, K. M. (1997) ‘The Ulu Burun glass ingots, cylindrical vessels and Egyptian glass’, *Journal of Egyptian Archaeology*, 83.

Nicholson, P. T. and Peltenburg, E. J. (2000) ‘Egyptian faience’, in Nicholson, P. T. and Shaw, I. (eds) *Ancient Egyptian materials and technology*. Cambridge: Cambridge University Press, pp. 177–194.

Nikita, K. and Henderson, J. (2006) ‘Glass analyses from Mycenaean Thebes and Elateia: compositional evidence for a Mycenaean glass industry’, *Journal of Glass Studies*, 48, pp. 71–120.

Nolte, B. (1968) *Die Glassgefässe im alten Ägypten*, *Münchner Ägyptologische Studien*. Berlin: Verlag Bruno Hessling.

Oates, D. and Oates, J. (1991) ‘Excavations at Tell Brak 1990-91’, *Iraq*. British Institute for the Study of Iraq, 53, pp. 127–145. Available at: http://www.jstor.org/stable/4200342 (Accessed: 30 April 2023).

Oates, D., Oates, J. and McDonald, H. (1997) *Excavations at Tell Brak, volume 1: The Mitanni and Old Babylonian Periods (McDonald Institute Monograph)*. Cambridge: British School of Archaeology in Iraq.

Oates, J. (2005) 'Archaeology in Mesopotamia: Digging deeper at Tell Brak', *Proceedings of the British Academy*, 131, pp. 1–39. doi: 10.5871/bacad/9780197263518.003.0001.

Ogden, J. (2000) 'Metals', in Nicholson, P. and Shaw, I. (eds) *Ancient Egyptian materials and technology*. Cambridge: Cambridge University Press.

Oppenheim, A. L. *et al.* (1970) 'Glass and glassmaking in ancient Mesopotamia', *Corning Museum of Glass*, pp. 105–128.

Oppenheim, A Leo (1970) 'The cuneiform tablets with instructions for glassmakers', *Oppenheim et al*, pp. 22–67.

Oppenheim, A L (1970) 'The Cuneiform Texts', in *Glass and glass-making in ancient Mesopotamia*. New York: Corning Museum of Glass.

Oppenheim, A. L. (1973) 'Towards a history of glass in the ancient Near East', *Journal of the American Oriental Society*, 93, pp. 259–266.

Oppenheim, A. L. (1977) *Ancient Mesopotamia: portrait of a dead civilization*. Revised ed. Edited by Revised by E. Reiner. Chicago: University of Chicago Press.

Panagiotaki, M. *et al.* (2005) 'A Glass Workshop at the Mycenaean Citadel of Tiryns in Greece', *Annales du 16e congrès de l'association internationale pour l'histoire du verre (London 2003)*, pp. 14–19.

Paul, A. (1990) *The chemistry of glasses*. London: Chapman and Hall.

Pelletier, J. A. (2013) 'From Ancient to Modern Logistics: Evidence in Ancient Egypt & the Early Development of Marketing', in *Proceedings of the Conference on Historical Analysis and Research in Marketing*, pp. 195–209.

Peltenburg, E. J. (1987) 'Early faience: Recent Studies, origins and relations with glass', in Bimson, M. and Freestone, I. C. (eds) *Early vitreous materials*. London: British Museum Occasional Papers, 56, pp. 5-23.

Petrie, F. (1924) 'Glass found in Egypt.', *Transactions of the Newcomen Society*. Taylor & Francis, 5(1), pp. 72–76.

Petrie, W. M. F. (1891) *Illahun, Kahun and Gurob*. London: David Nutt.

Petrie, W. M. F. (1894) *Tell el-Amarna*. London: Methuen & Co Ltd.

Petrie, W. M. F. (1904) 'The Sinai Expedition', *Archaeological Report (Egypt Exploration Fund)*. Egypt Exploration Society, pp. 10–12.

Petrie, W. M. F. (1906) *Researches In Sinai*. London: John Murray.

Pfälzner, P. (2012) 'Levantine Kingdoms of the Late Bronze Age', in Potts, D. T. (ed.) *A Companion to the Archaeology of the Ancient Near East*. Oxford: Blackwell, pp. 770–796.

Piccione, P. A. (1999) 'Tomb Furnishings', in Bard, K. (ed.) *Encyclopedia of the Archaeology of Ancient Egypt*. Oxford: Routledge, pp. 839–841.

Polikreti, K. *et al.* (2011) 'XRF analysis of glass beads from the Mycenaean palace of Nestor at Pylos, Peloponnesus, Greece: New insight into the LBA glass trade', *Journal of Archaeological Science*. Academic Press, 38(11), pp. 2889–2896. doi: 10.1016/j.jas.2011.05.003.

Pulak, C. (1998) 'The Uluburun shipwreck: an overview', *The International Journal of Nautical Archaeology*. Elsevier, 27(3), pp. 188–224.

Pulak, C. (2001) 'The cargo of the Uluburun ship and evidence for trade with the Aegean and beyond', in Bonfante, L., Karageorghis, V., and Costakis and Leto Severis Foundation(Nicosia, C. (eds) *Italy and Cyprus in antiquity 1500 - 450 BC: proceedings of an international symposium held at the Italian Academy for Advanced Studies in America at Columbia University, November 16-18, 2000*. Nicosia: The Costakis and Leto Severis Foundation, pp. 13–60.

Pulak, C. (2008) 'The Uluburun shipwreck and late bronze age trade', *Beyond Babylon: Art, trade, and diplomacy in the second millennium BC*. Metropolitan Museum of Art: New York, NY, USA, 289, p. 310.

Pulak, C. (2012) 'Uluburun Shipwreck', *The Oxford Handbook of the Bronze Age Aegean*, 1. doi: 10.1093/oxfordhb/9780199873609.013.0064.

Pusch, E. and Herold, A. (1999) 'Qantir/Pi-Ramesses', in Bard, K. (ed.) *Encyclopedia of the Archaeology of Ancient Egypt*. Abingdon: Routledge, pp. 647–649.

Pusch, E. and Rehren, Th (2007) *Hochtemperatur-Technologie in der Ramses-Stadt:*

Rubinglass für den Pharao - Teil 2. Hildesheim: Gerstenburg.

Pusch, E. and Rehren, Th (2007) *Hochtemperatur-Technologie in der Ramses Stadt: Rubinglas für den Pharao - Teil 1*. Hidesheim: Gerstenburg.

Rademakers, F. W., Rehren, Th. and Pernicka, E. (2017) 'Copper for the Pharaoh: Identifying multiple metal sources for Ramesses' workshops from bronze and crucible remains', *Journal of Archaeological Science*, 80, pp. 50–73.

Ragai, J. (1986) 'Colour: its significance and production in Ancient Egypt', *Endeavour*, 10(2), pp. 74–79. doi: 10.1016/0160-9327(86)90134-1.

Rao, K. J. (2002) *Structural Chemistry of Glasses*. Elsevier Science. Available at: https://books.google.co.uk/books?id=Xk-lYXtqM-4C.

Rasmussen, S. C. (2012) *How glass changed the world: The history and chemistry of glass from antiquity to the 13th century*. Springer Science & Business Media.

Reade, W. (2021) *The First Thousand Years of Glass-Making in the Ancient Near East*, *The First Thousand Years of Glass-Making in the Ancient Near East*. Oxford: Archaeopress.

Reader, A. (2003) *Near Eastern Archaeology: A Reader*. Edited by S. Richard. Pennsylvania State University Press.

Redford, D. (1992) *Egypt, Canaan, and Israel in ancient times*. Princeton: Princeton University Press.

Reeves, N. and Wilkinson, R. H. (2008) *The Complete Valley of the Kings: Tombs and Treasures of Egypt's Greatest Pharaohs*. Thames & Hudson. Available at: https://books.google.co.uk/books?id=PxgTPQAACAAJ.

Rehren, Th. (2000a) 'New aspects of ancient Egyptian glassmaking', *Journal of Glass Studies*, 42, pp. 13–24.

Rehren, Th. (2000b) 'Rationales in Old World base glass compositions', *Journal of Archaeological science*. Elsevier, 27(12), pp. 1225–1234.

Rehren, Th. (2008) 'A review of factors affecting the composition of early Egyptian glasses and faience: alkali and alkali earth oxides', *Journal of Archaeological Science*, 35(5), pp. 1345–1354.

Rehren, Th. and Pusch, E. (1997) ‘New Kingdom glass melting crucibles from Qantir-Piramesses, Nile Delta’, *Journal of Egyptian Archaeology*, 83.

Rehren, Th. and Pusch, E. (2005) ‘Late Bronze Age glass production at Qantir-Piramesses, Egypt’, *Science*, 308, p. 1756.

Rehren, Th. and Pusch, E. B. (2008) ‘Crushed rock and molten salt? Some aspects of the primary glass production at Qantir/Pi-Ramesse’, in *itreous Materials in the Late Bronze Age Aegean*. Oxbow Books, pp. 14–33.

Rehren, Th., Pusch, E. B. and Herold, A. (1998) ‘Glass coloring works within a copper-centered industrial complex in Late Bronze Age Egypt’, in *Prehistory & history of glassmaking technology*. AMER CERAMIC SOC, pp. 227–250.

Rehren, Th., Pusch, E. and Herold, A. (2001a) ‘Problems and possibilities in workshop reconstruction: Qantir and the organisation of LBA glass workshops’, in Shortland, A. J. (ed.) *The social context of technological change*. Oxford: Oxbow books.

Rehren, Th., Pusch, E. and Herold, A. (2001b) ‘Qantir-Piramesses and the organisation of the Egyptian glass industry’, in *The Social Context of Technological Change*. Oxford: Oxbow books, pp. 223–238.

Renfrew, C. (2011) *The Emergence of Civilisation: The Cyclades and the Aegean in the Third Millennium BC*. Oxbow Books.

Ribechini, E. *et al.* (2011) ‘Discovering the composition of ancient cosmetics and remedies: analytical techniques and materials’, *Analytical and bioanalytical chemistry*. Springer, 401, pp. 1727–1738.

Rivero, E. P. (2021) ‘Gift-exchange in the Amarna Letters: A Concise Study of the Letters from the Great Kings’, *Trabajos de Egiptología. Papers on Ancient Egypt*, (12), pp. 139–158.

Rowe, A. (1940) *The four Canaanite temples of Beth-Shan. 1. The temples and cult objects.* Philadelphia: The University Museum.

Von Saldern, A. (1970) ‘Other Mesopotamian Glass Vessels (1500-600 B.C.)’, in *Glass and glass-making in ancient Mesopotamia*. New York: Corning Museum of Glass, pp. 203–228.

Saleem, S. N. and Hawass, Z. (2016) *Scanning the Pharaohs: CT Imaging of the New Kingdom Royal Mummies*. Cairo: American University in Cairo Press.

Sayre, E. V and Smith, R. W. (1961a) ‘Compositional catagories of ancient glass’, *Science 133*, pp. 1824–1826.

Sayre, E. V and Smith, R. W. (1961b) ‘Compositional categories of ancient glass’, *Science*, 133, pp. 1824–1826.

Sayre, E. V and Smith, R. W. (1974) ‘Analytical studies in ancient Egyptian glass’, in Bishay, A. (ed.) *Recent Advances in the Science and Technology of Materials*. New York.

Schlick-Nolte, B. and Werthmann, R. (2003) ‘Glass Vessels from the Burial of Nesikhons’, *Journal of Glass Studies*. Corning Museum of Glass, 45, pp. 11–34.

Schoer, B. and Rehren, Th. (2007) ‘The composition of glass and associated ceramics from Qantir’, in Pusch, E. B. and Rehren, Th. (eds) *Rubinglas für den Pharao*. Hildesheim: Gerstenberg, pp. 171–199.

Schreurs, J. W. H. and Brill, R. H. (1984) ‘Iron and sulfur related colors in ancient glasses’, *Archaeometry*, 26(2), pp. 199–209.

Schuler, F. (1962) ‘Ancient glassmaking techniques: the Egyptian core vessel process’, *Archaeology*, 15, pp. 32–37.

Sethe, K. (1907) *Urkunden der 18. Dynastie, Historisch-biographische Urkunden. Vol 3 Part 9/10 of Urkunden des aegyptischen Altertums.* Leipzig: J.C. Hinrichs.

Shaw, I. (2003) *The Oxford History of Ancient Egypt*. OUP Oxford (The oxford history of ancient Egypt). Available at: https://books.google.co.uk/books?id=yugRDAAAQBAJ.

Shaw, I. (2007) *The royal harim at Medinet el-Ghurob: new fieldwork (2005-7)*. Liverpool.

Shaw, I. (2011a) ‘New fieldwork at the Medinet el-Gurob New Kingdom settlement: investigating a harem palace town in the Faiyum (summary of the 2009-10 seasons)’, in Belova, G. A. and Ivanov, S. V. (eds) *Achievements and Problems of Modern Archaeology: Proceedings of the International Conference*. Moscow: Russian Academy of Sciences Center for Egyptological Studies, pp. 1–18.

Shaw, I. (2011b) ‘Seeking the Ramesside royal harem: new fieldwork at Medinet el-Gurob’, in Collier, M. and Snape, S. (eds) *Ramesside Studies in Honour of Ken Kitchen*. Bolton: Rutherford Press, pp. 453–63.

Shaw, I. (2012) ‘The Gurob Harem palace project, Spring 2012’, *Journal of Egyptian*

Archaeology, 98, pp. 43–54.

Shaw, I. and Nicholson, P. T. (1995) *British Museum Dictionary of Ancient Egypt*. London: British Museum Press.

Shelby, J. E. (2005) *Introduction to glass science and glass technology*. Cambridge: Royal Society of Chemistry.

Shelby, J. E. (2020) *Introduction to glass science and technology*. Royal society of chemistry.

Sherratt, A. and Sherratt, S. (1991) 'From luxuries to commodities: the nature of Mediterranean Bronze Age trading systems', in Gale, N. H. (ed.) *Bronze Age trade in the Mediterranean*. Jonserad: Paul Astroms Forlag (Studies in Mediterranean Archaeology XC).

Sherratt, E. S. (2016) 'From'institutional'to'private': traders, routes and commerce from the Late Bronze Age to the Iron Age'. Oxbow Books.

Shortland, A. (2002) 'The use and origin of antimonate colorants in early Egyptian glass', *Archaeometry*, 44(4), pp. 517–530.

Shortland, A. *et al.* (2006a) 'Natron as a flux in the early vitreous materials industry: sources, beginnings and reasons for decline', *Journal of Archaeological Science*. Elsevier, 33(4), pp. 521–530.

Shortland, A. *et al.* (2006b) 'Natron as a flux in the early vitreous materials industry: Sources, beginnings and reasons for decline', *Journal of Archaeological Science*, 33(4), pp. 521–530.

Shortland, A. J. (2000) *Vitreous materials at Amarna: the production of glass and faience in 18th dynasty Egypt*. Oxford: British Archaeological Reports International Series, S827, Archaeopress.

Shortland, A. J. (2001) 'Social influences on the development and spread of glass and glazing technologies', in Shortland, A. J. (ed.) *The social context of technological change - Egypt and the Near East 1650-1150 BC*. Oxford: Oxbow Books, pp. 211–223.

Shortland, A. J. (2002) 'The use and origin of antmonate colorants in early Egyptian glass', *Archaeometry*, 44(4), pp. 517–531.

Shortland, A. J. (2004) 'Evaporites of the Wadi Natrun: Seasonal and annual variation and its implication for ancient exploitation', *Archaeometry*, 46, pp. 497–516.

Shortland, A. J. (2005) ‘The raw materials of early glasses: the implications of new LA-ICPMS analyses’, in Cool, H. (ed.) *Proceedings of the 16th International Congress of the Association Internationale pour l’Histoire du Verre, London 2003*. Nottingham, England: AIHV.

Shortland, A. J. (2006) ‘Application of lead isotope analysis to a wide range of late bronze age Egyptian materials’, *Archaeometry*, 48(4), pp. 657–669.

Shortland, A. J. (2012) *Lapis Lazuli from the Kiln : Glass and Glassmaking in the Late Bronze Age*. Leuven: Leuven University Press.

Shortland, A. J. *et al.* (2017) ‘The analysis of Late Bronze Age glass from Nuzi and the question of the origin of glassmaking’, *Archaeometry*, 60(4), pp. 764–783.

Shortland, A. J. and Eremin, K. (2006) ‘The analysis of second millennium glass from Egypt and Mesopotamia, Part 1: new WDS analyses’, *Archaeometry*, 48(4), pp. 581–605.

Shortland, A. J., Freestone, I. and Rehren, Th. (2009) *From mine to microscope : advances in the study of ancient technology*. Oxford, UK Oakville, CT: Oxbow Books ; Distributed in the U.S. by D. Brown Bk. Co.

Shortland, A. J., Nicholson, P. T. and Jackson, C. M. (2000) ‘Lead isotopic analysis of 18th dynasty Egyptian eyepaints and lead antimonate colorants’, *Archaeometry*, 42(1), pp. 153–159.

Shortland, A. J., Nicholson, P. T. and Jackson, C. M. (2001) ‘Glass and Faience at Amarna: different methods of both supply for production, and subsequent distribution.’, in Shortland, A. J. (ed.) *The Social Context of Technological Change*. Oxford: Oxbow Books, pp. 147–160.

Shortland, A. J., Rogers, N. and Eremin, K. (2007) ‘Trace element discriminants between Egyptian and Mesopotamian Late Bronze Age glasses’, *Journal of Archaeological Science*, 34(5), pp. 781–789.

Shortland, A. J. and Tite, M. S. (1998) ‘The interdependence of glass and vitreous faience at Amarna’, in McCray, P. and Kingery, W. D. (eds) *The Prehistory and History of Glassmaking Technology*. The American Ceramics Society, USA, pp. 251–268.

Shortland, A.J. and Tite, M. S. (2000) ‘Raw materials of glass from Amarna and implications for the origins of Egyptian glass’, *Archaeometry*, 42(1), pp. 141–151.

Shortland, A J and Tite, M. S. (2000) ‘Raw materials of glass from Amarna and implications for the origins of Egyptian glass’, *Archaeometry*, 42(1), pp. 141–153.

Shugar, A. and Rehren, Th. (2002) ‘Formation and composition of glass as a function of firing temperature’, *Glass Technology*, 43, pp. 145–150.

Simpson, P. (1990) ‘Egyptian Core Glass Vessels from Sinai’, *The Journal of Egyptian Archaeology*. Egypt Exploration Society, 76, pp. 185–186.

Smirniou, M. and Rehren, Th. (2011) ‘Direct evidence of primary glass production in Late Bronze Age Amarna, Egypt’, *Archaeometry*, 53(1), pp. 58–80.

Smirniou, M. and Rehren, Th. (2013) ‘Shades of blue - cobalt-copper coloured blue glass from New Kingdom Egypt and the Mycenaean world: A matter of production or colourant source?’, *Journal of Archaeological Science*, 40, pp. 4731–4743.

Smirniou, M., Rehren, Th. and Gratuze, B. (2018) ‘Lisht as a New Kingdom Glass-Making Site with Its Own Chemical Signature’, *Archaeometry*, 60(3), pp. 502–516.

Smith, C. (1981) ‘A Search for Structure: Selected Essays on Science’, *Art and History*, 62.

Snape, S. (2014) *The Complete Cities of Ancient Egypt*. London: Thames and Hudson Ltd.

Soennecken, K. *et al.* (2021) *Tall Zirāʿa: The Gadara Region Project (2001-2011) Final Report. Volume 8.1*. Edited by D. Vieweger and J. Häser. Jerusalem/Amman/Wuppertal: Deutsches Evangelisches Institut für Altertumswissenschaft des Heiligen Landes/ Biblisch-Archäologisches Institut Wuppertal, Jerusalem/Amman/Wuppertal.

Soennecken, K. A. P. (2017) *Kulturelle Umbrüche in der südlichen Levante. Der Übergang von der Bronze- zur Eisenzeit unter besonderer Berücksichtigung des Tall Zirāʿa.* Universitätsbibliothek Wuppertal.

Spalinger, A. (1977) ‘A Critical Analysis of the “Annals” of Thutmose III (Stücke V-VI)’, *Journal of the American Research Center in Egypt*. American Research Center in Egypt, 14, pp. 41–54.

Starr, R. F. (1939) *Nuzi. Report on the excavations at Yorgan Tepa near Kirkuk, Iraq, conducted by Harvard Univ. in conjunction with the American Schools of Oriental Research and the Univ. Museum of Philadelphia 1927-1931. With app. by Ruth Sears Chute and others.* Cambridge, MA: Harvard University Press.

Stern, E M and Schlick-Nolte, B. (1994) *Early glass of the ancient world: 1600 B.C.-A.D. 50 : Ernesto Wolf collection*. Ostfildern: Verlag Gerd Hatje.

Stern, E. M. and Schlick-Nolte, B. (1994) 'Formschmelzen', in *Early Glass of the Ancient World, 1600 B.C.–A.D. 50*. Ostfildern, Germany: Verlag Gerd Hatje: Ernesto Wolf Collection, pp. 48–54.

Stern, W. B. (2017) 'Phosphate: a neglected argument in studies of ancient glass technology', *Swiss Journal of Geosciences*, 110(3), pp. 725–740. doi: 10.1007/s00015-016-0242-3.

Steuernagel, C. (1926) 'Der 'Adschlūn.', *Zeitschrift des Deutschen Palästina-Vereins*, pp. 1–162.

Stoch, Z., Pakulska, M. and Stoch, I. (1978) 'The influence of the structure and shape of grains of mineral raw materials upon the melting speed of soda-lime batches', *Szklo Ceramic*, 29(9), pp. 238–241.

Swann, C. P., McGovern, P. E. and Fleming, S. J. (1990) 'Colorants used in ancient Egyptian glassmaking: Specialized studies using PIXE spectrometry', *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*. Elsevier, 45(1–4), pp. 311–314.

Tait, H. (1991) *Five thousand years of glass*. London: British Museum Press.

Tanimoto, S. and Rehren, Th. (2008) 'Interactions between silicate and salt melts in LBA glassmaking', *Journal of Archaeological Science*. Elsevier, 35(9), pp. 2566–2573.

Tatton-Brown, V. and Andrews, C. (1991) 'Before the Invention of Glass Blowing: Egypt c.1450-1100 bc', in Tait, H. (ed.) *Five Thousand Years of Glass.* London: British Museum Press, pp. 26–37.

Thilo Rehren (2016) 'Another order for glass – or: how much glass does Pharaoh need?'

Tiradritti, F. (1998) *Egyptian treasures from the Egyptian Museum in Cairo*. Vercelli: White Star.

Tite, M. S. and Shortland, A. J. (2003) 'Production technology for copper- and cobalt-blue vitreous materials from the New Kingdom site of Amarna - a reappraisal', *Archaeometry*, 45(2), pp. 285–312.

Tite, M. S. and Shortland, A. J. (2008) *Production Technology of Faience and Related Early*

Viteous Materials. Oxford: Oxford University School of Archaeology (Monograph (Oxford University School of Archaeology)).

Tufnell, O. (1958) *Lachish (Tell ed-Duweir): The Bronze Age. Text and Plates*. London: Oxford University.

Turner, W. E. S. (1954) 'Studies in ancient glasses and glass making processes. Part I. Crucibles and melting temperatures employed in Ancient Egypt at about 1370 BC', *Journal of the Society of Glass Technology*, 38, pp. 436–444.

Turner, W. E. S. (1956a) 'Studies in ancient glasses and glass making processes. Part III. The chronology of glass making constituents', *Journal of the Society of Glass Technology*, 40, pp. 39–52.

Turner, W. E. S. (1956b) 'Studies in ancient glasses and glass making processes. Part IV. The chemical composition of ancient glasses', *Journal of the Society of Glass Technology*, 40, pp. 162–184.

Turner, W. E. S. (1956c) 'Studies in ancient glasses and glass making processes. Part V. Raw materials and melting processes', *Journal of the Society of Glass Technology*, 40, pp. 277–300.

Tytus, R. de P. (1903) *Preliminary report on the re-excavation of the palace of Amenhetep III*. New York: Winthrop Press.

Vandiver, P. (1983) 'Glass technology at the mid-second-millennium BC Hurrian site of Nuzi', *Journal of Glass Studies*, 25, pp. 239–247.

Varberg, J. *et al.* (2016) 'Mesopotamian glass from Late Bronze Age Egypt, Romania, Germany, and Denmark', *Journal of Archaeological Science*, 74, pp. 184–194.

Varberg, J., Gratuze, B. and Kaul, F. (2015) 'Between Egypt, Mesopotamia and Scandinavia: Late Bronze Age glass beads found in Denmark', *Journal of Archaeological Science*, 54, pp. 168–181.

Vicenzi, E P *et al.* (2002) 'Microbeam characterisation of Corning archaeological reference glasses: new additions to the Smithsonian Microbeam standard collection', *Journal of Research of the National Institute Standards and Technology*, 107, pp. 719–727.

Vieweger, D. and Häser, J. (2017) *Tall Zirā'a The Gadara Region Project (2001–2011) Final*

Report. Gütersloh.

Vieweger, D. and Häser, J. (2019) *Tall Zirāʿa - Mirror of Jordan's history*. Edited by J. Häser and K. Schmidt. Berlin: Wichern Verlag.

Wagner, B. *et al.* (2012) 'Critical assessment of the elemental composition of Corning archeological reference glasses by LA-ICP-MS', *Analytical and Bioanalytical Chemistry*, 402(4), pp. 1667–1677.

Walton, M *et al.* (2009) 'Evidence for the trade of Mesopotamian and Egyptian glass to Mycenaean Greece', *Journal of Archaeological Science*, 36, pp. 1496–1503.

Walton, M. *et al.* (2009) 'Evidence for the trade of Mesopotamian and Egyptian glass to Mycenean Greece', *Journal of Archaeological Science*, 36, pp. 1496–1503.

Walton, M. *et al.* (2012) 'Analysis of Late Bronze Age Glass Axes From Nippur - A New Cobalt Colourant', *Archaeometry*, 54(5), pp. 835–852.

Wedepohl, K. H. (2003) *Glas in Antike und Mittelalter*. Stuttgart, Germany: Schweizerbart Science Publishers.

Weyl, W. A. (1951) *Coloured glasses*. Sheffield: Society of Glass Production.

Wilkinson, A. (1971) *Ancient Egyptian Jewellery*. London: Methuen & Co Ltd.

Wilkinson, R. H. (2017) *The Complete Temples of Ancient Egypt*. London: Thames & Hudson Limited.

Wilkinson, T. (2010) *The Rise and Fall of Ancient Egypt*. London: Bloomsbury Publishing.

Wosinski, J. F. and Brill, R. H. (1968) 'A petrographic study of Egyptian and other cored vessels', in *Studies in glass history and design. Congress on glass, london 1st-6th july, 1968*, pp. 123–124.

Wreszinski, W. (1923) *Atlas zur altaegyptischen Kulturgeschichte*. Leipzig: J.C. Hinrichs.

Zaccagnini, C. (1983) 'Patterns of Mobility among Ancient near Eastern Craftsmen', *Journal of Near Eastern Studies*. University of Chicago Press, 42(4), pp. 245–264. Available at: http://www.jstor.org/stable/544537.

Zaccagnini, C. (2000) 'The Interdependence of the Great Powers', in Cohen, R. and Westbrook, R. (eds) *Amarna Diplomacy: The Beginnings of International Relations*.

Baltimore: Johns Hopkins University Press, pp. 141–153.

Zacharias, N. *et al.* (2018) ‘Mycenaean glass from the Argolid, Peloponnese, Greece: A technological and provenance study’, *Microchemical Journal*, 141, pp. 404–417. doi: https://doi.org/10.1016/j.microc.2018.05.027.

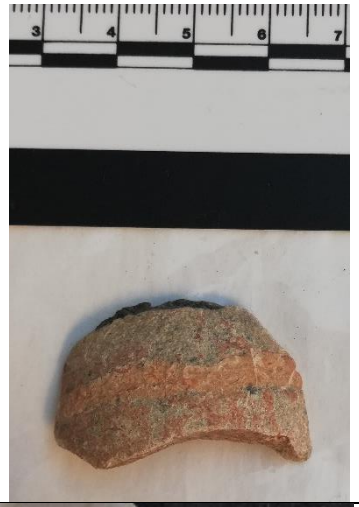
Zachariasen, W. H. (1932) ‘The atomic arrangement of glass’, *Journal of the American Chemical Society*, 54(10), pp. 3841–3851.

11 Appendix A

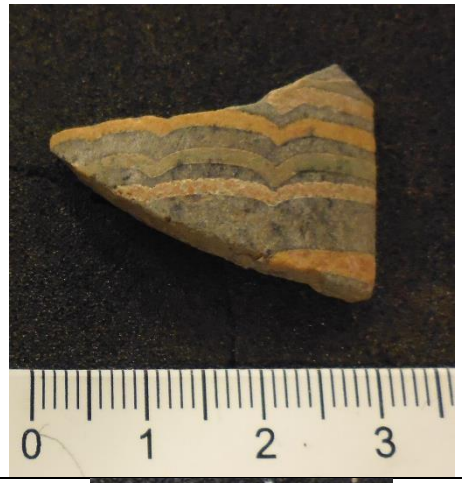
Supplementary material submitted with Kemp V, Delbey T & Shortland A (2023) The dating and provenance of glass fragments from the site of Serabit el-Khâdim, Sinai, Journal of Archaeological Science: Reports, 49 (June)

Acc. #	Main body colour	Opaque/ Translucent	Fragment description	Image
OX122	Black	Semi translucent	Vessel fragment with feather, garland or arcade dragged pattern applied in two colours: white and apparent yellow/brown. Transecting thicker white band bordering the pattern.	

OX144	Black	Semi translucent	Vessel fragment with straight white band applied transecting the fragment.	

OX299	Black	Translucent	Vessel fragment with straight white band applied transecting the fragment.	
OX358	Amber/brown	Translucent	Vessel fragment with decorative threads of yellow/white visible on the cross section. Pattern imperceptible.	

OX420	Brown	Translucent	Vessel fragment with garland pattern applied in at least two different colours.		
OX561	Brown	Translucent	Vessel fragment with possible decoration applied in yellow.		

OX189	Mid Blue	Translucent	Vessel fragment with flat arcade/garland pattern applied with three colour thread combination. Pattern appears to be applied in the pattern form rather than using an implement to drag over the surface, forming the pattern.	
OX193	Dark blue	Translucent	Vessel fragment with elaborate feather pattern applied in apparent white and yellow threads.	

OX414	Dark blue	Opaque	Unknown object. No perceptible pattern, prominent white thread transecting the fragment.	
OX433	Dark blue	Translucent	Vessel fragment with possible garland pattern applied in lighter colour.	

OX437	Dark Blue	Translucent	Vessel fragment with possible garland pattern applied in at least two different colours. Rim made from twisted threads.	
OX669	Dark blue	Translucent	Vessel fragment with regular white garland/arcade pattern applied in lighter colour.	

OX84	Dark blue	Translucent	Vessel fragment with possible feather pattern and two white transecting bands.	

OX107	Dark blue	Semi translucent	Possible vessel fragment with no perceptible pattern.	
OX183	Dark blue	Translucent	Vessel fragment with elaborate pattern (possibly feather) applied in at least three colours	

OX200	Dark blue	Translucent	Vessel fragment with pattern applied with yellow, white and light blue threads.	
OX481	Black/dark blue	Semi translucent	Vessel fragment with white thread present in rim section.	

OX501	Dark blue/black	Semi translucent	Unknown object type with no perceptible pattern.	

OX70	Light blue	Translucent	Vessel fragment with yellow and dark blue thread applied in a straight design.	

OX103	Turquoise	Translucent	Unknown object type with no perceptible pattern.	

OX127	Mid blue	Translucent	Unknown object type with no perceptible pattern. Semi translucent.	

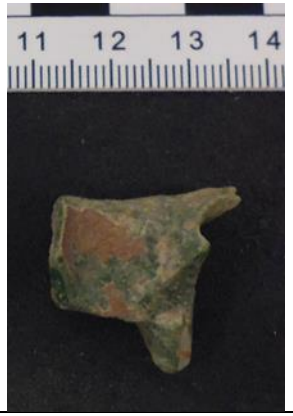
OX195	Blue	Semi translucent	Vessel fragment with consistent, even feather pattern applied in three (?) colours.	

OX198	Light blue	Translucent	Vessel fragment with apparent feather pattern applied in yellow and white threads, thicker white band transecting the fragment.	
OX235	Light blue	Semi translucent	Vessel fragment with possible feather pattern applied in yellow and white threads.	

OX429	Turquoise blue	Translucent	Vessel fragment with no perceptible pattern. Rim contains merged yellow and blue glass.	
OX442	Light blue	Translucent	Vessel fragment with possible garland or feather pattern applied. Rim applied with at least two colours of twisted glass of apparent white and dark blue.	

OX472	Turquoise blue	Translucent	Vessel fragment with feather pattern applied in two other colours, one possibly yellow.	
OX482	Blueish green	Translucent	Vessel fragment with garland pattern applied with at least two different colours, one being yellow. Rim applied in solid opaque yellow.	

OX488	Mid blue	Translucent	Vessel fragment with no perceptible pattern, rim applied in darker blue and white twisted glass.	
OX897	Light blue	Translucent	Vessel fragment with no perceptible pattern.	

E.4486	Green	Opaque	Unknown object type. Fragment is flat with no perceptible pattern applied	
E.4486.1	Green	Semi translucent	Unknown object type with no perceptible pattern.	

OX140	Green	Opaque	Unknown object type with no perceptible pattern.	
OX484	Green/blue	Translucent	Rounded fragment - "leaf" from a pomegranate vessel? Yellow rim applied to the edge of rounded section.	

OX77	Black/Purple	Translucent	Vessel fragment with pattern applied in at least two different coloured threads.	
OX85	Purple/brown	Translucent	Unknown object type with no perceptible pattern.	

OX641	White	Opaque	Vessel fragment with dark blue/black band visible under red deposit, white prominent thread transecting fragment	
OX264	Yellow	Semi translucent	Vessel fragment with no perceptible pattern.	

OX444	Yellow	Opaque	Vessel fragment with no perceptible pattern. Rim applied in white and black/dark brown coloured glass.	
OX334	Dark red	Semi translucent	Unknown object type with no perceptible pattern.	

OX226	Amber/brown	Translucent	Vessel fragment with undetermined pattern applied in two lighter colours, possible yellow and white.		

12 Appendix B Publication 1

archaeometry

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LA-ICP-MS ANALYSIS OF LATE BRONZE AGE BLUE GLASS BEADS FROM GUROB, EGYPT*

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Laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) analysis was undertaken on 37 blue glass beads excavated from a tomb in the southern Faiyum region of northern Egypt. The tomb was undisturbed, contained the remains of seven females and two children, and dated between the reigns of Amenhotep I (1525–1504 BCE) and Tuthmosis III (1479–1425 BCE). The glass beads were coloured by copper and the trace element concentrations were compositionally consistent with glasses from Mesopotamia rather than from Egypt. Therefore, these glass beads represent a rare example of Mesopotamian glass to be discovered in Egypt, in addition to being some of the earliest glass found. Gurob is known to have been the site of a 'harem palace' established in the reign of Tuthmosis III, the implication being that these beads represent luxury items transported to Egypt by high-ranking foreign women, possibly in connection with the harem palace.

KEYWORDS: EGYPT, GLASS, GUROB, HAREM, LA-ICP-MS, LATE BRONZE AGE, MESOPOTAMIA

INTRODUCTION

The first regular finds of glass appear in the archaeological records of Mesopotamia and Egypt *c.*1500 BCE (Lilyquist *et al.* 1993, 23; Nicholson 1993, 45–46; Tite and Shortland 2008, 209), but the exact geographical source of the first glass-*making* is still a matter of debate. Excavations have provided supporting physical evidence of glass-*making* sites at Qantir and Amarna in Egypt (Lucas and Harris 1962, 179–194; Jackson and Nicholson 2007, 13–25; Pusch and Rehren 2007; Smirniou and Rehren 2011;), and glass*working* at Tell Brak and Nuzi in modern-day Syria and northern Iraq, respectively (Henderson 1998; Shortland *et al.*2017). However, the evidence for the manufacture of glass from raw materials is often inferred, particularly in Mesopotamia, where poor preservation conditions impact the successful recovery of glass artefacts and no glass-making site has been confidently identified (Shortland *et al.* 2007; Shortland 2012, 49). It is very rare to find glass identified as Egyptian in Mesopotamia, or vice versa (Walton et al. 2009). The sole example is two green glass rods excavated from Amarna in Egypt, the trace element analysis of which suggested that the composition was similar to glasses of Mesopotamian origin (Varberg *et al.* 2016).

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Glass was an extremely valuable commodity in the Late Bronze Age, the ownership of which was closely controlled by, and limited to, royalty or the élite. Therefore, it played a significant role in the elaborate ritual of gift exchange between Egypt, the Near East and their vassal states (Liverani 2000, 24). Contemporary textual evidence for the supply of glass to Egypt appears in the Amarna letters (EA 148, 235, 314, 323 and 331), cuneiform tablets that detail the diplomatic correspondence between Egyptian officials and vassal states during the reigns of Amenhotep III (1391–1353 BCE) and Akhenaten (1353–1333 BCE) (Moran 1992; Shortland 2012, 147; Rehren 2016). The text explicitly documents the 'ordering' of glass from the Syria–Palestinian states by the king of Egypt. In addition, the Hall of the Annals in Karnak, dated to the mid-15th century BCE (Spalinger 1977), illustrates the apparent import of glass into Egypt from the Levant and Syria, either as spoils of the military campaigns undertaken by Tuthmosis III or as 'gifts' made in tribute by subordinate foreign rulers (Wreszinski 1923, 40). Physical evidence for the import of glass in this early period has not been found until the results reported in this paper.

Laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) can be used to quantify geologically significant trace elements in glass, enabling the region of production potentially to be inferred (Shortland *et al.*2007; Walton et al.2009). Trace elements are introduced during the glass-*making* procedure by the addition of raw materials rather than during the glass*working* process, which may have occurred at a different site or another country (Shortland 2005; Jackson and Nicholson 2010). These compositional differences have been crucial at distinguishing between glasses manufactured in Egypt and the Near East.

The analysis and provenance of early examples of glass could provide fundamental supporting evidence for the location of primary sites capable of manufacturing glass from raw materials. The subsequent transport of glass and the patterns of exchange would contribute to the understanding of an important emerging technology and the subsequent exchange of its products. Several mechanisms might be responsible for glass transportation between the two countries: direct diplomatic gifts; personal items brought by royalty, diplomatic parties others of high status; or even the movement of glassworkers. Diplomatic marriages were common in both Egypt and Mesopotamia (Bryan 2000, 80), and it was customary that the intended bride would be joined by a substantial entourage (Snape 2014, 48); it can be assumed that glass objects in the form of jewellery were among the personal effects of such élite retinues of women and potentially part of other gifts. Royal harems in Egypt would almost certainly have included foreign women who were married to the king to secure diplomatic relationships, especially with the Hittite and Mitanni nations (Shaw 2011). Examples of this include the three 'Foreign Wives' of Tuthmosis III, who may have been residents of the palace at Gurob discussed here, but who were buried near Thebes (Lilyquist 2004, 336). Although little is known about the princesses, they were described as 'Asiatic' women of high status and their tomb contained elaborate headdresses and jewellery inlayed with some of the first glass known, and possibly of foreign, perhaps Mitanni, styles (Feucht 1999, 385). Another later example is the diplomatic marriage between Amenhotep III and Mitanni princess Gilukhepa, where it is recorded on a commemorative scarab that she was accompanied by 317 'chief women of the harem' (Snape 2014, 48). This indicates the size of a palace and the resources required to accommodate multiple royal marriages and associated retinues.

THE MEDINET EL-GHUROB SITE

Medinet el-Ghurob, or Gurob, is located in the Faiyum region of northern Egypt and is of particular interest as it is the site of the only palace identified as a harem (Shaw 2011). It has been

proposed that the harem palace was established during the reign of Tuthmosis III (1479–1425 BCE) with the primary purpose of accommodating royal foreign women who had been married to the king (Hodgkinson 2017, 188). The palace was situated near the ancient town of Mer-wer and thrived during the reign of Amenhotep III (1390–1352 BCE), expanding to provide for larger structures, including a fort and a temple, as well as cemeteries and areas of local settlement. The palace itself is a large construction, the enclosure measuring approximately 240 × 225 m, which served as a ceremonial centre as well as having an administrative function (Hodgkinson 2017, 192). As semi-independent institutions, harems had autonomous economic importance, and therefore significance. The harem palace at Gurob would have also accommodated senior royal wives, lesser wives and concubines in addition to their staff, servants and harem officials (Kemp 2006, 288).

In 1920, G. Brunton and R. Engelbach excavated the main New Kingdom cemetery at Gurob and discovered three undisturbed tombs at its northernmost point. The three tombs were distinctly separate, located approximately 365 m from the main concentration of burials and subsequently labelled as Tombs 20, 26 and 27. Tomb 27 was the largest of the three and contained the remains of seven females, two children and their associated grave goods (Brunton and Engelbach 1927). These goods comprised 26 pottery vessels, one brick-red handled pot and a variety of cosmetic items, including several kohl pots and a mirror, likely bronze. The smaller finds, including the beads, were scattered by the collapse of the roof, and their exact location in the tomb could not be recorded once the tomb was entered. The smaller finds were listed as 29 scarab-like beads, some of which were mounted in silver or gold, and strings of stone and glass beads. The excavators asserted that the three tombs probably belonged to a family group and determined the date by examination of the grave goods as being from the reign of Amenhotep I, but caveated the date by stating that the ceramic vessels were customarily dated slightly later to the reign of Tuthmosis III (Brunton and Engelbach 1927, 10). It is inferred that the women might have a foreign origin as there is a notable lack of *shabtis* and *canopics* in all three tombs in the family group, important parts of the Egyptian burial ritual (Ikram 2015, 129) and other foreign objects are present, for example, a spindle bottle. The isolated position of the tomb, the all-female nature of the dead and

Figure 1 *Beads excavated from Tomb 27 at Gurob, Egypt, in 1920. Bead B1 is lower left; the beads were numbered sequentially anticlockwise to B44. Courtesy: Hunterian Museum, Glasgow, D.1921.48.*

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the 'foreigness' speculated on by the excavators all suggest the possibility is that these women were part of the harem and/or its staff.

This study reports the analysis of one of the finds from Tomb 27: a string of blue and clear beads, now in the Hunterian Museum, Glasgow (D.1921.48) (Fig. 1).

METHODOLOGY

D.1921.48 is a string of 44 beads; beads 1, 2, 9, 15, 24 and 33 are transparent quartz with a partial blue glaze on the surface. This paper reports the analysis of 37 of the remaining 38 beads, all of which are made of translucent, blue glass. The single missing bead was bead 28, which fell out of focus during the run; therefore, the results have been omitted from the final reporting. Only 37 beads are therefore discussed in the results.

Table 1 *Average results of the Corning A secondary standards (n = 6), compared with two sets of reference values*

	n = 6 Corning A, two with each analytical run			*Shortland et al.* (2007) and Vicenzi et al. (2002)		*Wagner et al.* (2012)	
	Average	*SD*	*Precision*	*Reference value*	*deltawt%*	*Reference value*	*deltawt%*
Li	47	0.8	1.7	46	2.4	51	−7.8
B	548	64.4	11.8	537	2	851	−35.6
Na	101 387	1050	1	106 083	−4.4	99 407	2
Mg	16 439	242	1.5	16 043	2.5	15 078	9
Al	5040	134	2.7	5291	−4.8	4339	16.2
Si	316 488	1746	0.6	310 883	1.8	316 768	−0.1
K	21 031	2022	9.6	22 639	−7.1	28 714	−26.8
Ca	36 872	615	1.7	35 954	2.6	35 311	4.4
Ti	4468	286	6.4	4226	5.7	4428	0.9
Cr	19	0.7	3.7	17.9	6.2	21	−7.4
Mn	7221	437	6.1	6921	4.3	8752	−17.5
Fe	6654	323	4.9	6537	1.8	6841	−2.7
Co	1182	128	10.9	1188	−0.5	1336	−11.6
Ni	170	6.5	3.8	160	6.3	181	−5.9
Cu	9346	346	3.7	7842	19.2	8786	6.4
Zn	502	82	16.3	410	22.5	386	30.3
Rb	86.8	2.7	3.1	81.5	6.5	82	5.5
Sr	951	13.9	1.5	860	10.5	897	6
Y	0.28	0.0	6.8	n.d.	n.d.	n.d.	n.d.
Zr	44	1.7	4	39.9	10.9	37	19.5
Sn	1490	92.4	6.2	1194	24.8	1357	9.8
Sb	14 334	1521	10.6	10 649	34.6	14 002	2.4
Ba	4605	175	3.8	3905	17.9	4122	11.7
La	0.34	0.0	12.4	0.28	20.7	n.d.	n.d.
Ce	0.27	0.0	9.1	0.24	12.4	n.d.	n.d.
Pb	694	68.1	9.8	595	16.7	678	2.5
Bi	8.6	0.6	7.2	7.8	9.8	9	−4.5
Th	0.3	0.0	6.5	0.3	2.5	n.d.	n.d.
U	0.18	0.0	9	0.16	13.5	n.d.	n.d.

Values are ppm.
Sources: Vicenzi et al. (2002), Shortland et al. (2007) and Wagner et al. (2012).

The beads were ablated directly in the large sample chamber of an electrospray ionization (ESI) new-wave laser ablation system attached to a Thermo X-Series II inductively coupled plasma-mass spectrometry (ICP-MS). The laser ablation settings and ICP-MS system were optimized using a series of standards to determine the working conditions used. The laser spot diameter was 80 µm with an energy of 0.42 mJ, pulsing at 10 Hz. The helium carrier gas flow rate was 500 ml min^{-1} through the laser into an argon stream for the ICP-MS. The nebulizer flow rate was 0.6–0.7 L min^{-1}. The spectrometer dwell time was 20 ms per mass, and 10 sweeps were averaged. The beads were analysed in three analytical runs, each interposed with gas blank analyses and calibrated against NIST SRM 610 and 612 reference glasses employing the consensus values (Jochum *et al*. 2011). Two measurements of the Corning A standard were carried out in each analytical run, one at the beginning and one at the end, and evaluated against the accepted values. Vicenzi and Shortland use the same sets of values; Wagner slightly different ones (Vicenzi et al.2002; Shortland *et al*.2007; Wagner *et al*.2012) (Table 1). The results on the Corning A standard show that the majority of the elements were in good agreement with accepted values; when expressed as a percentage difference between the ascertained and accepted values (RD), the values are typically > 20%. Note, too, that the Corning A standard was never intended as an LA-ICP-MS standard, so some trace elements were never intended to be used as standard values. However, agreement in general is good.

Each bead was subjected to three measurements on one spot and the results were averaged. The beads were not cleaned before analysis; however, pre-ablation would remove the very outermost weathering and care was taken to avoid apparent patches of corrosion. Most of the beads were in good condition, although some exhibited some surface corrosion mainly in the form of pitting and mottling. During an initial examination of the beads, small bubbles in the glass were observed below the surface and these were avoided.

The results were calibrated using the mathematical approach first proposed by Gratuze (1999) as an alternative to the use of an internal standard. The protocol used here was derived from that and follows van Elteren *et al*. (2009). This essentially works in a similar fashion to normalized scanning electron microscopy with energy-dispersive spectroscopy (SEM-EDS). It assumes that all elements are measured and calculates oxygen by stoichiometry. The total is then normalized to 100 wt% and either presented as weight per cent oxide or converted back to elemental ppm.

RESULTS

The data are presented in Table 2.

Major elements

The LA-ICP-MS analysis of the 37 blue glass beads showed that they are a soda lime silicate glass with typically 2–4% K_2O and 5–7% MgO. This major element composition was consistent with a typical Late Bronze Age, plant ash glass, which have high soda (> 15% Na_2O) and significant magnesia (> 3.0% MgO) and potash (> 2.0% K_2O). All the beads were coloured by Cu, with an average of 1.03 wt% CuO. Sb was present only in trace levels (< 25 ppm Sb), indicating that this was not deliberately added as an opacifier.

DISCUSSION

All 37 beads appear optically similar in colour; however, interesting compositional differences could be observed in the major elements. Fig. 2 shows MgO plotted against CaO. Two groups

Table 2 *Results of LA-ICP-MS analyses of the blue beads*

Bead	*Na_2O*	*MgO*	*Al_2O_3*	*SiO_2*	*K_2O*	*CaO*	*Fe_2O_3*	*CuO*	*Li*	*B*	*Ti*	*Cr*	*Mn*	*Co*	*Ni*	*Cu*	*Zn*	*Rb*	*Sr*	*Y*	*Zr*	*Sn*	*Sb*	*Ba*	*La*	*Ce*	*Pb*	*Bi*	*Th*	*U*
B3	16.6	5.2	1.0	68.0	2.3	5.2	0.6	1.0	17	136	269	33	254	18	12	7658	20	10	342	2.6	11.0	3.6	1.7	62	2.2	7.5	9	0.2	0.6	0.2
B4	17.2	5.6	1.0	65.6	3.0	5.6	0.7	0.9	21	122	385	37	303	16	16	7422	38	17	421	2.7	15.5	11.8	10.9	49	2.5	5.3	21	0.2	0.7	0.3
B5	13.2	6.7	0.5	69.5	3.3	5.0	0.3	1.2	31	111	161	27	224	14	12	9212	18	21	356	1.6	6.9	1.1	3.4	29	1.3	3.4	10	0.1	0.3	0.1
B6	16.9	5.6	1.0	66.3	3.0	5.5	0.6	0.9	21	151	331	40	274	13	15	6965	24	17	420	2.5	14.8	6.1	6.4	50	2.2	5.4	8	0.1	0.6	0.2
B7	18.0	6.7	0.5	64.0	3.6	5.4	0.3	1.2	38	84	170	30	247	18	12	9569	20	15	373	1.9	9.0	1.1	3.6	27	1.6	3.3	10	0.1	0.4	0.1
B8	18.2	6.2	0.7	65.2	3.1	4.9	0.4	1.0	24	167	233	20	246	19	13	7798	19	17	392	2.1	9.6	1.6	0.7	37	1.8	4.0	5	0.1	0.4	0.2
B10	18.3	6.6	0.6	64.3	3.3	5.3	0.3	1.1	37	111	169	22	218	14	12	8535	38	15	360	1.8	8.4	7.1	5.5	112	1.4	3.2	14	0.2	0.4	0.1
B11	18.8	6.7	0.8	62.9	3.4	5.5	0.4	1.0	29	193	255	27	237	16	13	7878	47	14	459	2.4	12.8	4.4	6.1	37	1.7	3.7	25	0.2	0.5	0.2
B12	18.5	6.4	0.5	63.9	3.5	5.2	0.4	1.2	39	88	192	21	254	17	13	9428	35	17	361	1.8	8.6	3.5	20.2	28	1.6	3.4	36	0.1	0.4	0.1
B13	16.9	5.7	1.1	66.3	2.7	5.7	0.6	0.8	21	159	323	39	270	13	14	6648	21	16	434	2.8	16.8	50.3	6.4	50	2.3	5.3	10	0.1	0.6	0.2
B14	16.3	5.3	1.1	68.0	2.0	5.4	0.6	0.9	17	139	275	28	248	17	11	7393	18	8	361	3.2	13.4	9.4	0.5	62	2.4	5.2	5	0.2	0.7	0.2
B16	18.8	6.9	0.6	63.9	2.8	5.3	0.3	1.0	40	106	186	25	213	13	12	8212	28	15	353	1.8	7.9	6.0	4.1	24	1.3	3.9	11	0.2	0.3	0.1
B17	15.5	5.4	1.3	68.1	2.1	5.6	0.6	0.9	16	139	309	27	248	17	16	7064	41	8	363	3.2	13.4	4.0	4.6	66	2.5	6.1	27	0.2	0.7	0.2
B18	16.8	5.5	1.1	67.5	1.9	5.4	0.6	0.9	19	137	315	22	242	18	11	6979	19	10	365	3.2	12.8	2.8	1.2	65	2.3	5.4	8	0.3	0.7	0.2
B19	16.7	5.7	1.1	66.4	2.7	5.7	0.6	0.8	21	143	321	41	274	13	15	6677	32	17	448	2.9	16.9	29.6	10.5	54	2.4	5.5	36	0.2	0.6	0.2
B20	17.7	5.8	1.1	65.8	2.3	5.5	0.6	0.9	23	151	344	45	276	13	15	6897	30	16	416	2.8	16.5	47.3	6.8	45	2.2	5.3	21	0.2	0.6	0.2
B21	18.1	4.8	0.8	64.2	3.8	6.4	0.4	1.1	16	111	239	24	227	9	15	8428	35	11	417	2.1	10.6	50.6	4.3	37	1.8	4.1	19	0.1	0.5	0.2
B22	17.8	6.2	0.5	64.7	3.5	4.9	0.4	1.6	38	84	221	24	248	18	13	12788	97	15	337	1.6	9.7	25.2	6.8	27	1.5	3.5	37	0.5	0.4	0.2
B23	15.8	5.2	1.0	68.2	2.5	5.3	0.7	1.0	17	106	283	25	280	21	12	7739	31	12	353	3.0	12.9	2.3	1.0	82	2.9	5.5	8	0.2	0.8	0.2
B25	18.1	6.4	0.5	64.5	3.6	5.0	0.3	1.2	39	79	164	27	246	17	13	9515	41	16	356	1.8	8.2	84.8	4.5	31	1.7	3.5	15	0.2	0.4	0.2
B26	17.0	5.3	1.0	66.6	2.9	5.3	0.6	0.9	21	120	320	40	305	17	16	7502	74	16	410	2.7	15.9	8.9	9.1	50	2.6	5.4	15	0.3	0.7	0.3
B27	16.3	5.1	1.0	67.9	2.5	5.2	0.7	1.0	17	104	286	30	286	22	13	7958	28	9	349	2.9	13.2	19.1	3.0	69	2.8	5.7	12	0.2	0.9	0.3
B29	16.4	5.4	1.0	66.8	3.0	5.5	0.6	0.9	22	111	353	51	297	16	15	7371	26	18	421	2.8	17.0	10.1	8.5	54	2.8	5.6	8	0.2	0.7	0.3
B30	18.1	6.6	0.5	65.1	2.9	5.1	0.3	1.1	40	99	178	26	216	14	12	8567	25	15	347	1.8	9.7	15.3	3.4	24	1.4	4.9	10	0.1	0.3	0.1
B31	16.7	5.6	1.1	66.3	2.8	5.7	0.6	0.9	21	111	337	39	306	16	15	7111	36	17	454	3.2	19.2	12.3	12.9	55	3.0	5.9	14	0.2	0.8	0.3
B32	16.8	5.7	1.1	66.5	2.6	5.5	0.6	0.8	22	140	319	40	265	13	14	6619	113	15	435	3.0	17.4	22.2	9.2	52	2.4	5.6	37	0.2	0.6	0.2
B33	16.2	5.3	1.1	66.9	3.0	5.5	0.7	0.9	21	112	369	39	303	16	16	7503	55	19	434	3.1	17.7	14.7	10.1	54	2.8	5.6	26	0.2	0.7	0.3
B34	17.8	6.4	0.5	65.0	3.3	5.2	0.3	1.1	38	95	170	23	221	14	12	9075	87	18	368	1.8	8.5	9.1	7.8	29	1.5	3.7	16	1.0	0.3	0.1
B35	15.9	3.7	1.4	69.5	2.9	4.2	0.8	1.1	17	64	451	19	174	4	19	8647	29	25	224	3.2	15.9	16.0	13.5	47	2.7	5.4	62	1.0	0.8	0.3
B36	16.4	5.4	1.2	66.0	2.9	5.8	0.7	1.0	21	111	346	37	303	16	16	7622	79	17	451	3.2	19.2	12.8	11.8	59	3.1	6.1	37	1.3	0.8	0.3
B37	15.9	5.2	1.0	68.5	2.2	5.3	0.7	0.8	17	121	318	24	246	17	11	7102	37	9	367	3.2	14.3	17.1	4.9	77	2.6	5.8	20	0.3	0.7	0.2

(*Continues*)

Table 2 *(Continued)*

Bead	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	Fe_2O_3	CuO	Li	B	Ti	Cr	Mn	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Sn	Sb	Ba	La	Ce	Pb	Bi	Th	U
B38	18.4	6.6	0.7	64.0	3.3	5.2	0.4	0.9	33	168	208	23	230	16	13	7537	50	14	433	2.3	11.9	11.1	5.5	34	1.7	3.8	20	0.1	0.5	0.2
B39	18.0	6.7	0.6	64.9	2.8	5.3	0.3	1.1	41	99	197	33	218	14	11	8729	24	19	369	1.9	8.2	3.3	5.0	28	1.4	3.5	14	0.1	0.3	0.1
B40	16.8	5.8	1.1	66.2	2.4	5.8	0.6	0.8	22	140	357	55	274	13	14	6607	32	18	456	3.1	18.8	4.8	9.2	48	2.4	5.7	10	0.1	0.6	0.2
B41	16.2	5.4	1.1	68.5	1.8	5.2	0.6	0.9	18	130	304	25	246	17	12	7072	22	8	352	3.1	13.5	2.6	2.2	57	2.3	5.6	9	0.1	0.7	0.2
B42	18.0	6.6	0.5	65.1	2.8	5.2	0.3	1.1	40	96	177	23	215	14	11	8454	19	15	363	1.8	9.7	3.9	3.4	26	1.4	3.5	12	0.1	0.3	0.1
B43	16.7	5.7	1.0	66.5	2.8	5.5	0.6	0.9	21	137	317	40	269	13	15	6808	32	17	446	2.9	17.6	18.4	7.0	52	2.3	5.5	9	0.1	1.0	0.2
B44	16.1	5.3	1.1	68.3	2.0	5.3	0.6	0.9	18	125	312	27	247	17	11	7191	20	10	356	3.1	13.2	20.0	1.1	59	2.4	5.8	11	0.1	1.0	0.2

Oxides are in per cent oxide; trace elements in ppm.

are evident: a low MgO group with MgO content between 5.1 wt% and 5.8 wt%, and a high MgO group with MgO content between 6.2 wt% and 6.9 wt%. The beads in the high MgO group consistently contained the highest concentrations of Na, Li and Cu, and the lowest concentrations of Ti, Y, Mn and Zr. These distinct groupings indicate that the beads were potentially made from two main separate batches of glass, probably from slightly different plant ashes. Two outliers were observed, beads 21 and 35, potentially representing other batches. It is rare to be able to analyse all the beads of a necklace. More typically, one or two might be chosen. This is one of the advantages of LA-ICP-MS: the very minimal damage caused in sampling allows more objects to be analysed and highlights interesting variations such as this.

Colourant

Egyptian Cu-blue glasses tend to exhibit elevated levels of Pb, As and Sn (Smirniou et al. 2013), which is attributed to the use of bronze as a source of Cu for the colourant (Kaczmarczyk et al. 1983; Freestone 1991; Shortland et al. 2000). In contrast, Near Eastern glasses tend to have these elements at no higher-than-trace levels. The beads analysed here contained only trace levels of Sn and Pb, averaging 17 and 19 ppm, respectively, indicating that a purer Cu source was used, conforming with the characteristic colourant composition of Near Eastern glasses.

Trace element composition

LA-ICP-MS trace element analysis can provide concentrations of Cr, La, Ti and Zr, which form a 'compositional fingerprint' that can be used to distinguish between Late Bronze Age glasses of unknown sources (Shortland *et al.* 2007). Egyptian glasses exhibit a relatively low Cr/La ratio with a higher, more variable Zr/Ti ratio. Conversely, glasses originating from Mesopotamia

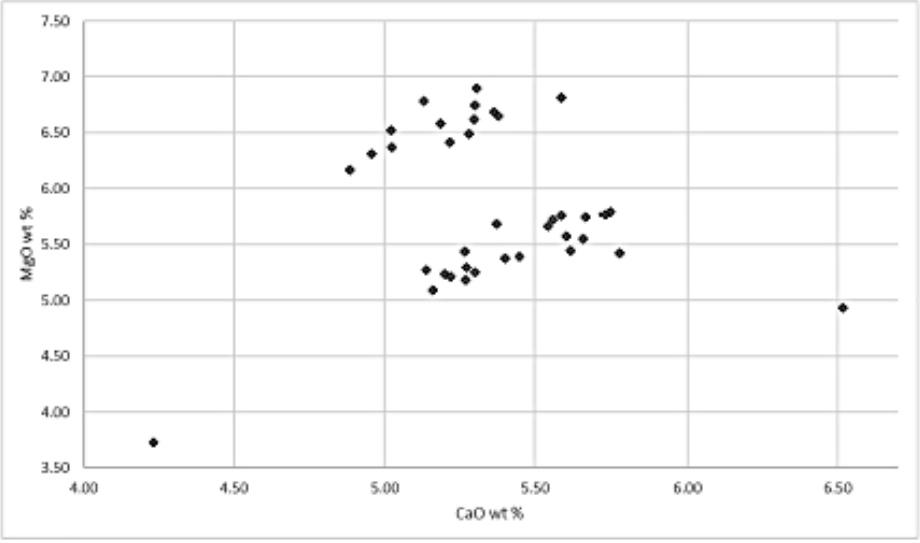

Figure 2 *Covariation of MgO with CaO of the blue beads (wt%) indicating two distinct main groups: high and low MgO, with two outliers, potentially representing other batches.*

exhibit lower, but consistent, Zr/Ti ratios and higher, more variable, Cr/La ratios, Mesopotamian glasses being relatively rich in Cr.

The LA-ICP-MS trace element data (Table 2) show that the glass beads contained relatively high concentrations of Cr, between 18.7 and 54.2 ppm, with an average of 31 ppm, and lower concentrations of La (1.5–3.1 ppm, averaging 2.4 ppm). These data were plotted against the trace element values obtained from the LA-ICP-MS analysis of glasses from known Egyptian and Mesopotamian origin (Shortland *et al.* 2007; Walton et al. 2009) (Fig. 3). The beads show a positive correlation with the Mesopotamian glasses, but it was observed that they have an overall higher average Cr concentration than the Mesopotamian glasses analysed by Shortland *et al.,* (2007) and Walton (2009).

The Ti concentration of the beads ranged from 164 to 452 ppm, with an average of 274 ppm; the Zr concentration ranged from 7.0 to 19.2 ppm, with an average of 13 ppm. When plotted with the glasses of known origin, the trace element data from the beads are consistent with the composition of the Mesopotamian glasses (Fig. 4). Trace element compositions therefore strongly suggest that the beads are compositionally consistent with Near Eastern glasses and distinct from almost all the glass previously recovered and analysed from Egypt. They are also early, some of the earliest glass known in Egypt, which has implications for the study of where the first glass might have originated (see Shortland *et al.* 2017 for a summary). Traditionally it has been assumed that glass originated in the Near East, and this early Near Eastern glass in Egypt tends to support that fact. However, it is clear that there is glass nearly this early as this in Egypt, so it is far from clear which has priority (Shortland *et al.* 2017).

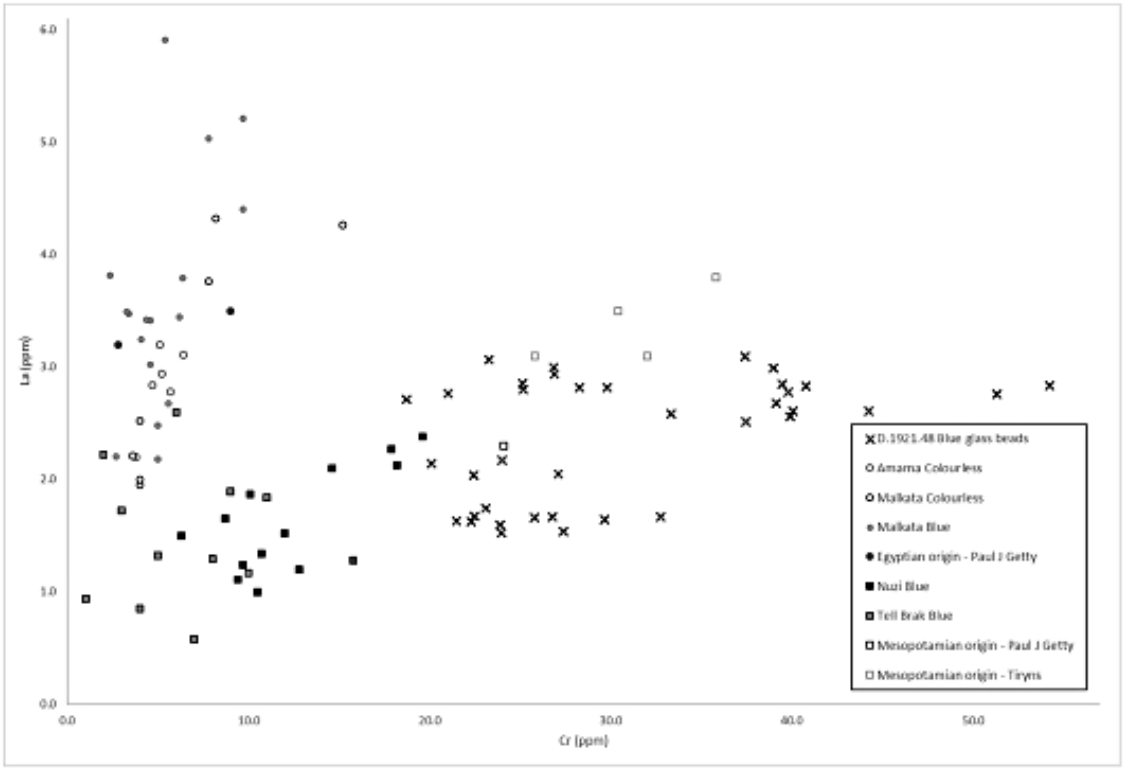

Figure 3 *Covariation of La with Cr in the blue beads of unknown origin compared with Egyptian and Mesopotamian blue and colourless glasses of known origin. Sources: Shortland et al. (2007) and Walton et al. (2009).*

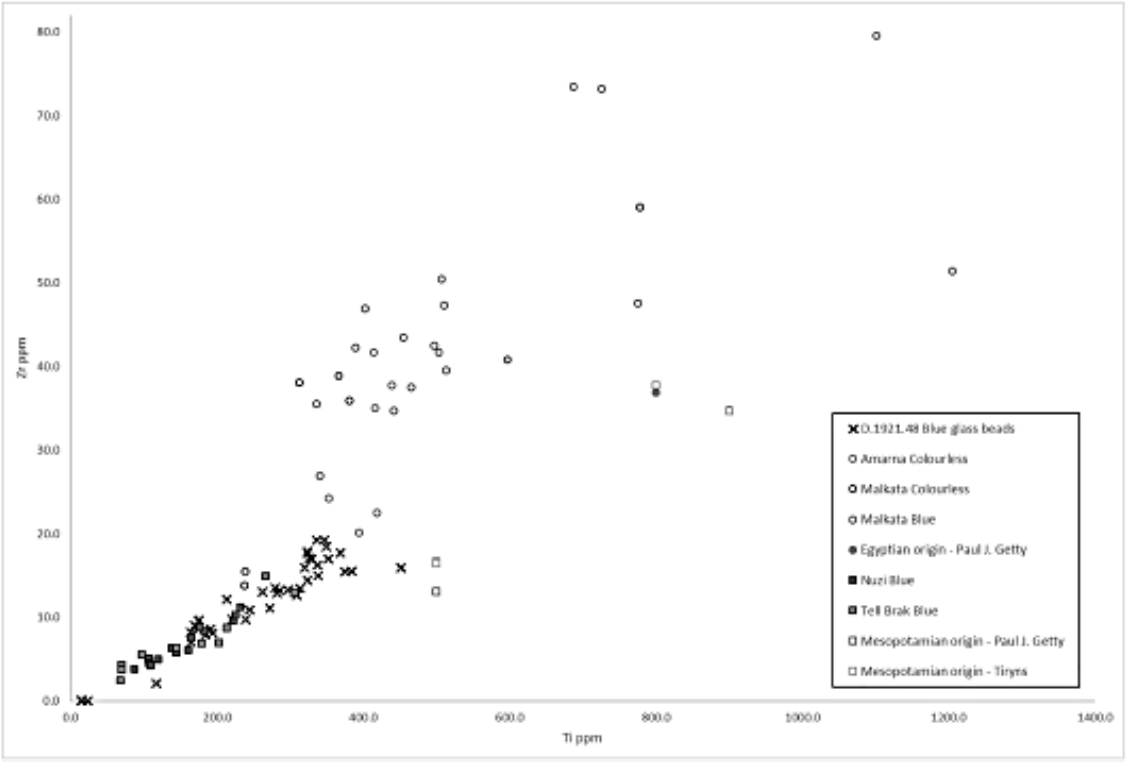

Figure 4 *Covariation of Zr with Ti in the blue beads of unknown origin compared with Egyptian and Mesopotamian blue and colourless glasses of known origin. Sources: Shortland et al. (2007) and Walton et al. (2009).*

CONCLUSIONS

The 37 blue glass beads analysed by LA-ICP-MS in this study have trace element compositions consistent with glass manufactured in Mesopotamia, therefore they represent the only confirmed finished object of Mesopotamian glass to be discovered in Egypt. The major element composition is consistent with that of standard Late Bronze Age plant ash glass, but potentially represents two main compositional groups: a low MgO group and a high MgO group, suggesting that these beads were manufactured from two different batches of glass. A pure form of Cu was used as a blue colourant, as opposed to a bronze source, which was typically the practice in Late Bronze Age Egyptian glass technology. The beads were excavated from a previously undisturbed tomb that contained the remains of seven women and two children. The tomb, and therefore the beads, were dated from between the reigns of Amenhotep I (1525–1504 BCE) and Tuthmosis III (1479–1425 BCE), and are therefore some of the earliest glass identified. The excavators implied that the women were foreign by the manner of the burial and from the associated grave goods and context (Brunton and Engelbach 1927, 10). The beads found in the tomb are certainly consistent with glass from the Near East. Evidence from the analysis of the beads should be considered alongside the isolated location of the 'higher status' brick-constructed tomb, which contained only females and children. The nearby harem palace may be the origin of these individuals, and it would be consistent with the evidence if the beads were brought to the among the personal effects transported into Egypt from Mesopotamia by women of status in connection with that palace.

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REFERENCES

Brunton, G., and Engelbach, R., 1927, *British School of Archaeology in Egypt and Egyptian research account, twenty fourth year, 1918—Gurob*, British School of Archaeology in Egypt, London.

Bryan, B. M., 2000, The Egyptian perspective on Mittani, in *Amarna relations: The beginnings of international relations* (eds. R. Cohen and R. Westbrook), 71–84, Johns Hopkins University Press, Baltimore.

van Elteren, J. T., Tennent, N. H., and Šelih, V. S., 2009, Multi-element quantification of ancient/historic glasses by laser ablation inductively coupled plasma mass spectrometry using sum normalization calibration, *Analytica Chimica Acta*, **644**(1–2), 1–9.

Feucht, E., 1999, Jewelry, in *Encyclopedia of the archaeology of ancient Egypt* (ed. K. Bard), 385–7, Routledge, Oxford.

Freestone, I. C., 1991, Looking into glass, in *Science and the past* (ed. S. Bowman), 37–56, British Museum Press, London.

Gratuze, B. (1999) 'Obsidian characterisation by laser ablation ICPMS and its applicationto prehistoric trade in the Mediterranean and the Near East'. *Journal ofArchaeological Science*, **26**, 869–91.

Henderson, J., 1998, Scientific analysis of glass and glaze from tell Brak and its archaeological implications, in *Excavations at tell Brak, volume 1: The Mitanni and old Babylonian periods* (eds. D. Oates, J. Oates, and H. McDonald), 94–8, McDonald Institute Monographs, Cambridge.

Hodgkinson, A. K., 2017, *Technology and urbanism in Late bronze age Egypt (Oxford studies in Egyptian archaeology)*, OUP Oxford, Oxford.

Ikram, S., 2015, *Death and burial in ancient Egypt*, American University in Cairo press (American University in Cairo press series), Cairo, Egypt.

Jackson, C. M., and Nicholson, P. T., 2007, in *Brilliant things for Akhenaten: The production of glass, vitreous materials and pottery at Amarna site O45.1* (ed. P. T. Nicholson), Egypt exploration society, London.

Jackson, C. M., and Nicholson, P. T., 2010, The provenance of some ingots from the Uluburun shipwreck, *Journal of Archaeological Science*, **37**(2), 295–301.

Jochum, K. P., Weis, U., Stoll, B., Kuzmin, D., Yang, Q., Raczek, I., Jacob, D. E., Stracke, A., Birbaum, K., Frick, D. A., and Günther, D., 2011, Determination of reference values for NIST SRM 610-617 glasses following ISO guidelines, *Geostandards and Geoanalytical Research*, **35**(4), 397–429.

Kaczmarczyk, A., and Hedges, R. E. M., 1983, *Ancient Egyptian faience: An analytical survey of Egyptian faience from predynastic to Roman times*, Aris and Phillips, Warminster.

Kemp, B. J., 2006, *Ancient Egypt: Anatomy of a civilization*, 2nd edn, Routledge, London.

Lilyquist, C., 2004, *The tomb of three foreign wives of Tuthmosis III*, Yale University Press, New York.

Lilyquist, C., Brill, R. H., Brill, R. H., and Wypyski, M. T., 1993, Part 2. Glass, in *Studies in ancient Egyptian glass* (eds. C. Lilyquist and R. H. Brill), 23–58, Metropolitan museum of Art, New York.

Liverani, M., 2000, The great Powers' Club, in *Amarna relations: The beginnings of international relations* (eds. R. Cohen and R. Westbrook), 15–27, The Johns Hopkins University Press, Baltimore.

Lucas, A., and Harris, J. R., 1962, *Ancient Egyptian materials and industries*, 3rd edn, Edward Arnold & Co, London.

Moran, W. L., 1992, *The Amarna letters*, The Johns Hopkins Press, Baltimore.

Nicholson, P. T., 1993, *Ancient Egyptian faience and glass*, Shire Egyptology, London.

Pusch, E., and Rehren, T., 2007, *Rubinglass für den Pharao: Hochtemperatur-Technologie in der Ramses-Stadt*, Gerstenburg, Hildesheim.

Rehren, Th (2016) 'Another order for glass – Or: How much glass does pharaoh need?'

Shaw, I., 2011, Seeking the Ramesside royal harem: New fieldwork at Medinet el-Gurob, in *Ramesside studies in honour of ken kitchen* (eds. M. Collier and S. Snape), 453–63, Rutherford Press, Bolton.

Shortland, A. J., 2005, The raw materials of early glasses: The implications of new LA-ICPMS analyses, in *Proceedings of the16th international congress of the association Internationale pour l'Histoire du Verre, London 2003* (ed. H. Cool), 1–5, AIHV, Nottingham, England.

Shortland, A. J., 2012, *Lapis lazuli from the kiln: Glass and glassmaking in the Late bronze age*, Leuven University Press, Leuven.

Shortland, A. J., and Tite, M. S., 2000, Raw materials of glass from Amarna and implications for the origins of Egyptian glass, *Archaeometry*, **42**(1), 141–53.

Shortland, A. J., Rogers, N., and Eremin, K., 2007, Trace element discriminants between Egyptian and Mesopotamian Late bronze age glasses, *Journal of Archaeological Science*, **34**(5), 781–9.

Shortland, A. J., et al., 2017, The analysis of Late bronze age glass from Nuzi and the question of the origin of glassmaking, *Archaeometry*, **60**(4), 764–83.

Smirniou, M., and Rehren, T., 2011, Direct evidence of primary glass production in Late bronze age Amarna, Egypt, *Archaeometry*, **53**(1), 58–80.

Smirniou, M., and Rehren, T., 2013, Shades of blue-cobalt–copper coloured blue glass from new kingdom Egypt and the Mycenaean world: A matter of production or colourant source? *Journal of Archaeological Science*, **40**, 4731–43.

Snape, S., 2014, *The complete cities of ancient Egypt*, Thames and Hudson Ltd, London.

Spalinger, A., 1977, A critical analysis of the 'annals' of Thutmose III (Stücke V–VI), *Journal of the American Research Center in Egypt. American Research Center in Egypt*, **14**, 41–54.

Tite, M. S., and Shortland, A. J., 2008, *Production Technology of Faience and Related Early Viteous Materials*, Oxford University School of Archaeology (Monograph (Oxford University School of Archaeology)), Oxford.

Varberg, J., et al., 2016, Mesopotamian glass from Late bronze age Egypt, Romania, Germany, and Denmark, *Journal of Archaeological Science*, **74**, 184–94.

Vicenzi, E. P., et al., 2002, Microbeam characterisation of corning archaeological reference glasses: New additions to the Smithsonian microbeam standard collection, *Journal of Research of the National Institute of Standards and Technology*, **107**, 719–27.

Wagner, B., et al., 2012, Critical assessment of the elemental composition of corning archeological reference glasses by LA-ICP-MS, *Analytical and Bioanalytical Chemistry*, **402**(4), 1667–77.

Walton, M., et al., 2009, Evidence for the trade of Mesopotamian and Egyptian glass to Mycenean Greece, *Journal of Archaeological Science*, **36**, 1496–503.

Wreszinski, W., 1923, *Atlas zur altaegyptischen Kulturgeschichte*, J.C. Hinrichs, Leipzig.

13 Appendix C Publication 2

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Ancient Biographies: Trace Element Analysis to Investigate Provenance and Transportation Mechanisms of Late Bronze Age Glass

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LA-ICPMS analysis was carried out on a scaraboid blue glass bead (Hunterian Museum Glasgow, D.1921.39) excavated from Tomb 27 in Gurob, in the Southern Fayum region of Egypt. Gurob is known to have been the site of a "harem palace" established in the reign of Tuthmosis III (1479–1425 BC). The tomb was located at the northernmost point of the New Kingdom cemetery and was undisturbed, containing the remains of seven females and two children, and was dated by the excavators to between the reigns of Amenhotep I (1525–1504 BC) and Tuthmosis III. The glass scarab was coloured by copper and trace element values of La, Cr, Ti and Zr exhibited compositional consistency with glasses from Mesopotamia, rather than from Egypt. Therefore, the glass scarab represents a rare example of Mesopotamian glass to be discovered in Egypt, in addition to being some of the earliest glass found. The finds support iconographic references in the Hall of the Annals at Karnak to the import of early glass into Egypt. The implication is that these beads represent luxury items transported into Egypt by high-ranking foreign women perhaps in connection with the Gurob harem palace.

Introduction

The theory and practice of both forensic science and archaeology are based on the same underlying principles: both disciplines use standard operating practices, developed over years of best practice, to collect, preserve and examine physical evidence to support scientific propositions, which in turn substantiate facts.

Forensic science and archaeology are correlative and often overlap, not only using similar methodologies but also employing the same analytical techniques which find practical applications in both modern crime investigations and ancient contexts. Although forensic science is concerned primarily with obtaining results for presentation in a court of law, archaeology also relies on the same incontestable recovery

Keywords: Late Bronze Age glass, LA-ICP-MS, Gurob, grave goods, trace element, evidence, forensic, Egypt, Mesopotamia

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and analysis of evidence. The results obtained from archaeological analyses are considered to establish new hypotheses or support existing theories, which can significantly alter the understanding of historical events, cultures or a specific individual.

Fundamentally, the application of forensic science and archaeology is to examine associated objects to construct a factual narrative of events. This article examines a glass scarab found in an undisturbed tomb dated to the early New Kingdom era. The trace element analysis undertaken on the scarab provides provenance data, contributing to the biography of the women in connection with a harem palace in Ancient Egypt.

The resource of grave goods

The provision of grave goods was fundamental in ancient Egyptian funerary practices, and protocol dictated that the deceased be interred with items they used in everyday life, in addition to amuletic objects that would protect the dead, allowing them to continue their existence in the afterlife (Piccione 1999, 841). Burials of the poor would include a few modest belongings, whereas the tombs of the elite would contain prestige items, such as gold jewellery and cosmetics. The quantity and quality of grave goods were directly determined by the material wealth and social importance of the individual, with most items specially made for an individual post-mortem.

When placed in the context of an extensive cemetery, patterns of social stratification can be identified and applied regarding the town, city and area. Jewellery specifically played a significant role in Egyptian life and death; ceremonial jewellery and amulets were often purposefully manufactured for the deceased once they had died; these items were placed on the body, within the linen wrappings, as well as in the tomb. It is acknowledged that only a fraction of funerary jewellery remains from the quantity initially produced in the Dynastic period (Aldred 1971, 14). In modern archaeology, grave goods are one of the most critical and common sources of evidence which allow both scientists and archaeologist to establish facts about the culture and society of a group, as well as evidence of the technological capabilities of the era.

The arid environment in Egypt has in many cases allowed both grave goods and human remains to remain remarkably preserved, however the frequent tomb robberies, both in antiquity and relatively recently, has meant that critical information about the Egyptian "mortuary cult" has been lost or destroyed. Before Egyptology and archaeology employed standard operating procedures for recording and excavating, artefacts were removed from affluent burials and distributed between sponsors and museums, with few records made of the context. These pieces when removed from their original location immediately lose vital information, specifically the contextual meaning and evidential weight; many artefacts also sustain damage due to the clandestine manner of the removal. The discovery of the tomb of Tutankhamun in 1922 was a significant landmark because, for the first time, the relatively undisturbed tomb provided a complete picture of how a king of Egypt was buried. Tutankhamun was not a notable potentate in his lifetime, yet the find revealed the variety and wealth of grave goods that were afforded to a minor ruler. The opportunity enabled

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Howard Carter to make a meticulous survey of the burial, and the grave goods in context, as well as taking a photographic record over the eight years required to clear the tomb (Reeves 2007).

The excavators of a small, but significant Egyptian site, Medinet el-Ghurob, or Gurob, in the Southern Faiyum region of Northern Egypt, also employed a more structured approach to earlier excavations in 1918–1920. The work carried out by Brunton and Engelbach was more comprehensively documented than previous investigations, comprising of a plan of the area and town, descriptions of the excavated graves and tombs, as well as lists and diagrams of the items recovered. Most of the smaller or seemingly less valuable items were removed from site and archived in museum legacy collections. In conjunction with the archaeological reports and historical data, the application of more developed analytical techniques to ostensibly less prestigious artefacts from legacy collections can provide new information about domestic technological capability, foreign migration and the transport of luxury items. In the case of Gurob, specifically by foreign women of high status who were resident at the harem palace.

Foreign women in Egypt

Diplomatic marriages were customary in ancient Egypt and Tuthmosis III (1479–1425 BC), like other Kings of Egypt, entered into several unions with foreign women of high status to cement advantageous relations and political stability with other states (Shaw 2011b; Kemp 2006, 293). A tomb discovered in 1916 by local villagers in Wadi Qurud (a remote valley southwest of the Valley of the Kings, near modern Luxor) which contained the remains of three women also provides contemporary archaeological evidence of three diplomatic marriages made by Tuthmosis III during his reign. Although the walls of the chamber were undecorated, hieroglyphs on the canopic jars and other grave goods revealed that the tomb was constructed for three "Asiatic" women of high status, who were married to Tuthmosis III (Lilyquist 2004, 7). The names of the women: "Manuwai," "Manhata" and "Maruta" were determined as being West Semitic in origin (Lilyquist 2004, 333), although the tomb and its grave goods provide the only tangible information on the archaeological record about the three women. It is not known precisely which country they were from, or if they were related. The coffins and remains of the women were in an extremely advanced stage of decomposition due to flood water entering the tomb; therefore, the bodies themselves could not be examined. The tomb was dated to approximately 1450 BC, during the joint reigns of Hatshepsut and Tuthmosis III, which predates the death of Tuthmosis III by approximately 25 years (Lilyquist 2004, 333). Although considered to be lesser wives of Tuthmosis III, the tomb contained a quantity of glass grave goods including jewellery, bracelets, headdresses and vessels. This collection of royal grave goods is an example of early New Kingdom glass jewellery related to foreign women of high status, potentially from both Egypt and Mesopotamia. The tomb contained a lotiform chalice (Accession Number: 23.9, Metropolitan Museum of Art) bearing the name of Tuthmosis III, which is recognized as stylistically Egyptian (Lilyquist and Brill 1993, 62). The goldwork was also considered to be primarily Egyptian, apart

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from the granulated gold beads (Lilyquist 2004, 185). Other pieces in the tomb, however, showed a strong influence from Mitanni design: a wig covering, comprising of gold rosettes, described as the "Great Headdress" (Metropolitan Museum of Art, New York, Accession Number: 26.8.117), is attributed to Near Eastern technique and style. The gazelle diadem (Metropolitan Museum of Art, New York, Accession Number: 26.8.99) also shows strong foreign influence (Feucht 1999, 385).

Lilyquist proposed that the most likely residence for the three foreign wives of Tuthmosis III would have been at the harem palace at Gurob. Gurob was recurrently inhabited from the pre-dynastic era (circa 3000 BC). However, it was during the 18th Dynasty that the site gained real significance, with a temple and a "harem palace" being established during the reign of Tuthmosis III (Shaw 2011b). Harems played an essential function in ancient Egypt: the palaces provided accommodation for female members of the royal family, including widows of former kings and lesser wives of the incumbent ruler (Kemp 2006, 288).

Archaeological excavations at Gurob

Flinders Petrie initiated work at Gurob between 1888–1890, but only preliminary excavations were achieved. The second season of excavations at Gurob was left in the hands of a volunteer, Hughes-Hughes while Petrie devoted his time to the nearby sites of Illahun. Hughes-Hughes had little formal archaeology training or surveying experience, and few records of the excavation were completed. A brief plan of the area was drawn when Petrie returned at the end of the second season to finalize the work (Petrie 1891, 15). Currelly and Loat undertook subsequent excavations in 1904, and a brief investigation by Ludwig Borchardt was completed in 1905. Brunton and Engelbach initiated excavations in 1920 but noted that progress was impeded by the lack of records produced by the previous excavators, particularly when opening graves that had already been cleared (Brunton and Engelbach 1927, 1).

The excavations undertaken by Brunton and Engelbach focused on the remains of the temple and surrounding cemeteries. The main cemetery contained individuals of lower or middle status and the burials were classified by era, ranging from the 0–1st dynasty to burials from the 19th dynasty (Brunton and Engelbach 1927, fig. 1). Brunton and Engelbach also surveyed 500 New Kingdom shaft tombs belonging to officials and high-status individuals; this included the tomb of Pi-Ramessu who may have been the son of Seti I.

At the northernmost point of the main cemetery site, point Q, three tombs were discovered in an isolated group; Tombs 20, 26 and 27. The three undisturbed tombs were similar in construction and design, being brick lined with arched roofs and plastered walls (Brunton and Engelbach 1927, 10.). The excavators also commented that it was likely that the three tombs belonged to a family group. Tomb 27 was the largest of the three tombs and contained the remains of seven females and two children with associated grave goods. Although larger objects were recorded in situ by Brunton and Engelbach in a scaled plan (Brunton and Engelbach 1927, plate XX), the positions of the small objects were not recorded in the publication due to the displacement caused by the accidental collapse of the roof during excavations.

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Evidence of foreign occupation at Gurob

Although there is evidence stating that large numbers of foreign women of high status were forcibly transported to Egypt following one of the first campaigns of Tuthmosis III, conclusive evidence for foreign occupation of high-ranking women specifically at Gurob during the reign of Tuthmosis III is limited. The seventh pylon from the temple at Karnak describes the capture and deportation of the wives and children of the King of Qadesh, and of other Syrian leaders, by the King of Egypt, who were given as servants (Sethe 1907, 185) and subsequently disappear from the archaeological records. Other textual evidence comes from the Gurob Papyri, discovered by Petrie between 1889 and 1890; Papyrus UCL 32795 states that foreign wives were in residence at the palace in the Ramesside era. It was proposed that foreigners were resident on the site, most likely in connection with the harem (Petrie 1891, 16; Bard 1999, 361).

In the excavation records, Petrie claimed that there were "light haired bodies" in the Gurob cemetery and noted the discovery of a custom, previously unseen in ancient Egypt: the burning and deposition of valuable possessions in pits, under the floor of a residence, none of which appeared to contain human remains. Petrie attributed this custom to foreign residents at Gurob (Petrie 1891, 16; Politi 2001, 107–111), the find being comparable with documented Mesopotamian burial customs (Van De Mieroop 1997, 83; Cohen 2005, 16).

Brunton and Engelbach did not record the presence of canopic jars in any of the three tombs at Point Q, which indicates that the individuals were not mummified, despite being wealthy enough to afford a private tomb (Brunton and Engelbach 1927, 10). Mummification during the New Kingdom era was standard practice for Egyptian burials and had been adopted by non-royal individuals who could afford it (Ikram 2015, 65). However, few canopic jars were in evidence at the site, and most of the tombs at Gurob were regarded as "shaft tombs," suggesting that a simpler burial was the prevailing practice performed at Gurob. It is the notable lack of shabtis in tombs 20, 26 and 27 which is most significant; shabtis would be expected in an Egyptian burial regardless of status (Ikram 2015, 129), and they are in evidence elsewhere in contemporaneous tombs about the site. Therefore, the evidence indicates elements associated with a foreign burial. Further studies investigating the extent of the presence of foreigners at Gurob, particularly Hittites and Mycenaeans, are currently ongoing (Hodgkinson 2017, 189). Current fieldwork also aims to establish more information about the Gurob site, including ascertaining a firm chronology of the site, undertaking further excavations of the 'industrial area' where kilns were identified, and cataloguing small finds following a series of illicit lootings in 2011–2012 (Shaw, 2011a, 2012).

The grave goods of Tomb 27, Gurob

Among the grave goods recovered from Tomb 27 were thirteen pottery vessels and a kohl pot, sixteen scaraboid beads (including one glass example, the subject of this article), cosmetic tools and strings of stone and glass beads. Using evidence from the grave goods, Brunton and Engelbach dated all three burials to the reign of Amenhotep I but did caveat the date by noting that some of the pottery was usually attributed

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Figure 1. Scarab D.1921.39 Left in transmitted light and right in reflected light. The thread can be seen at the bottom and the inscribed legs at the top. The thread hole is seen in transmitted light and the black coating in both. The grid is 5mm squares.

to the reign of Tuthmosis III, therefore giving a conservative date of 1525–1425 BC. The scarab is 15mm long by 11mm wide at its widest point; One side is domed, the other side is flat and without inscription (Figure 1). The domed side has two shallow inscribed lines representing the two front legs of the beetle, and a slight depression representing the mouth. In transmitted light, the scarab is translucent blue, with a green tinge. The drill hole can be seen running longitudinally, and was drilled from each end, meeting in the middle. Part of the original threading is present - a stiff thread, probably organic - that still survives extending 2mm from the thread hole.

A surface 'coating' was observed on the two ends of the scarab, particularly at the rear end. The coating appeared dark grey to black but was not present on the raised areas of the scarab or the flat surface on the back.

The scarab was not cleaned before the Environmental Scanning Electron Microscopy (ESEM) or the Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) analysis and care was taken to avoid patches of visible corrosion or coating for the analysis of the body area of the scarab. The purpose of the ESEM analysis was to produce elemental data from the surface of the glass body, thereby enabling the identification of any original coatings or evidence of decorative settings.

The research question required that LA-ICP-MS analysis was conducted to provide major element compositional data from below the surface of the scarab to identify the scarab as being made from a typical Late Bronze Age high magnesia, plant ash glass. LA-ICP-MS analysis also provided trace element compositional data to confirm the provenance of the scarab by identifying the concentrations of known trace elements which are incorporated during the glass making process and occur in discrete levels, thereby enabling discrimination between the regions of production (Shortland *et al.* 2007).

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Table 1. Analyses of the scarab by ESEM-EDS and LA-ICP-MS.

	ESEM-EDS			LA-ICP-MS		
Wt%						
Na_2O	5.0	4.0	5.4	13.9	12.5	14.9
MgO	4.3	4.4	4.1	2.6	2.5	2.5
Al_2O_3	2.7	2.8	2.6	0.7	0.7	0.6
SiO_2	64.3	69.7	61.9	73	75.6	73.2
P_2O_5	1.6	1.1	2	0.2	0.2	0.2
SO_3	2.7	2.2	3.1	—	—	—
Cl	2.9	2.6	3	—	—	—
AgO	3.8	1.9	4.6		see ppm	
K_2O	1.9	1.8	2.1	2.1	2.0	2.2
CaO	6.9	6.5	6.8	6.2	5.0	5.1
TiO_2	0.3	nd	0.5		see ppm	
Fe_2O_3	1.3	1.2	1.3	0.3	0.3	0.3
CuO	2.4	1.7	2.6	0.8	0.9	0.9
ppm						
Ti	—	—	—	295	285	285
Cr	—	—	—	17	16	17
Zr	—	—	—	9	8	8
Ag	—	—	—	5	10	6
Sn	—	—	—	65	68	66
La	—	—	—	1.6	1.6	1.6

ESEM and LA-ICP-MS analysis was performed on the scarab; The results of both analyses are presented in Table 1. ESEM was performed using a Hitachi SU3500N, running at 20kV with a live time of 50s. Quantification was carried out with standard EDAX software. The scarab was ablated directly in the large sample chamber of a New Wave 213 laser attached to a Thermo Series II ICP-MS. The conditions for analysis are laid out by Giannini (Giannini *et al.* 2017).

Results

The LA-ICP-MS analysis of the glass body, showed significantly higher soda with magnesia and potash, confirming that the glass is consistent with the well-documented composition of Late Bronze Age, plant-ash glass (Turner 1956a, 1956b; Henderson 1985; Lilyquist *et al.* 1993), and that the scarab was coloured with copper. The covariant trace element analysis of the scarab showed that it was relatively high in chro-

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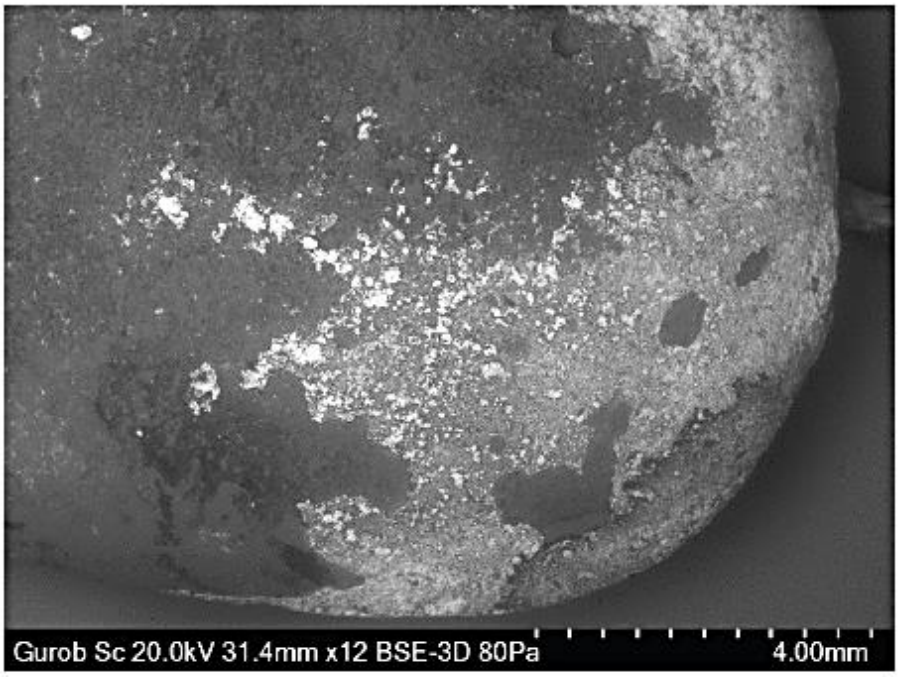
mium, with an average of 17 ppm, and lower in lanthanum, zirconium and titanium, with an average of 1.6 ppm, 8.1 ppm and 288.8 ppm respectively (Figure 3). This signature is characteristic of glass made in Mesopotamia rather than Egypt, therefore it is very likely that the scarab represents imported glass from the Near East. Conversely, glasses made in Egypt are characteristically higher in titanium, zirconium and lanthanum, but lower in chromium.

Egyptian blue glasses which are coloured with copper exhibit characteristically higher levels of lead, arsenic and tin (Smirniou *et al.* 2013) which is attributed to the use of bronze as a source of copper for the colourant (Kaczmarczyk *et al.* 1983; Free-



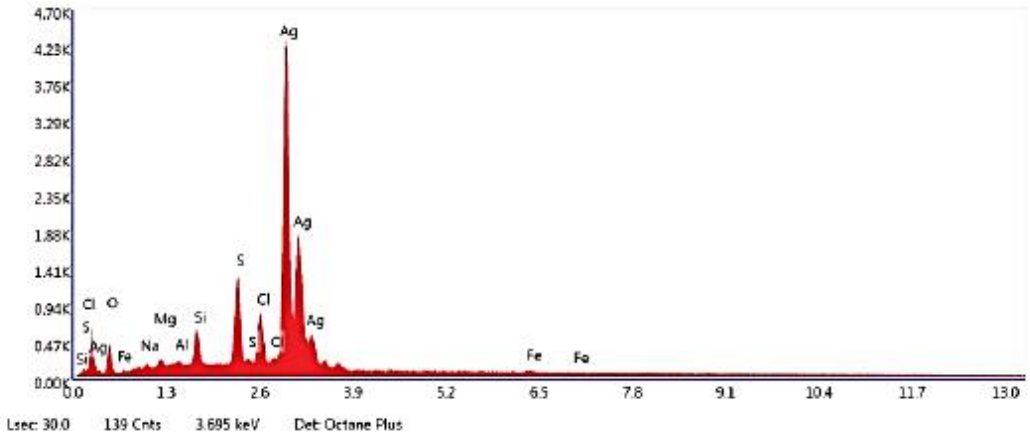


Figure 2. SEM results for the scarab. The image, in backscattered electron mode, shows a bright partial layer on the glass, which the EDS spectra confirms is silver rich.

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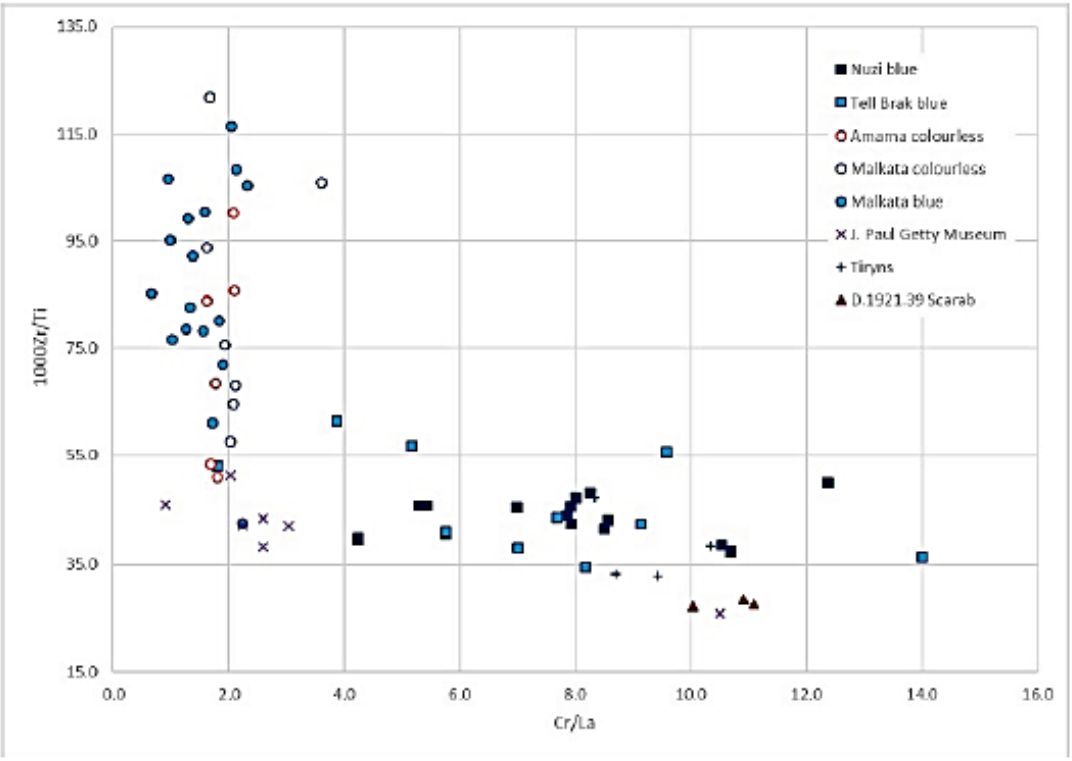

Figure 3. 1000Zr/Ti ppm against Cr/La ppm of the D.1921.39 scarab compared with Egyptian and Mesopotamian blue and colourless glasses of known origin (Shortland, Rogers and Eremin 2007; Walton *et al.*, 2009).

stone 1991, 43; Shortland *et al.* 2000). The expected level of tin present as an associated element in Egyptian copper coloured glasses is approximately 10% of the copper value. In contrast, the scarab analysed here had an average copper concentration of 7053.1 ppm, but contained only trace levels of lead, arsenic and tin; averaging 361.9 ppm, 43.9 ppm and 66.7 ppm respectively, indicating that a purer copper source was used, conforming with the characteristic colourant composition of Near Eastern glasses.

Images taken from the ESEM analysis (Figure 2) showed that the dark coating, thought initially to be a weathering layer, appeared bright in the backscatter image; subsequent analysis showed that the coating contained silver with sulphur and chlorine. It is probable that the scarab was originally mounted in silver, and that the detected sulphides and chlorides are a result of corrosion.

Compared with the LA-ICP-MS data, the ESEM analysis of the surface suggests lower soda and higher magnesia, alumina, iron and copper due to weathering of the glass. The relatively high levels of sulphur, chlorine and phosphorus on the surface can be attributed to corrosion caused by routine handling, or from contact with substances with a high salt content (Aldred 1971, 33). The high silver level detected on the surface of the glass which appears uncoated suggests that a larger surface area of the scarab was covered in silver than is evident from the visible black coating.

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Origin of glass and the transport of luxury items by high status foreign women

By employing a multi-disciplinary approach to the investigation of the scarab and combining the analysis data with the burial context, this research establishes that Mesopotamian glass was being brought into Egypt possibly from the reign of Amenhotep I by foreign women of the social elite. The results of the SEM and LA-ICP-MS analysis confirms that the scarab represents one of the first examples of Mesopotamian glass to be identified in Egypt. It is also the first confirmed Mesopotamian glass object to be presented in a typically Egyptian design. Since Near Eastern glass is generally poorly preserved when excavated domestically, well preserved examples which can be reliably dated to the early New Kingdom contribute to the knowledge of Mesopotamian glassmaking on the archaeological record, and thereby negating the preservation bias.

Further provenance analysis of glass objects from undisturbed, early New Kingdom tombs in Gurob would provide frequency data of foreign versus domestic glass from the earliest known production era, hence providing supporting evidence for the original region of glass production. Supporting evidence for the original production site of glass is supported by textual, stylistic, compositional and technological evidence, the two primary candidates for the original production of glass being Egypt and Mesopotamia. The first significant amounts of glass on the archaeological record come from Egyptian tombs, specifically from Tuthmosis III's tomb and the tombs of the three foreign wives. However, the dating of the first glass vessel is complicated owing to the reburial of Tuthmosis I by his grandson, and it cannot be confirmed if the glass vessels were part of the original grave goods of Tuthmosis I (Shortland 2012, 50). The glasses from the tomb of Tuthmosis III date to the later part of his reign, whereas the glass items from the tomb of the foreign wives contained pieces which were made approximately 25 years earlier.

The earliest datable glass was discovered in quantity at the site of Tell Atchana in the Levant; unequivocal archaeological evidence of glass making in Syro-Palestine to date is rare (Moorey 1994, 202; Shortland *et al.* 2017). Further evidence of glassmaking and glassworking sites has been proposed by the discovery of glass debris or associated tools and kilns (Pusch and Rehren 2007; Nicholson 2007), particularly in Mesopotamia (Shortland, Rogers and Eremin 2007; Shortland 2012). Archaeological evidence of primary production of glass was only recently established in Amarna, Egypt (Smirniou and Rehren 2011) and green glass rods, Mesopotamian in composition, were discovered as part of glass making debris (Varberg *et al.* 2016). As discussed, early Mesopotamian glass is generally poorly preserved, and therefore the recovery of intact pieces is rare. It is also equally rare to find Mesopotamian glass in Egypt, and vice versa (Shortland 2012, 49).

Stylistic and textual evidence has supported the supposition that glass first originated in Mesopotamia and was imported into Egypt initially as a direct result of the successful military campaigns of Tuthmosis III (Moorey 1994). The Hall of Annals in Karnak depicts in detail what is believed to show the range of tributes extracted, or given as gifts, from vassal states, which include glass vessels and what has been interpreted as coloured raw glass ingots (Wreszinski 1923, 50; Moorey 2001, 9).

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The Amarna letters, cuneiform texts dating from between the reigns of Amenhotep III to Tutankhamun, record the orders for glass which were regularly requested by the King of Egypt from vassal states, Canaan and Amurru (Moran 1992, 351–355). Evidence of other methods of transportation from Mesopotamia to Egypt has also been discussed, such as the capture or loaning of skilled workers, or artisans who were in the employ of the royal court (Moorey 2001, 11). Studies undertaken by Shortland, Walton and Jackson and Nicholson have demonstrated the efficacy of using trace element analysis to distinguish between glasses made in Egypt and Mesopotamia. Geologically relevant trace elements incorporated into the glass during manufacture can be detected using LA-ICP-MS, thereby determining the origin of production and when placed in the context of the burial, the mechanism of migration of the glass objects themselves (Shortland, Rogers and Eremin 2007; Walton *et al.* 2009; Jackson and Nicholson 2010).

Discussion

The proposed date of the tomb establishes the scarab as some of the earliest glass on the archaeological record and the first confirmed Mesopotamian glass found in Egypt. The scarab, in connection with the contextual burial at Gurob potentially establishes the importance of women in the transport of early glass from Mesopotamia to Egypt. The grave goods from Tomb 27 contained many items of glass, gold and silver jewellery, which denotes that the women were of elevated status, or in the employ of a high ranking individual; jewels were customarily given to favoured servants and officials as a sign of the owners wealth (Aldred 1971, 18).

The silver coating detected on the scarab suggests that the body may have been entirely coated in metallic silver, or more likely mounted in a bezel as other examples of this kind of setting were recovered from the site. Brunton and Engelbach also describe another scarab from Tomb 27 itself, specifically as having a silver mount. Silver was rare in Egypt, and there are few examples of it being used in the New Kingdom (Ogden 2000, 170; Aldred 1971, 33). Silver items were also found in the tomb of the Three Foreign Wives of Tuthmosis III (Lilyquist 2004, 152), which draws another contemporary similarity with the tomb at Gurob. Silver coatings on glass are unusual in Egypt, with gold coatings being more common in Egypt and Mycenae. This use of glass is unknown, but most likely lies in the amuletic value of glass, evident from written sources, which detail in length the power of stones and glass to ward off evil and heal the body (Wilkinson 1971, 7). The scarab, although characteristically Egyptian, was exported from Egypt in large quantities from the Twelfth Dynasty (1985–1795 BC) to the Levant and subsequently increased in popularity, being widely distributed from Canaan throughout the Mediterranean. In a non-Egyptian context, the scarab may not have inferred religious connotation, however the desire for foreign jewellery may have been a driving factor for the prevalent adoption (Richard 2003, 219).

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Conclusion

The data obtained by LA-ICP-MS shows that the scarab is consistent with the known composition of standard Late Bronze Age plant ash glass. The scarab is coloured with a pure source of copper which is indicative of glasses from the Near East. The trace element analysis also indicates that the scarab is consistent with glasses of Mesopotamian origin. The date of the tomb, between Amenhotep I (1525–1504 BC) and Tuthmosis III (1479–1425 BC), indicates that the scarab represents some of the earliest Mesopotamian glass to be identified in Egypt, and associated with foreign women of high status living at Gurob. The scarab also represents an early example of Mesopotamian glass being used to make amulets in the shape of a quintessentially Egyptian symbol. The ESEM analysis indicates that the scarab was coated or had been mounted in silver, which is unusual in Egyptian grave goods, suggesting a foreign influence.

About the authors

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Professor Andrew Shortland (MA, MSt, DPhil Oxon, FSA, FGS) is Professor of Archaeological Science and Director of Cranfield Forensic Institute, part of Cranfield University. He leads a multidisciplinary team that is interested in niche forensic areas such as explosives, ballistics, body recovery/identification and digital forensics. His own research concentrates on applying scientific techniques to the investigation of historical and archaeological objects, especially those with dating, provenance or authenticity questions hovering over them. He advises the British Army, Metropolitan Police and major auction houses and museums about cultural property protection and the problems of illicit antiquities.

References

Aldred, C. 1971. *Jewels of the Pharaohs: Egyptian Jewellery of the Dynastic Period*. London: Thames and Hudson.

Aruz, J. *et al.* 2008. *Beyond Babylon: Art, Trade, and Diplomacy in the Second Millennium B.C.* Metropolitan Museum of Art (Metropolitan Museum of Art).

Brunton, G., and R. Engelbach. 1927. *British School of Archaeology in Egypt and Egyptian Research Account, Twenty Fourth Year, 1918 - Gurob*. London: British School of Archaeology.

Carter, H. and J. Romer. 2008. *The Tomb of Tutankhamun*. Max Press.

Cohen, A. C. 2005. *Death Rituals, Ideology, and the Development of Early Mesopotamian Kingship: Towards a New Understanding of Iraq's Royal Cemetery of Ur*. Ancient Magic and Divination. Leiden: Brill Academic Publishers.

Feucht, E. 1999. "Jewelry." In *Encyclopedia of the Archaeology of Ancient Egypt*, edited K. Bard, 385–387. Oxford: Routledge.

Freestone, I. C. 1991. "Looking into Glass." In *Science and the Past*, edited S. Bowman, 37–56. London: British Museum Press.

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Giannini, R., I. C. Freestone and A. J. Shortland. 2017. "European cobalt sources identified in the production of Chinese famille rose porcelain." *Journal of Archaeological Science* 80: 27–36.
Grajetski, W. 2003. *Burial Customs in Ancient Egypt: Life in Death for Rich and Poor*. Bloomsbury Academic.
Henderson, J. 1985. "The raw materials of early glass production." *Oxford Journal of Archaeology* 4(3): 267–291.
Hodgkinson, A. K. 2017. *Technology and Urbanism in Late Bronze Age Egypt*. Oxford Studies In Egyptian Archaeology. Oxford: Oxford University Press.
Ikram, S. 2015. *Death and Burial in Ancient Egypt*. Cairo: American University in Cairo Press.
Jackson, C. M. and P. T. Nicholson. 2007. *Brilliant things for Akhenaten: The Production of Glass, Vitreous Materials and Pottery at Amarna Site O45.1*. Edited by P. T. Nicholson. London: Egypt Exploration Society.
———. 2010. "The provenance of some ingots from the Uluburun shipwreck." *Journal of Archaeological Science* 37(2): 295–301.
Kaczmarczyk, A. and R. E. M. Hedges. 1983. *Ancient Egyptian Faience: An Analytical Survey of Egyptian Faience from Predynastic to Roman Times*. Warminster: Aris and Phillips.
Kemp, B. J. 2006. *Ancient Egypt: Anatomy of a Civilization*. 2nd edition. London: Routledge.
Lilyquist, C. *et al.* 1993. "Part 2. Glass." In *Studies in Ancient Egyptian Glass*, edited by C. Lilyquist and R. H. Brill, 23–58. New York: Metropolitan Museum of Art.
Lilyquist, C. 2004. *The Tomb of Three Foreign Wives of Tuthmosis III*. New York: Metropolitan Museum of Art.
Lucas, A. and J. R. Harris. 1962. *Ancient Egyptian Materials and Industries*. 3rd edition. London: Edward Arnold & Co.
Moorey, P.R.S. 1994. *Ancient Mesopotamian Materials and Industries*. Oxford: Oxford University Press.
———. 2001. "The mobility of artisans and opportunities for technology transfer." In *The Social Context of Technological Change*, edited by A. J. Shortland, 39–58. Oxford: Oxbow Books.
Ogden, J. 2000. "Metals." In *Ancient Egyptian Materials and Technology*, edited by P. Nicholson and I. Shaw. Cambridge: Cambridge University Press.
Petrie, W. M. F. 1891. *Illahun, Kahun and Gurob*. London: David Nutt.
Piccione, P. A. 1999. "Tomb Furnishings." In *Encyclopedia of the Archaeology of Ancient Egypt*, edited by K. Bard, 839–841. Oxford: Routledge.
Politi, J. 2001. "Gurob – The Papyri and the 'Burnt Groups'." *Göttinger Miszellen* 182.
Pusch, E. and Th. Rehren. 2007. *Rubinglass für den Pharao: Hochtemperatur-Technologie in der Ramses-Stadt*. Hildesheim: Gerstenburg.
Reader, A. 2003. *Near Eastern Archaeology: A Reader*. Edited by S. Richard. State College: Pennsylvania State University Press.
Reeves, N. 2007. *The Complete Tutankhamun*. London: Thames and Hudson.
Sethe, K. 1907. *Urkunden der 18. Dynastie, Historisch-biographische Urkunden. Vol 3 Part 9/10 of Urkunden des aegyptischen Altertums*. Leipzig: J.C. Hinrichs.
Shaw, I. 2007. *The Royal Harim at Medinet el-Ghurob: New Fieldwork (2005-7)*. Liverpool.
———. 2011a. "New fieldwork at the Medinet el-Gurob New Kingdom settlement: Investigating a harem palace town in the Faiyum (summary of the 2009-10 seasons)." In *Achievements and Problems of Modern Archaeology: Proceedings of the International Conference*, edited G. A. Belova and S. V. Ivanov, 1–18. Moscow: Russian Academy of Sciences Center for Egyptological Studies.
———. 2011b. "Seeking the Ramesside royal harem: New fieldwork at Medinet el-Gurob." In *Ramesside Studies in Honour of Ken Kitchen*, edited M. Collier and S. Snape, 453–463. Bolton: Rutherford Press.
———. 2012. "The Gurob Harem palace project, Spring 2012." *Journal of Egyptian Archaeology* 98: 43–54.
Shortland, A. J. 2012. *Lapis Lazuli from the Kiln: Glass and Glassmaking in the Late Bronze Age*. Leuven: Leuven University Press.
Shortland, A. J., S. Kirk, K. Eremin, P. Degryse and M. Walton. 2018. "The analysis of Late Bronze Age glass from Nuzi and the question of the origin of glassmaking." *Archaeometry* 60(4): 764–783.
Shortland, A. J., N. Rogers and K. Eremin. 2007. "Trace element discriminants between Egyptian and Mesopotamian Late Bronze Age glasses." *Journal of Archaeological Science* 34(5): 781–789.
Shortland, A. J. and M. S. Tite. 2000. "Raw materials of glass from Amarna and implications for the origins of Egyptian glass." *Archaeometry* 42(1): 141–153.
Smirniou, M. and Th. Rehren. 2011. "Direct evidence of primary glass production in Late Bronze Age Amarna, Egypt." *Archaeometry* 53(1): 58–80.

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Smirniou, M. and Th. Rehren. 2013. "Shades of blue—cobalt-copper coloured blue glass from New Kingdom Egypt and the Mycenaean world: A matter of production or colourant source?" *Journal of Archaeological Science* 40: 4731–4743.

Turner, W.E.S. 1956a. "Studies in ancient glasses and glass making processes. Part III. The chronology of glass making constituents." *Journal of the Society of Glass Technology* 40: 39–52.

———. 1956b. "Studies in ancient glasses and glass making processes. Part IV. The chemical composition of ancient glasses." *Journal of the Society of Glass Technology* 40: 162–184.

Van De Mieroop, M. 1997. *The Ancient Mesopotamian City*. Oxford: Oxford University Press.

Varberg, J. *et al.* 2016. "Mesopotamian glass from Late Bronze Age Egypt, Romania, Germany, and Denmark." *Journal of Archaeological Science* 74: 184–194.

Walton, M. *et al.* 2009. "Evidence for the trade of Mesopotamian and Egyptian glass to Mycenean Greece." *Journal of Archaeological Science* 36: 1496–1503.

Wilkinson, A. 1971. *Ancient Egyptian Jewellery*. London: Methuen & Co.

Wreszinski, W. 1923. *Atlas zur altaegyptischen Kulturgeschichte*. Leipzig: J. C. Hinrichs.

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ORIGINAL ARTICLE

The investigation and provenance of glass vessel fragments attributed to the Tomb of Amenhotep II, KV35, Valley of the Kings

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Abstract

Four polychrome glass fragments, excavated from tomb KV35 in the Valley of the Kings, attributed to Amenhotep II, were analysed to further investigate the composition and provenance of early Late Bronze Age (LBA) glasses. An additional fragment, EA64163, cited by the British Museum as being stylistically analogous to the fragments from KV35, although with a findspot simply recorded as 'Thebes', was also analysed. Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analysis was used to analyse multiple colours on the fragments to determine the major element composition, the colouring strategies and to establish provenance using trace element analysis. The resulting data obtained were compared with four polychrome fragments of standard LBA Egyptian composition, excavated from the palace of Amenhotep III at Malkata, previously analysed by scanning electron microscopy with wavelength dispersive spectroscopy (SEM-WDS). Analysis showed that the glasses excavated from KV35 are standard LBA glass of Egyptian composition and were most likely produced in Egypt during the 18th Dynasty. The fragment EA64163 is a low magnesia, low potash glass comparable with Iron Age composition and therefore should be reconsidered as a later glass. The analysis of glasses excavated from a reliable, early Egyptian context supports the proposition that glass technology for multiple colours was established in Egypt at least as early as 1400 BCE.

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KEYWORDS
Amenhotep II, Amenhotep III, ancient Egypt, glass, Iron Age, KV35, LA-ICP-MS, Late Bronze Age, Malkata, provenance, tomb, vessel

INTRODUCTION

The first man-made glass appears in the archaeological record in quantity in the Late Bronze Age (LBA) of Egypt and the Near East. There are early, sporadic finds of glass stretching back to the third millennium BCE (Beck, 1934; Peltenburg, 1987; Moorey, 1994, 190–192), but it is 15th-century contexts where the first glass in any quantity is found. Most commentators of the last 30 or so years have placed the source of the glass-making innovation in the Near East, perhaps in Northern Syria (Lilyquist, Brill, & Wypyski, 1993; Moorey, 1994; Nicholson, 1993; Shortland et al., 2017). However, recent re-examination of finds and their contexts have suggested that this is by no means as clear as first thought and proposed that it is difficult to determine whether Egypt or the Near East was the source of the first glass (Shortland et al., 2017). Certainly, there are good textual and iconographic sources that show that glass was a prized commodity in the LBA, with a value similar to a precious stone, at least in the first century of its production (Nicholson et al., 1997; Oppenheim, 1973). As such, glass was used for several purposes, including beads, inlays and amulets. However, the most significant object produced in glass was the core-formed glass vessel, manufactured by hot-working the glass around a clay/dung core (Nicholson & Henderson, 2000, 203). The most common body colour was blue, ranging from light to very dark blue hues, and vessels were often decorated with contrasting colours including yellow and white. Glass in green, red, brown, colourless and black were also used, but less often in vessels (Nolte, 1968). It is also often the case that vessels that appear black are in fact very dark purple, blue or brown.

Because of its perceived high value and portability as beads, jewellery and ingots, glass was therefore part of a wide-ranging exchange network, with evidence that Egyptian and Near Eastern glass was being transported as far as Mycenae (Walton et al., 2009) and later as far as Northern Europe (Varberg et al., 2015, 2016). The Ulu Burun shipwreck found off the southern coast of Turkey and dating to *c.*1300 BCE contained a large consignment of glass ingots, some or all of which originated in Egypt (Jackson & Nicholson, 2010; Nicholson et al., 1997; Pulak, 2001). Glass is therefore an interesting material to provenance, being of markedly high value and apparently widely traded.

Glass discovered in Egypt tends to be almost always found in royal tombs in this earliest period, with the first regular finds of glass to be recovered in palaces, temples, workshops or other urban settings not common until the 14th century BCE. Early glass objects excavated in Egypt, such as beads, are seen from the Tomb of Queen Ahhotep, mother of Ahmose (1550–1525 BCE), and from contemporary tombs in Qau (Lilyquist, Brill, Wypyski, & Koestler, 1993, 23). Blue transparent beads and a glass scarab were excavated from a later tomb from the site of Gurob, the location of the Harem palace established during the reign of Tuthmosis III (1479–1425 BCE), although these were items were determined as being Mesopotamian in origin (Kemp et al., 2017, 2019). It is during the reign of Tuthmosis III where glass vessels appear in quantity and from multiple sources, such as the tomb of the three foreign wives and the Tomb of Tuthmosis III, KV34 (Lilyquist, Brill, Wypyski, & Koestler, 1993, 25–26). *Die Glassgefässe im alten Ägypten* describes and dates (where possible) the largely intact early glass vessels excavated or acquired in Egypt, thereby establishing a timeline (Nolte, 1968).

We are fortunate to have an excellent chronology for the Egyptian kings, which means many of these tombs can be dated to a particular decade, or with even greater accuracy. In the

Near East, the pattern is more mixed, and the dating can be problematic, in part due to the less expedient preservation conditions. Work by Dardeniz extends the glass-making regions to Northern Syria, specifically Tell Atchana, ancient Alalakh, proposing that production in this area may pre-date workshops at Amarna (Dardeniz, 2018). Further evidence is pending to support an early glass-making industry, specifically a detailed chronology for the site and the dating of pyrotechnic installations at Tell Atchana. It is therefore to Egypt that one first looks to in order to investigate the beginning of glass production.

This paper analyses glass attributed to KV35, the Tomb of Amenhotep II (1427–1401 BCE) with the aim of demonstrating whether this early glass might have been made in an Egyptian workshop or imported from the Near East.

Dating glass

Attempts to date early glass objects stylistically have been problematic. As mentioned above, there seems a preference for many early glass vessels in blue, but certainly not all blue glasses are among the first vessels produced. A safer method of dating is to resort to the classic archaeological procedure of context. For example, it is very likely that glass recovered from the Valley of the Kings tombs of Tuthmosis III (KV34) and Amenhotep II (KV35) date to those kings' reigns. A second way of dating the glass is where the glass object has a king's name inscribed upon it. Egyptian kings of this period have distinguishing names which are represented in a 'cartouche'. It is likely that an object that bears a king's cartouche dates to his reign, but some kings were the subject of cults after their death, so it is possible, if unlikely, that they could be later.

This represents the simple pattern for dating an object, but it should be noted that it can be more complex than this. Good examples are two small, turquoise-coloured glass persea fruits which were found by Howard Carter in KV62, the Tomb of Tutankhamen (Lilyquist, Brill, Wypyski, & Koestler, 1993, 25–26). This tomb dates to 1327 BCE, plus or minus a year or two, but one fruit bears the cartouche of Tuthmosis III, who had been dead for nearly a century at this point. It is likely that this is a curated object, saved from his reign, but Tuthmosis III was the subject of a significant cult, so it could have been produced later. It is certainly no later than the completion of Tutankhamen's tomb. It is therefore safer to regard cartouches as a *terminus post quem*, whereas a secure tomb is a *terminus ante quem*.

Provenancing glass

Glassworking sites might reveal themselves by having distinctive object types or producing distinctive styles of decoration, although ultimately this has been exceedingly difficult to prove with LBA sites (; Rehren, 2000; Rehren et al. 2001; Jackson, 2005). However, glass-making sites can only be determined by something distinctive in the composition of the glass they produce. Much work has been devoted to analysing LBA glass to determine where it was made, and trace element analysis, therefore, has proved useful for provenance studies.

The production of glass objects can be divided into two distinct stages: glass-*making* and glass*working*. Glass-making is the production of glass from its raw materials, in this period quartz pebbles, plant ash, colorant(s) and perhaps a lime source (Brill, 1999). It requires a furnace capable of temperatures > 1000°C to produce. LBA glasses discovered in Egypt, the Near East and ancient Greece have a silica content of 62–65%, a high soda content of between 15% and 20%, and elevated levels of magnesia, approximately 2–5%, with a similar potash content of between 2% and 4% and a lime content of 4% (Lilyquist, Brill, Wypyski, & Koestler, 1993; Sayre & Smith, 1961; Shortland & Eremin, 2006). However, trace element

analysis of LBA glasses has shown a distinct compositional difference between LBA glass found in the Near East and Egypt. The first element shown to distinguish between these two groups was Ti, which is high in Egyptian glasses, but relatively low in Near Eastern glasses (Shortland et al., 2007). Further analysis of a full suite of trace elements showed that almost a clear distinction could be drawn between glasses of the Near East and Egypt by plotting covariates of Ti, Cr, La and Zr. This method was successfully used in the provenancing of Mycenaean, Ulu Burun and Levantine glasses (Jackson & Nicholson, 2010; Kemp et al., 2020; Shortland et al., 2007; Walton et al., 2009).

Previous analysis of Amenhotep II glass

The most recent analysis of glass thought to be from the reign of Amenhotep II is by Nicholson and Jackson (2013)). The analysis was of a single sherd of a glass vessel now in the Swansea Museum (Swansea 959.3), believed to have originally been part of CG 24804, a particularly fine vessel which was later reconstructed in Cairo Museum (Nolte, 1968, 53; Stern & Schlick-Nolte, 1994, 25). It is 43 mm across and features what is quite clearly part of the two cartouches of Amenhotep II. However, the object was recorded as being originally found in KV55, a hotly debated tomb in the Valley of the Kings with connections to the Amarna Royal family (Reeves & Wilkinson, 2008, 120–121; Saleem & Hawass, 2016, 119). Although curatorial history of the sherd is equivocal, it is likely that the piece dates from the reign of Amenhotep II and was originally part of his burial equipment (Nicholson & Jackson, 2013). Nicholson and Jackson carried out trace element analysis using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) on the piece and compared the trace element plots with Shortland et al. (2007). They concluded that it had much in common with the Egyptian composition with relatively high La and Ti, but in the Cr/La plot the concentrations of the amber and white samples from the Swansea glass sat slightly outside the general compositional group for Egypt.

The present paper provides additional analyses of early glass material on a range of colours from nine fragments attributed to tomb KV35 and the palace at Malkata (Newberry 1900, 1902; de Tytus, 1903). The Malkata material is of standard Egyptian LBA glass composition and was analysed as a control to observe whether a small offset from the Egyptian field was directly comparable or reflected slightly different analytical settings in two different LA-ICP-MS systems. By analysing the Malkata controls in the same machine and at the same time as the KV35 unknown, small differences in minor and trace elements, indicative of composition, can be observed and compared, as well as negating any potential detection drift.

METHODOLOGY

The objects analysed in this paper were originally sampled for Shortland *et al.* (2006) and analysed by scanning electron microscopy with wavelength dispersive spectroscopy (SEM-WDS). The same SEM blocks and samples were used here (Table 1). A total of nine objects were selected, all glass vessel fragments. Four are securely provenanced to KV35, the Tomb of Amenophis II, by the British Museum, which describes the provenance as 'probable' (Cooney, 1976, 52, 143); however, it is known that KV35 was later opened and used as a cache for royal mummies (Baikie, 1932). The provenance of fragment EA64163 is given as 'probably Thebes' by the British Museum, and is described as having 'a chequer-board pattern closely following those found in fused bowls from the tomb of Amenhotep II' (Cooney, 1976, 53), being stylistically comparable with the bowl sherd MMA 26.7.1164 (The Metropolitan Museum of

TABLE 1 Objects analysed by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), described in the catalogue of the Egyptian antiquities of the British Museum (Cooney, 1976)

Museum no.	Colour	Findspot	Origin
EA64123	Blue Yellow	KV35	Fragment from the neck and shoulder of a globular, amphora vessel in translucent dark blue glass. On the neck and shoulder are decoration in turquoise blue, yellow and white
EA64124	Purple Yellow	KV35	Fragment of a vessel with opaque deep violet body, decorated with wide threads in yellow, white, light green and turquoise blue in a marbleized pattern
EA64125	Blue	KV35	Fragment from the shoulder and neck of a vessel in opaque dark blue glass. There are remains of four impressed units in the form of cornflowers or rosettes represented in the top view
EA59244	Blue White	KV35	Fragment of a jar with a hemispherical body, dark blue ground, decorations of chevrons on the neck and clustered festoons on the body, both combining opaque white and yellow
EA64163	Red White Blue	Thebes (?), stylistically related to fragments in KV35	Unusual fragment with a chequer-board pattern closely following those found in moulded, fused bowls from the Tomb of Amenhotep II. Impressed on both the exterior and interior surfaces are registers of opaque red squares and translucent dark blue squares, alternating. The squares are arranged so that a red and a blue square touch only at their corners
EA64149	Purple Yellow	Malkata palace	Fragment from the body of a vessel in deep violet glass decorated with clustered festoons in white, yellow and light blue. Directly over these decorations vertical canes were impressed, three of which survive
EA64151	Purple Yellow	Malkata palace	Fragment of the lower neck and body of a vessel in opaque amethyst glass, with decorations in yellow, opaque white and turquoise blue, probably simple festoons
EA64154	Black Turquoise White	Malkata palace	Fragment of a shallow, opaque mosaic glass bowl, matt surface. Assembled from several layers of small pieces of brick red, turquoise blue, opaque white, yellow and black glass. The bowl was formed by moulding either in an open mould or by press-moulding
EA64155	Red Blue Turquoise	Malkata palace	Fragment of a shallow mosaic glass bowl composed of small pieces of light and dark blue, red, and white glass

Art, New York) from KV35 (Lilyquist, Brill, Wypyski, & Koestler, 1993, 29, 35). Three of the fragments attributed to KV35 can be viewed on the British Museum website (https://www.britishmuseum.org/collection/object/Y_EA64163); EA64125 is shown a top right, EA64124 at middle right and EA64163 at bottom right (also see Table 1 for descriptions). Four other vessels from the Palace of Malkata dating to Amenhotep III (1390–1352 BCE) were also analysed as controls—by all expectations these should be Egyptian in composition.

The samples were subjected to LA-ICP-MS analysis at The Natural History Museum, London. The instruments used were an Agilent 7700 quadrupole inductively coupled plasma mass spectrometer (ICP-Q-MS) coupled to an ESI NWR193 with laser-type ArF excimer with an ablation spot of 50 μm, as detailed in Table 2.

TABLE 2 Set-up conditions for the laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS)

Laser ablation system	
Instrument	ESI NWR193
Laser type	ArF excimer
Wavelength	193 nm
Pulse duration	< 4 ns
Repetition rate	10 Hz
Analysis type	Spot
Spot diameter	50 μm
Fluence	3.5 J/cm^2
Carrier gas (He)	500 mL/min
Primary reference material	NIST 612
Secondary reference material(s)	NIST 610, corning A, corning B
Mass spectrometer	
Instrument	Agilent 7700 ICP-Q-MS
Plasma gas flow (Ar)	1.1 L/min
Individual element dwell time	0.01 s
Analysis duration	60s
Blank duration	30s

Each sample was analysed at five different spots, avoiding any obvious weathered areas. Corning A standard was run throughout the LA-ICP-MS analysis to check for accuracy and drift. The results on Corning A secondary standards show good agreement for the most elements, with the standards averaging < 10% error on the accuracy. The results were consistent with Kemp et al. (2020)).

RESULTS

The results, presented in Tables 3 and 4, show analyses of the glasses excavated from KV35 and fragment EA64163, which has been stylistically ascribed to KV35, and glasses from the palace at Malkata.

DISCUSSION

High magnesia/high potash (HMHK) glasses

All samples apart from fragment EA64163 are consistent with LBA plant ash glasses, which are characterized by a HMHK content.

Malkata

The glass samples analysed that were excavated from the palace at Malkata are all compositionally standard LBA glasses of Egyptian composition, which have been widely published. These can therefore be used as a reference to comparatively discuss the samples attributed to KV35.

TABLE 3 Average results for the laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analyses showing major and minor elements of the samples from KV35, the palace at Malkata and the fragment stylistically attributed to KV35, findspot cited by the British Museum as 'Thebes' (wt%)

Sample no.	Colour	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	MnO	FeO	CoO	CuO	Sb_2O_3	PbO
KV35														
EA64123	Blue	17.5	3.7	1.8	66.1	0.10	0.72	8.9	0.24	0.12	0.11	0.03	0.19	0.04
EA64125	Blue	19.5	3.9	2.9	61.6	0.22	1.24	7.5	0.29	0.18	0.25	0.21	1.5	0.02
EA59244	Blue	19.9	5.1	2.8	61.2	0.17	1.09	8.4	0.25	0.24	0.16	0.03	0.08	0.02
EA64124	Purple	19.4	3.7	0.74	65.4	0.23	2.61	6.9	0.61	0.15	0.01	0.01	0.01	0.00
EA59244	White	18.9	4.9	0.74	60.4	0.15	1.89	9.9	0.02	0.15	0.00	0.01	2.6	0.04
EA64123	Yellow	16.3	3.2	0.65	59.1	0.25	1.85	7.7	0.10	0.17	0.00	0.11	1.4	8.4
EA64124	Yellow	18.5	5.5	0.59	60.3	0.14	2.30	9.7	0.02	0.10	0.00	0.07	2.7	0.04
Malkata palace														
EA64154	Black	15.6	3.7	0.79	65.9	0.17	2.15	7.5	1.95	0.18	0.02	1.6	0.02	0.09
EA64155	Blue	19.5	4.8	1.9	62.1	0.22	1.77	6.8	0.19	0.15	0.20	0.31	1.5	0.01
EA64149	Purple	20.3	3.7	0.73	64.5	0.24	2.71	6.8	0.61	0.16	0.01	0.06	0.01	0.00
EA64151	Purple	17.1	3.3	0.40	66.8	0.21	3.07	8.0	0.55	0.30	0.01	0.06	0.01	0.00
EA64155	Red	14.7	3.8	0.96	53.1	0.22	2.14	8.8	0.02	0.25	0.02	13.1	2.1	0.14
EA64154	Turquoise	17.6	5.2	0.65	60.2	0.17	2.41	7.8	0.02	0.15	0.01	2.4	2.9	0.05
EA64155	Turquoise	19.7	4.7	0.48	59.8	0.25	2.45	7.0	0.03	0.13	0.01	2.9	2.3	0.03
EA64154	White	19.1	4.7	0.71	62.5	0.22	2.30	7.6	0.02	0.15	0.00	0.07	2.5	0.04
EA64149	Yellow	14.9	4.3	0.73	52.6	0.21	2.43	7.5	0.22	0.30	0.00	0.06	4.0	11.5
EA64151	Yellow	18.0	3.2	0.38	67.6	0.18	3.05	6.2	0.46	0.30	0.01	0.03	0.02	0.41
Fragment stylistically related to KV35, findspot cited by the British Museum as 'Thebes'														
EA64163	Blue	17.9	0.98	2.6	67.9	0.10	1.03	6.2	0.81	0.78	0.10	0.47	0.48	0.24
EA64163	Red	13.7	1.9	3.1	58.7	0.73	1.90	10.2	0.74	0.60	0.02	2.8	0.40	4.4
EA64163	White	15.4	0.79	2.2	61.7	0.14	1.12	5.8	0.85	0.25	0.02	0.04	6.8	4.6

TABLE 4 Average results for the laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analyses (ppm)

Sample no.	Colour	Li	Be	B	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Zr	Nb	Ag	Sn	Sb	Cs	Ba	La	Ce	Au	Pb	Bi	Th	U
KV35																														
EA64823	Blue	5.9	0.09	131.8	489	5.8	4.3	1884	933	888	466	251	650	5.3	4.0	670	45.6	1.4	0.34	12	1565	0.06	53.6	2.7	6.3	0.03	338	0.03	0.64	0.40
EA64825	Blue	10.2	0.00	93.8	68	11.2	7.6	2220	1432	1931	974	1711	2477	19.4	6.4	505	48.8	1.9	0.25	42	12,562	0.09	57.3	3.9	10.5	0.12	18.5	0.01	1.00	0.69
EA59244	Blue	8.3	0.23	141.3	791	11.3	5.0	1899	1856	1269	848	207	1840	5.2	7.8	560	47.2	2.3	0.17	9.4	703	0.12	66.6	4.8	11.8	0.02	14.8	0.05	1.23	0.71
EA64824	Purple	9.6	0.18	70.4	588	13.8	5.1	4717	1131	4.6	4.5	110	25.3	0.9	9.8	738	58.9	1.7	0.16	1.1	6.8	0.11	75.2	3.4	6.6	0.00	1.7	0.05	0.84	0.52
EA59244	White	7.8	0.08	69.7	463	7.5	5.3	164	1181	3.9	8.1	101	26.4	55.0	11.7	985	42.1	1.5	0.29	1.1	21,970	0.21	40.0	3.0	6.0	0.00	41.0	0.04	0.77	0.31
EA64823	Yellow	6.3	0.11	79.8	444	6.5	10.4	795	1349	3.1	6.3	840	3615	23.6	11.1	1294	37.4	1.3	1.7	4.2	11,630	0.12	99.8	2.6	4.7	0.04	78,370	3.1	0.57	0.57
EA64824	Yellow	5.5	0.00	64.5	345	6.0	4.1	178	788	1.7	6.0	57.0	22.9	66.6	10.7	1127	32.6	1.2	0.21	0.85	22,153	0.28	35.5	2.2	4.2	0.06	35.9	0.04	0.54	0.22
Malkata palace																														
EA64854	Black	6.1	0.14	49.0	656	34.6	7.7	15,095	3406	11.8	17.9	12,833	38.9	39.3	9.7	651	58.5	1.7	0.68	705	182	0.12	185	3.6	6.4	0.17	79.8	0.26	0.62	1.02
EA64855	Blue	9.4	0.09	79.2	421	6.2	4.2	1443	1191	1592	892	2476	1296	12	6.2	563	31.2	1.2	1.4	2.0	12,386	0.07	41.7	2.2	5.4	0.04	13.4	0.02	0.52	0.18
EA64849	Purple	7.7	0.03	73.1	583	13.9	5.1	4747	1229	4.7	4.4	49.9	25.7	0.9	8.8	727	63.4	1.7	0.32	1.1	7.5	0.11	77.3	3.5	6.9	0.04	1.63	0.05	0.89	0.54
EA64851	Purple	9.2	0.10	56.7	291	5.9	4.1	4242	2367	4.7	5.6	47.3	98.9	1.3	13.2	1372	36.9	0.88	0.03	0.94	11.5	0.14	45.8	1.9	3.7	0.00	3.94	0.00	0.47	0.56
EA64855	Red	7.8	0.13	59.0	766	12.0	9.1	176	1963	18.0	89.2	104,726	32.6	530	9.4	828	51.9	1.9	7.9	1993	17,637	0.12	51.5	3.4	6.6	0.29	1279	0.78	0.78	0.32
EA64854	Turquoise	7.2	0.00	77.5	419	6.4	3.2	129	1145	4.4	14.8	19,371	24.5	130	12.7	966	37.8	1.3	0.78	1652	24,074	0.14	32.8	2.5	5.0	0.33	44.3	0.14	0.62	0.22
EA64855	Turquoise	9.6	0.06	76.3	370	5.7	3.5	243	1025	6.6	16.3	22,927	25.7	111	8.8	579	29.2	1.0	1.8	571	19,405	0.09	34.6	1.9	3.8	0.35	28.9	0.09	0.46	0.17
EA64854	White	6.8	0.07	73.7	419	6.4	4.9	141	1160	2.9	7.3	56.4	18.2	57.4	10.0	590	29.8	1.5	1.1	1.6	21,179	0.15	43.9	3.0	5.8	0.04	38.5	0.04	0.66	0.20
EA64849	Yellow	5.7	0.08	106	441	9.2	14.1	1687	2328	3.7	19.1	495	7581	49.1	11.2	1140	40.0	1.3	1.5	3.7	33,459	0.17	251	3.1	5.7	0.07	107,019	0.95	0.72	0.85
EA64851	Yellow	6.6	0.28	49.9	277	5.8	3.9	3577	2158	4.4	5.1	245	82.3	1.0	11.0	969	33.1	0.87	0.67	0.96	13.0	0.11	35.1	1.6	3.4	0.06	3818	0.01	0.44	0.46
Pregment stylistically related to KV35, findspot cited by the British Museum as 'Thebes'																														
EA64863	Blue	7.0	0.06	210	1188	22.7	26.3	6299	6028	754	31.0	3793	85.8	7.1	7.1	431	99.3	3.2	3.6	92	3994	0.11	218	7.7	14.7	0.04	2210	0.2	1.7	1.4
EA64863	Red	6.5	0.20	134	1764	30.0	29.9	5718	4700	178	25.2	22,321	148	101	10.7	667	145	5.3	7.7	2933	3325	0.20	230	10.3	20.3	0.06	40,387	3.8	2.4	1.4
EA64863	White	5.9	0.21	132	950	19.6	22.9	6552	1913	15.1	13.7	280	42.9	22.9	6.4	417	88.4	2.8	5.0	396	56,556	0.08	221	7.3	13.3	0.24	42,726	3.0	1.6	1.3

The black glass in EA64154 contains the highest concentration of Mn in the study group (2.0% MnO) with elevated levels of Cu (1.6% CuO), therefore making this glass optically very deep purple-blue to achieve a black hue.

The blue glass from EA64155 is coloured with both Co and Cu at 0.2% and 0.3%, respectively, and opacified with 1.5% of an Sb opacifier, most likely Ca antimonate (Shortland, 2002). EA64155 exhibits the elevated levels of Al, Mn, Ni and Zn and low concentrations of potash, which is the expected composition pattern for LBA Egyptian glass coloured with Co (Shortland et al., 2007; Shortland & Eremin, 2006).

The Malkata turquoise glasses, EA64154 and EA64155, are similar in major element composition and colouring strategy; these glasses are coloured with a relatively higher concentration of Cu (2.4% and 2.9% CuO, respectively) and are opacified with an Sb constituent (containing 2.9% and 2.3% Sb_2O_3, respectively), thereby representing typical Cu coloured, opacified, turquoise glasses of Egyptian composition.

The two purple glasses, EA64149 and EA64151, are both coloured with a concentration of 0.6% Mn. Although there is a slight variation in the major elements, both glasses exhibit standard LBA Egyptian purple glass composition.

The red glass, EA64155, exhibits noticeably lower levels of silica and soda compared with the other coloured glasses: 53.1% (SiO_2) and 14.7% (Na_2O), respectively. However, this corresponds with the WDS analysis findings in Shortland and Eremin (2006) of LBA Egyptian red glasses. The glass is coloured with Cu and represents the highest concentration of the study group (13.1% CuO). An Sb opacifier (2.11% Sb_2O_3) with some trace concentrations of Pb (0.1% PbO) was also detected.

The white glass, EA64154, contains excess Sb (2.5% Sb_2O_3), suggesting that this glass is opacified by Ca antimonate (Shortland, 2002), representing a typical LBA Egyptian white glass composition (Shortland & Eremin, 2006). The two yellow glasses show variation between their respective major element compositions and colouring strategies: EA64149 contains high levels of Pb (11.5% PbO), whereas EA64151 contains comparatively low concentrations of Pb (0.4% PbO); however, both are comparable with known compositions of LBA Egyptian yellow glasses (Shortland & Eremin, 2006).

KV35

The glasses excavated from KV35 are typical HMHK plant ash glasses comparable with the glasses analysed from Malkata and standard Egyptian LBA glasses produced in the 18th Dynasty (Shortland & Eremin, 2006), in both major elemental composition and colouring strategy. The two blue glasses coloured only with Co, EA64123 and EA59244, show the expected elevated levels of Al, Mn, Ni and Zn and relatively low concentrations of potash which are characteristic of LBA Egyptian Co coloured glass. The composition of the blue Co-Cu coloured glass from KV35, EA64125, is comparable with that of Malkata, EA64155, specifically with regards to the colouring strategy, which is almost identical, containing similar concentrations of Co, Cu and Sb.

The purple glass, EA64124, is coloured with Mn and compares well with the purple glasses from Malkata, particularly EA64149, which is almost identical to the KV35 purple glass.

The white glass from KV35, EA59244, is almost compositionally identical to EA64154 from the palace at Malkata; the lime content is the only major difference, which is 9.9% in the KV35 white glass and 7.6% in the Malkata glass. As mentioned above, the two yellow glasses from Malkata exhibit notably different compositions; the two yellow glasses from KV35 also show some variation between the two compositions. EA64123 from KV35, comparable with EA64149, contains Pb (8.4% PbO) and Sb (1.4% Sb_2O_3), therefore likely coloured yellow by Pb

antimonate (Shortland, 2002). However, Pb was not detected in the yellow glass in EA64124 but exhibits elevated levels of Sb (2.65% Sb_2O_3). The two KV35 glasses exhibit decreased levels of Mn compared with the two yellow glasses from Malkata.

EA64163, a low magnesia/low potash glass

Across the three glasses, EA64163 contains an average magnesia content of 1.2% MgO and an average potash content of 1.4% K_2O, which is notably different compared with the compositions of the HMHK glasses from Malkata and KV35. Natron glasses, using a soda-mineral flux, are characteristically low in magnesia and potash, each containing concentrations < 1.5%. Therefore, the major element composition of the glasses constituting EA64163 are comparable with natron glasses commonly produced in the Iron Age (Sayre & Smith, 1961; Freestone, 1991, 39–40).

The blue, red and white glasses comprising the EA64163 fragment exhibit over double the concentrations of the major elements Al, Mn and Fe in addition to containing over double the average concentrations of the geologically relevant trace elements Ti, Cr, La and Zr compared with those from the HMHK group. This elevated concentration is also seen across the rare earth and transition metal elements analysed. The Co-Cu coloured blue glass in EA64163 exhibits elevated levels of Mn, Fe and Pb compared with the KV35 and Malkata blue glass samples in the study group. The Co colourant used to colour the EA64163 blue glass is compositionally consistent with Co sources used to colour later

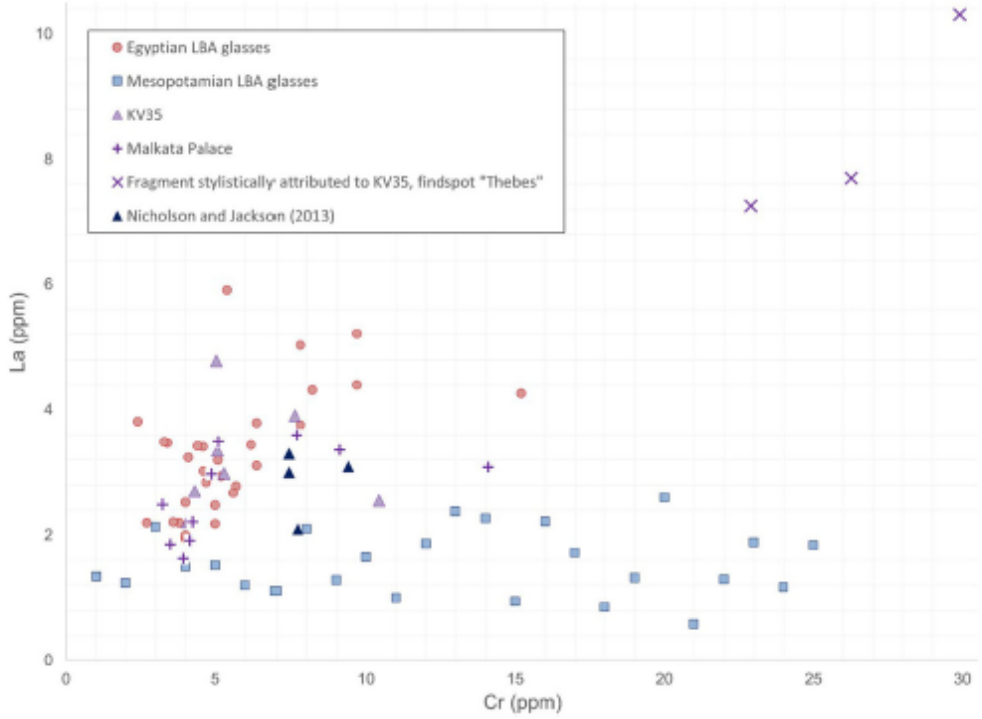

FIGURE 1 Covariant plot of La with Cr comparing the glasses from KV35, the palace at Malkata, the fragment attributed to KV35 (the findspot described by the British Museum as 'Thebes') and the Swansea fragment (Nicholson & Jackson, 2013). Samples are plotted against the Egyptian and Mesopotamian glasses of known origin (Shortland et al., 2007)

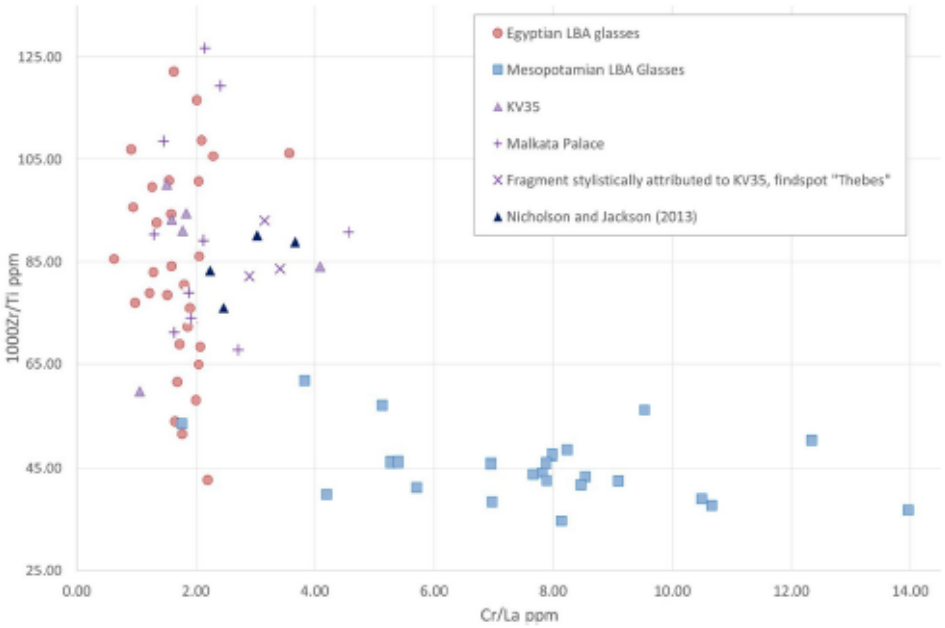

FIGURE 2 Covariant plot of 1000Zr/Ti with Cr/La comparing the glasses from KV35, the palace at Malkata, the fragment attributed to KV35 (findspot described by the British Museum as 'Thebes') and the Swansea fragment (Nicholson & Jackson, 2013). Samples are plotted against the Egyptian and Mesopotamian glasses of known origin (Shortland et al., 2007)

glasses produced in the 19th and 20th Dynasties (Abe et al., 2012). This is significantly different to the Zn-rich Egyptian Co used to colour the HMHK glasses, and is likely from an Iranian source, characterized by low levels of Ni and Zn, with an elevated concentration of Mn (Kaczmarczyk, 1986; Mass et al., 2002).

The red glass in EA64163 exhibits notably low levels of silica and a low soda concentration, containing 58.7% and 13.7%, respectively, comparable with the silica and Na levels observed in the red glass EA64155 from Malkata. However, as mentioned previously, the EA64163 glass contains significantly elevated levels of Al (3.1% Al_2O_3), Mn (0.7% MnO), Fe (0.6% FeO), Cu (2.8% CuO) and Pb (4.4% PbO). As discussed in the HMHK section, the composition of red glasses is known to be variable; however, the red glass from EA64163 is distinctly different from the standard LBA Egyptian glass and that of EA64155 from Malkata in both major element and colourant composition.

The white glass in EA64163 has the highest lime concentration in the study at 10.2% and contains the highest concentration of Sb in the study group (6.8% Sb_2O_3). Two studies on LBA Egyptian white glass conducted by Mass et al. (2002) and Shortland and Eremin (2006) showed that the Sb concentration did not exceed 3.9% and 3.3%, respectively. Therefore, the Sb content of EA64163 is significantly higher than the expected Sb content in an LBA white glass. In addition, EA64163 contains 4.6% PbO compared with the white glasses from KV35 and Malkata that contain no detectable Pb content.

Therefore, both major and trace element compositions, in addition to the colouring strategies for the blue, red and white glasses, are notably different to the HMHK glasses from the KV35 tomb and Malkata groups, thereby making them notably distinct from standard LBA glasses produced in the 18th Dynasty.

Provenance of the glass fragments from and stylistically attributed to KV35

Ti, Cr, La and Zn can be used to distinguish between glasses most likely manufactured in Egypt and those produced in the Near East. Figure 1 shows the data from the glasses excavated from KV35, the fragment stylistically attributed to KV35 and the fragments from the palace at Malkata plotted in a covariant plot of La against Cr, compared with the data from the Swansea fragment (Nicholson & Jackson, 2013) and data from the glasses in Shortland et al. (2007). As mentioned, the majority of the glasses from the study show a positive correlation with those of Egyptian composition; however, two yellow glasses, EA64123 from KV35 and EA64149 from Malkata, appear to lie between the Egyptian and Near Eastern compositions due to the high Cr content. This indicates that yellow glasses may have been produced at a third site using Cr-rich raw materials, or that raw yellow glass may have been imported from the Near East, which was then diluted with Egyptian colourless glass (Mass et al., 2002). The glasses comprising EA64163 can be seen as the outliers in Figure 1. Figure 2 shows the same data plotted in 1000Zr/Ti against Cr/La. This plot provides greater distinction between the Egyptian and Near Eastern trace element compositions. The analysis strongly suggests that all the HMHK glasses from KV35 and the palace at Malkata are of Egyptian manufacture, paralleling the analysis of the Swansea fragment (Nicholson & Jackson, 2013).

CONCLUSIONS

The four fragments recorded as being excavated from the tomb KV35 in the Valley of the Kings are of standard LBA Egyptian composition and compare well with the glasses from Malkata. In addition, all the colours analysed on each fragment are comparable with those of Egyptian provenance, the implication being that early Egyptian glass-making technology was refined enough at this early stage of glass-making history to produce glasses in several colours using a range of compositions and obtaining domestically sourced raw materials distinct from the Near Eastern sources. This signifies that early glassworkers working in Egypt were not as dependent on imported glasses manufactured in the Near East as previous research has speculated. The analysis of fragment EA64163, which is only stylistically attributed to Amenhotep II, shows that the composition of all three colours is significantly different compared with the same colour groups in the LBA glasses from KV35 and Malkata. This is established in the major, minor and trace element findings in the raw materials of the glass and the colourants; the low Mg, low potash content exhibited by EA64163 is characteristic of later glasses produced in the Iron Age using natron as an alkali flux.

PEER REVIEW

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REFERENCES

Abe, Y., Harimoto, R., Kikugawa, T., Yazawa, K., Nishisaka, A., Kawai, N., Yoshimura, S., & Nakai, I. (2012). Transition in the use of cobalt-blue colorant in the new kingdom of Egypt. *Journal of Archaeological Science, 39*(6), 1793–1808. https://doi.org/10.1016/j.jas.2012.01.021

Baikie, J. (1932). *Egyptian antiquities in the Nile Valley: A descriptive handbook*. London: Routledge.

Beck, H. (1934). *Glass before 1500 BC, ancient Egypt*. London: Macmillan.

Brill, R. H. (1999). *Chemical analyses of early glasses: Volume 1 (tables) and 2 (catalogue)*. Corning, New York: Corning Museum of Glass.

Cooney, J. D. (1976). *Catalogue of the Egyptian antiquities of the British Museum: Volume IV*. London: Glass, British Museum.

Dardeniz, G. (2018). The Preliminary Archaeological and Scientific Evidence for Glass Making at Tell Atchana/Alalakh, Hatay (Turkey), *Anatolian Archaeological Studies, Japanese Institute of Anatolian Archaeology*, Proceedings of JIAA Late Bronze Age Glass Workshop held at 27th–28th September, 2014 in Kaman, Turkey.

de Tytus, R. P. (1903). *Preliminary report on the re-excavation of the palace of Amenhotep III*. New York: Winthrop Press.

Freestone, I. C. (1991). Looking into Glass. In S. Bowman (Ed.), *Science and the past* (pp. 37–56). London: British Museum Press.

Jackson, C. M. (2005). Glassmaking in bronze age Egypt. *Science*, *308*, 1750–1752. https://doi.org/10.1126/science.1112553

Jackson, C. M., & Nicholson, P. T. (2010). The provenance of some ingots from the Uluburun shipwreck. *Journal of Archaeological Science*, *37*(2), 295–301. https://doi.org/10.1016/j.jas.2009.09.040

Kaczmarczyk, A. (1986). The source of cobalt in ancient Egyptian pigments. In J. S. Olin & M. J. Blackman (Eds.), *Proceedings of the 24th international Archaeometry symposium* (pp. 369–376). Washington: Smithsonian.

Kemp, V., McDonald, A., Brock, F., & Shortland, A. J. (2019). LA-ICP-MS analysis of late bronze age blue glass beads from Gurob, Egypt. *Archaeometry*, *62*(1), 42–53.

Kemp, V., McDonald, A., & Shortland, A. J. (2017). Ancient biographies: Trace element analysis to investigate provenance and transportation mechanisms of late bronze age glass. *Archaeological and Environmental Forensic Science*, *1*(2), 161–174.

Kemp, V., Schmidt, K., Brownscombe, W., Soennecken, K., Vieweger, D., Haser, J., & Shortland, A. (2020). Dating and provenance of glass artefacts excavated from the ancient city of tall Zirā'a, Jordan. *Archaeometry*, *62*(6), 1164–1181. https://doi.org/10.1111/arcm.12588

Lilyquist, C., Brill, R. H., & Wypyski, M. T. (1993). *Studies in early Egyptian glass*. New York: Metropolitan Museum of Art.

Lilyquist, C., Brill, R. H., Wypyski, W. T., & Koestler, R. J. (1993). Part 2. Glass. In C. Lilyquist & R. H. Brill (Eds.), *Studies in ancient Egyptian glass* (pp. 23–58). New York: Metropolitan Museum of Art.

Mass, J. L., Wypyski, M. T., & Stone, R. E. (2002). Malkata and Lisht glassmaking technologies: Towards a specific link between second millennium BC metallurgists and glassmakers. *Archaeometry*, *44*(1), 67–82. https://doi.org/10.1111/1475-4754.00043

Moorey, P. R. S. (1994). *Ancient Mesopotamian materials and industries*. Oxford: Oxford University Press.

Newberry, P. E. (1900). Extracts from My Note-books (III). PSBA 22.

Newberry, P. E. (1902). Extracts from My Note-books (V). PBSA 24.

Nicholson, P. T. (1993). *Ancient Egyptian faience and glass*. London: Shire Egyptology.

Nicholson, P. T., & Henderson, J. (2000). Glass. In P. T. Nicholson & I. Shaw (Eds.), *Ancient Egyptian materials and technology*. Cambridge: Cambridge University Press.

Nicholson, P. T., & Jackson, C. (2013). Glass of Amenhotep II from tomb KV55 in the valley of the kings. *The Journal of Egyptian Archaeology*, *99*, 85–99. https://doi.org/10.1177/030751331309900103

Nicholson, P. T., Jackson, C. M., & Trott, K. M. (1997). The ulu Burun glass ingots, cylindrical vessels and Egyptian glass. *Journal of Egyptian Archaeology*, *83*, 143–153. https://doi.org/10.1177/030751339708300108

Nolte, B. (1968). *Die Glassgefässe im alten Ägypten, Münchner Ägyptologische Studien*. Berlin: Verlag Bruno Hessling.

Oppenheim, A. L. (1973). Towards a history of glass in the ancient near east. *Journal of the American Oriental Society*, *93*, 259–266. https://doi.org/10.2307/599459

Peltenburg, E. J. (1987). Early faience: Recent studies, origins and relations with glass. In M. Bimson & I. C. Freestone (Eds.), *Early vitreous materials* (Vol. 5–29). British Museum.

Pulak, C. (2001). The cargo of the Uluburun ship and evidence for trade with the Aegean and beyond. In L. Bonfante, V. Karageorghis, Costakis and Leto Severis Foundation, & C. Nicosia (Eds.), *Italy and Cyprus in antiquity 1500–450 BC: Proceedings of an international symposium held at the Italian academy for advanced studies in America at Columbia University, November 16–18, 2000* (pp. 13–60). Nicosia: The Costakis and Leto Severis Foundation.

Reeves, N., & Wilkinson, R. H. (2008). *The complete valley of the kings: Tombs and treasures of Egypt's greatest pharaohs*. London: Thames & Hudson.

Rehren, T. (2000). New aspects of ancient Egyptian glassmaking. *Journal of Glass Studies*, *42*, 13–24.

Rehren, T., Pusch, E., & Herold, A. (2001). Problems and possibilities in workshop reconstruction: Qantir and the organisation of LBA glass workshops. In A. J. Shortland (Ed.), *The social context of technological change*. Oxford: Oxbow books.

Saleem, S. N., & Hawass, Z. (2016). *Scanning the pharaohs: CT imaging of the new kingdom Royal Mummies*. Cairo: American University in Cairo Press.

Sayre, E. V., & Smith, R. W. (1961). Compositional categories of ancient glass. *Science*, *133*, 1824–1826.

Shortland, A. (2002). The use and origin of antimonate colorants in early Egyptian glass. *Archaeometry*, *44*(4), 517–530. https://doi.org/10.1111/1475-4754.00083

Shortland, A. J., & Eremin, K. (2006). The analysis of second millennium glass from Egypt and Mesopotamia, part 1: New WDS analyses. *Archaeometry*, *48*(4), 581–605. https://doi.org/10.1111/j.1475-4754.2006.00274.x

Shortland, A. J., Kirk, S., Eremin, K., Degryse, P., & Walton, M. S. (2017). The analysis of late bronze age glass from Nuzi and the question of the origin of glassmaking. *Archaeometry*, *60*(4), 764–783.

Shortland, A. J., Rogers, N., & Eremin, K. (2007). Trace element discriminants between Egyptian and Mesopotamian late bronze age glasses. *Journal of Archaeological Science*, *34*(5), 781–789. https://doi.org/10.1016/j.jas.2006.08.004

Stern, E. M., & Schlick-Nolte, B. (1994). *Early glass of the ancient world: 1600 B.C.–A.D. 50: Ernesto wolf collection.* Ostfildern: Verlag Gerd Hatje.

Varberg, J., Gratuze, B., & Kaul, F. (2015). Between Egypt, Mesopotamia and Scandinavia: Late bronze age glass beads found in Denmark. *Journal of Archaeological Science*, *54*, 168–181.

Varberg, J., Gratuze, B., Kaul, F., Hansen, A. H., Rotea, M., & Wittenberger, M. (2016). Mesopotamian glass from late bronze age Egypt, Romania, Germany, and Denmark. *Journal of Archaeological Science*, *74*, 184–194. https://doi.org/10.1016/j.jas.2016.04.010

Walton, M., Shortland, A. J., Kirk, S., & Degryse, P. (2009). Evidence for the trade of Mesopotamian and Egyptian glass to Mycenean Greece. *Journal of Archaeological Science*, *36*, 1496–1503. https://doi.org/10.1016/j.jas.2009.02.012

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The dating and provenance of glass fragments from the site of Serabit el-Khâdim, Sinai

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ABSTRACT

Serabit el-Khâdim, located on the western coast of the Sinai Peninsula, is the site of an ancient turquoise mine established in the early 12th Dynasty (c. 1985 BCE) and active between the 18th and 20th Dynasties (c. 1550–1136 BCE). The temple dedicated to Hathor at Serabit detail the number of offerings made, thereby recording the level of activity at Serabit during each reign. The last offerings were made by Ramesses VI (1143–1136 BCE) corresponding with the collapse of the Late Bronze Age before the site was abandoned. 976 glass fragments were given to the Ashmolean Museum by Flinders Petrie following his 1905–6 excavations. 41 fragments from the collection were selected for LA-ICP-MS analysis with the aim of provenancing and dating an unknown collection of glass using composition and available stylistic features to further narrow the date of manufacture and therefore indicate the possible workshop of origin. The analysis showed that all 41 fragments are of Egyptian provenance and of standard Late Bronze Age high magnesia plant ash glass, except one fragment which is a unique example of natron blue glass applied as decoration to a white plant ash vessel body. Subtle compositional differences show that 18th Dynasty plant ash glass, plant ash Ramesside glass and natron Ramesside glass are all present, therefore corresponding with the known Egyptian activity at Serabit.

1. Introduction

Serabit el-Khâdim, or Serabit, is an ancient mining development located approximately 7 km east of the modern port of Abu Zenima, halfway down the western coast of the Sinai Peninsula. Due to the inhospitable environment, ancient Sinai was regarded as little more than a land bridge connecting Egypt and the Levant until the discovery of turquoise in the early dynastic period (c. 3150 BCE) (Mumford, 1999, p722). Strongly associated with ancient Egyptian jewellery, turquoise is a relatively rare stone and compounded with religious significance (Aldred, 1971, p34), therefore it was a highly prized, luxury item and used extensively for amulets and jewellery (Aston, Harrell and Shaw, 2000, p62). Despite the extraction of turquoise being exceedingly labour-intensive (Aldred, 1971, p128), the ancient Egyptian market was particularly lucrative, and private Egyptian workers, military forces and ranking officials were dispatched to ensure the successful recovery of the stone (Redford, 1992, p79). Thus, Serabit became what was arguably-one of the most significant centres of Egyptian enterprise in the Sinai-peninsula (Wilkinson, 2017, p239).

In the early 12th Dynasty (c. 1985 BCE), a temple dedicated to the Goddess Hathor, also named "the Mistress of Turquoise" and the "Lady of Malachite" was constructed; Hathor was the deity responsible for foreign expeditions and was believed to be the patron goddess of turquoise miners (Giveon, 1978, p54-62). Serabit was also a popular pilgrimage site with many gifts and offerings being placed at the temple as tribute, making evident the ancient Egyptian belief that mining expeditions would only be successful if the proper religious respects were paid (New, 1932; Mumford, 2006; Caelen, 2013). The temple itself contains numerous inscriptions denoting the increasing number of turquoise mining expeditions undertaken from the reign of Amenemhat I (1985–1956 BCE), the first king of the 12th Dynasty, to Amenemhat IV (1786–1777 BCE). Mining activities ceased at the end of the 12th Dynasty (c. 1785 BCE) following the immigration of the Canaanites and invasion of the Hyksos (Barrois, 1932; Grimal, 1992, p391), and only resumed when political stability returned following the formation of the New Kingdom (Mumford, 1999, p724). After 12 years of peace under Amenhotep I (1525–1504 BCE), mining was re-established along with the tradition of monument building; repairs, extensions and embellishments were made to the temple between the reigns of Hatshepsut (1473–1458 BCE) and Amenhotep III (1390–1352 BCE) (Mumford,

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1999a, p725; Wilkinson, 2017, p239). It is from the mid-18th Dynasty (c. 1550 BCE) that glass vessels and objects were included as part of the temple offerings. Strictly administered and regulated by the Egyptian royal court, glass became one of the highest symbols of elite status in the New Kingdom (Shortland, Nicholson and Jackson, 2001, p153), therefore the presence of glass core formed vessels at the temple demonstrates the high value of offerings made to Hathor and confirms the importance of turquoise mining activities at Serabit.

According to the temple inscriptions, 71 votive offerings were placed at Serabit between the reigns of Tuthmosis III and Ay (1327–1323 BCE) (Mumford, 2006) and an estimated 329 votives were placed between the reigns of Rameses I (1295–1294 BCE) and Tawosret (1188–1186 BCE), with 66 votives offered during the Iron Age (IA) reigns of Sethnakht (1186–1184 BCE) onwards (Mumford, 2006). Further building work, offerings and inscriptions were made between the reigns of Rameses IV (1153–1147 BCE) and Rameses VI (1143–1136 BCE), which were the last recorded activities, with the mines subsequently being abandoned, corresponding with the collapse of the Late Bronze Age (LBA) (Eckenstein, 1921, p63). Periods of mining activity at Serabit and political and social stability in Egypt and the Near East are therefore analogous, indicating that even highly profitable endeavours were abandoned during times of political crisis (Giveon, 1978, p51).

1.1. The excavation at Serabit

The temple at Serabit was re-discovered in 1762 by Carsten Niebuhr and revisited by several scholars, whose work was largely limited to making copies of inscriptions (Eckenstein, 1921, p17). The first extensive excavation was undertaken by Petrie in the winter of 1905–6, which resulted in the first complete plan of the temple with over 300 photographs taken of the site (Petrie, 1904).

According to Petrie's excavation notes, the temple offerings were mainly of "glazed ware", such as vases, bowls and cups, as well as other offerings such as *menats*, bracelets, sistra and wands. The damage to the offerings was so extensive that no item was observed intact, with the remains forming a layer on the temple floor "two or three inches thick" (Petrie, 1906, p138). After attempting some reconstruction work, Petrie concluded that a large portion of the fragments were missing, likely scattered outside the temple and left to disintegrate in the severe atmospheric conditions (Petrie, 1906, p122).

1.2. Samples

The Serabit expedition finds were divided between several museums, including the Cairo Museum, the British Museum, London, and the Ashmolean Museum, Oxford (Petrie, 1906, p123). 976 glass fragments from Serabit (Accession number E.4486) reside at the Ashmolean Museum (Simpson, 1990). Most fragments are on average between 1 and 4 cm, and are coated with a white, salt deposit or the distinctive red-brown deposit that reflects the red Nubian sandstone geology of Serabit. Although heavily coated with deposits, some fragments that have sustained recent breakage show good preservation. The colours are remarkably vibrant; turquoise, light and dark blue hues, black, brown, green and white are included in the collection. Also visible on some fragments are fine examples of feather and garland patterns applied in white and yellow, as well as rims created from thin, twisted coloured glass rods. Handles and other defining features allows the inference of the vessel type, therefore it can be speculated that pots, amphora, spherical vessels, pomegranate vessels and *kratiskeros* were among those presented to the temple (Nolte, 1968), in addition to items with glass inlays.

Forty-two fragments which exhibited good preservation, glass matrix uniformity and clarity of colour were selected for laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analysis. Description of the fragments are included in Table 1. All fragments included in the study are relatively small, therefore the pattern

Table 1
Description of fragments from Serabit selected for analysis by LA-ICP-MS.

Acc. #	Main body colour	Opaque/ Translucent	Fragment description	Shape and approximate size in centimetres
OX122	Black	Semi translucent	Vessel fragment with feather, garland or arcade dragged pattern applied in two colours: white and apparent yellow/ brown. Transecting thicker white band bordering the pattern.	3.0 × 2.5
OX144	Black	Semi translucent	Vessel fragment with straight white band applied transecting the fragment.	2.5 × 1.5
OX299	Black	Translucent	Vessel fragment with straight white band applied transecting the fragment.	3.0 × 2.0
OX358	Amber/ brown	Translucent	Vessel fragment with decorative threads of yellow/ white visible on the cross section. Pattern imperceptible.	2.5 × 1.5
OX420	Brown	Translucent	Vessel fragment with garland pattern applied in at least two different colours.	4.0 × 4.0
OX561	Brown	Translucent	Vessel fragment with possible decoration applied in yellow.	Oblong fragment 2.0 × 2.5
OX189	Mid Blue	Translucent	Vessel fragment with flat arcade/ garland pattern applied with three colour thread combination. Pattern appears to be applied in the pattern form rather than using an implement to drag over the surface, forming the pattern.	3.5 × 3.0
OX193	Dark blue	Translucent	Vessel fragment with elaborate feather pattern applied in apparent white and yellow threads.	Roughly triangular 1.5 × 3.0
OX414	Dark blue	Opaque	Unknown object. No perceptible pattern, prominent white thread transecting the fragment.	3.5 × 1.5
OX433	Dark blue	Translucent	Vessel fragment with possible garland pattern applied in lighter colour.	3.0 × 2.0
OX437	Dark Blue	Translucent		

(continued on next page)

Table 1 (*continued*)

Acc. #	Main body colour	Opaque/ Translucent	Fragment description	Shape and approximate size in centimetres
			Vessel fragment with possible garland pattern applied in at least two different colours. Rim made from twisted threads.	2 fragments, both 2.0 × 1.5
OX669	Dark blue	Translucent	Vessel fragment with regular white garland/arcade pattern applied in lighter colour.	Triangular fragment 2.5 × 1.5
OX84	Dark blue	Translucent	Vessel fragment with possible feather pattern and two white transecting bands.	2.5 × 3.0
OX107	Dark blue	Semi translucent	Possible vessel fragment with no perceptible pattern.	1.5 × 2.0
OX183	Dark blue	Translucent	Vessel fragment with elaborate pattern (possibly feather) applied in at least three colours	Triangular 3.5 × 2.0
OX200	Dark blue	Translucent	Vessel fragment with pattern applied with yellow, white and light blue threads.	Roughly triangular fragment approx. 3.2 × 1.7 at widest point
OX481	Black/dark blue	Semi translucent	Vessel fragment with white thread present in rim section.	Triangular fragment 2.0 × 2.0
OX501	Dark blue/ black	Semi translucent	Unknown object type with no perceptible pattern.	Oblong fragment 3.0 × 2.0
OX70	Light blue	Translucent	Vessel fragment with yellow and dark blue thread applied in a straight design.	1.5 × 2.5
OX103	Turquoise	Translucent	Unknown object type with no perceptible pattern.	3.0 × 2.5
OX127	Mid blue	Translucent	Unknown object type with no perceptible pattern. Semi translucent.	2.0 × 3.5
OX195	Blue	Semi translucent	Vessel fragment with consistent, even feather pattern applied in three (?) colours.	3.5 × 2.0
OX198	Light blue	Translucent	Vessel fragment with apparent feather pattern applied in yellow and white threads, thicker white band transecting the fragment.	Triangular fragment 2.5 × 3.0
OX235	Light blue	Semi translucent	Vessel fragment with possible feather pattern applied in yellow and white threads.	2.0 × 2.0
OX429	Turquoise blue	Translucent	Vessel fragment with no perceptible pattern. Rim contains merged yellow and blue glass.	4.0 × 4.0
OX442	Light blue	Translucent	Vessel fragment with possible garland or feather pattern applied. Rim applied with at least two colours of twisted glass of apparent white and dark blue.	2.5 × 2.0
OX472	Turquoise blue	Translucent	Vessel fragment with feather pattern applied in two other colours, one possibly yellow.	2.5 × 2.0
OX482	Blueish green	Translucent	Vessel fragment with garland pattern applied with at least two different colours, one being yellow. Rim applied in solid opaque yellow.	Triangular fragment 2.0 × 2.0
OX488	Mid blue	Translucent	Vessel fragment with no perceptible pattern, rim applied in darker blue and white twisted glass.	Square fragment 1.0 × 1.0
OX897	Light blue	Translucent	Vessel fragment with no perceptible pattern.	Square fragment 1.7 × 1.5
E.4486	Green	Opaque	Unknown object type. Fragment is flat with no perceptible pattern applied	Irregular shaped fragment 2.5 × 2.0
E.4486.1	Green	Semi translucent	Unknown object type with no perceptible pattern.	Irregular shaped fragment 2.5 × 2.0
OX140	Green	Opaque	Unknown object type with no perceptible pattern.	1.5 × 2.0
OX484	Green/ blue	Translucent	Rounded fragment - "leaf" from a pomegranate vessel? Yellow rim applied to the edge of rounded section.	Rounded fragment 2.0 × 1.5
OX77	Black/ Purple	Translucent	Vessel fragment with pattern applied in at least two different coloured threads.	3.0 × 2.0
OX85	Purple/ brown	Translucent	Unknown object type with no	6.0 × 3.0

(continued on next page)

Table 1 (*continued*)

Acc. #	Main body colour	Opaque/ Translucent	Fragment description	Shape and approximate size in centimetres
			perceptible pattern.	
OX641	White	Opaque	Vessel fragment with dark blue/ black band visible under red deposit, white prominent thread transecting fragment	Oblong fragment 3.2 × 1.7
OX264	Yellow	Semi translucent	Vessel fragment with no perceptible pattern.	Roughly triangular fragment 3.0 × 1.7 at widest point
OX444	Yellow	Opaque	Vessel fragment with no perceptible pattern. Rim applied in white and black/dark brown coloured glass.	2.5 × 2.5
OX334	Dark red	Semi translucent	Unknown object type with no perceptible pattern.	2.0 × 2.0
OX226	Amber/ brown	Translucent	Vessel fragment with undetermined pattern applied in two lighter colours, possible yellow and white.	3.0 × 2.0

described per fragment cannot be considered as descriptive of the complete object. Small samples were taken from the fragments with a pair of wire cutters and then mounted in resin blocks and polished.

2. Methodology

The analyses were carried out with an Agilent 8900 triple quadrupole ICP-MS coupled with an ESI New Wave Research NWR 193 ArF excimer laser. The operating conditions for the laser ablation system were set at 7 J/cm^2 with a frequency of 15 Hz and a spot size of 70 μm. The ICP-MS was operated with a RF power set at 1380 W, a plasma gas flow of 15 L min^{-1} and an auxiliary gas flow of 0.90 L min^{-1}. Helium was used as carrier gas (800 mL min^{-1}) in single MS mode with no cell gas. The ICP-MS was tuned before each session on the glass SRM NIST612 to achieve high sensitivity and stability (RSD < 5 %). The plasma condition was monitored with U/Th ratio (0.9–1.1) and ThO/Th ratio was used to assess a low oxide level (ThO/Th < 0.01). The ICP-MS was setup in full-quant mode for the acquisition of 42 masses. Gas blanks were recorded during the 15 *sec* warm-up time and 15 *sec* washout time. Each sample was analysed in triplicate with 60 *sec* of ablation per spot. The first 20 *sec* of ablation were considered as pre-ablation and were not used in the calculation of the concentration. Quantitative data were obtained using the calibration protocol described by Van Elteren et al. (Van Elteren, Tennent and Šelih, 2009) using linear combination of a set of four glass SRMs as external standards (NIST 612, NIST 610, Corning B and Corning D) and SiO_2 as the internal standard. The full set of SRMs used as external standards were regularly measured in the batches and the results were comparable to the accepted values (Vicenzi et al., 2002; Jochum et al., 2011; Wagner et al., 2012).

3. Results

The glasses contain between 16.0 % and 22.8 % Na_2O (Table 2) therefore represent the expected values for un-weathered Egyptian LBA glass. All samples contain an average of 4.2 % MgO and 1.7 % K_2O, thus compare with standard Egyptian LBA plant ash glasses produced in the 18th Dynasty (Sayre and Smith, 1961; Lilyquist et al., 1993; Shortland and Eremin, 2006) The exception is the Co + Cu blue glass from fragment OX641 which is discussed separately.

3.1. Provenance

Shortland et al. demonstrated that by using a covariant plot of Cr/La vs 1000Zr/Ti, glasses of Egyptian and Mesopotamian origin can be distinguished (Shortland, Rogers and Eremin, 2007). The trace elements from the Serabit study group (Table 3) were plotted against the glasses of known Egyptian and Mesopotamian origin, showing that all Serabit glasses are of Egyptian provenance (Fig. 1).(SeeTable 4.).

4. Discussion

4.1. Style and workshops

Vessels produced between the reigns of Amenhotep III and Akhenaten are considered to represent the "golden era" of Ancient Egyptian glassmaking due to the fine artistry and high quality of production. New Kingdom vessels are typified by the *amphoriskos* and *krateriskos* shape, created primarily in blue hues, with yellow and white threads applied in feather and garland patterns. Ramesside vessels by comparison show a diversity in colour and shape (such as the introduction of pomegranate and pilgrim flasks) often with no or basic patterns applied. Ramesside glasses are notably less sophisticated, both in glass quality and artistry following the decline of the glass industry after the end of the 18th Dynasty (c. 1295 BCE) (Nolte, 1968).

Two significant Ramesside glass workshops are known: debris from Qantir indicates that this was a primary glassmaking site between c. 1300–1270 BCE (Pusch and Rehren, 2007, p131) for the mass manufacture of red glass (and some cobalt glasses) in the form of ingots rather than objects (Rehren, Pusch and Herold, 2001; Rehren and Pusch, 2005; Rademakers, Rehren and Pernicka, 2017). The later site of Lisht is known to have produced vessels and other items, such as inlays, in a range of colours including Cu-blue, yellow, white, black, purple, brown and green dated to between 1295 and 1070 BCE (Keller, 1983). Notably, evidence of cobalt blue glass production at Lisht has not been confirmed, however, evidence of recycling is present at this site (Keller, 1983; Brill, 1999; Mass, Wypyski and Stone, 2002). Research indicates that glasses produced at Lisht have a distinctive chemical signature, characterised by low levels of lime, alumina and iron oxide in addition to relatively high concentrations of soda compared with other Egyptian glasses (Smirniou, Rehren and Gratuze, 2018). Also, Lisht Cu-blue glasses generally contain very little, if no, tin; therefore, both factors can indicate later Lisht glasses, or be used as exclusion criteria when comparing unknown samples.

Gurob has been identified as a lesser Ramesside glassworking site (Brunton and Engelbach, 1927 Shaw, 2007) and the available analyses suggest that white, black, Cu-blue (with elevated tin) and Co + Cu-blue glasses were worked at the site, the latter containing the "Type R" cobalt source, used exclusively in Ramesside glasses and characterised by low Zn, elevated Ni and lower Al compared with New Kingdom Co-glasses (Abe et al., 2012; Lankton, Pulak and Gratuze, 2022).

4.2. Cobalt blue

All six glasses in the Co blue group contain between 0.84 % and 1.2 % K_2O with an elevated average content of 2.43 % Al_2O_3, therefore comparable to standard CoO Egyptian LBA glasses, which are well published

Table 2
Average results for the LA-ICP-MS analyses showing major and minor elements of the samples from Serabit (wt%).

			Major and minor elements [wt %]												
High Magnesia High Potash															
As. Number	**Colour group**	**Translucent/ Opaque**	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**K_2O**	**CaO**	**MnO**	**Fe_2O_3**	**CoO**	**CuO**	**Sb2O3**	**PbO**
OX122	Black	Opaque	16.01	4.64	0.73	67.89	0.11	1.31	7.47	0.02	0.43	0.00	0.01	0.00	0.00
OX144	Black	Opaque	17.75	4.93	0.66	61.72	0.10	1.89	8.11	0.02	0.67	0.00	0.12	0.38	2.42
OX299	Black	Semi-translucent	18.47	4.65	0.76	62.75	0.13	1.76	9.40	0.02	0.43	0.00	0.00	0.00	0.00
Black average			**17.41**	**4.74**	**0.72**	**64.12**	**0.11**	**1.65**	**8.33**	**0.02**	**0.51**	**0.00**	**0.04**	**0.13**	**0.81**
OX358	Brown	Opaque	17.80	4.09	0.65	64.21	0.15	1.61	6.52	0.03	0.45	0.00	1.84	0.15	0.92
OX420	Brown	Opaque	18.34	3.50	0.41	64.99	0.16	1.53	5.81	0.02	0.28	0.00	2.02	0.19	0.88
OX561	Brown	Translucent	18.15	5.33	0.44	63.56	0.16	2.06	6.94	0.03	0.37	0.00	0.87	0.05	0.53
Brown average			**18.10**	**4.30**	**0.50**	**64.25**	**0.16**	**1.73**	**6.42**	**0.02**	**0.37**	**0.00**	**1.58**	**0.13**	**0.78**
OX189	Co blue	Translucent	20.79	5.33	3.17	59.25	0.11	0.98	7.99	0.21	0.44	0.07	0.02	0.03	0.00
OX193	Co blue	Translucent	18.77	3.50	1.10	65.90	0.10	0.93	7.08	0.08	0.52	0.13	0.03	0.01	0.01
OX414	Co blue	Opaque	19.66	3.36	2.12	62.33	0.18	1.20	8.22	0.18	0.33	0.18	0.01	0.29	0.00
OX433	Co blue	Translucent	20.66	4.94	2.25	58.74	0.09	0.84	9.73	0.11	0.47	0.10	0.01	0.07	0.00
OX437	Co blue	Translucent	20.35	5.41	3.01	59.88	0.12	0.93	7.74	0.16	0.50	0.08	0.02	0.00	0.00
OX669	Co blue	Translucent	20.30	5.10	2.96	60.19	0.13	0.99	7.85	0.15	0.47	0.07	0.02	0.00	0.00
Co Blue average			**20.09**	**4.61**	**2.43**	**61.05**	**0.12**	**0.98**	**8.10**	**0.15**	**0.45**	**0.10**	**0.02**	**0.07**	**0.00**
OX84	Co + Cu blue	Translucent	20.13	3.57	1.54	64.62	0.09	0.60	6.06	0.18	0.71	0.10	0.35	0.09	0.03
OX107	Co + Cu blue	Opaque	20.67	3.98	1.37	63.29	0.15	1.21	6.25	0.09	0.43	0.19	0.15	0.28	0.00
OX183	Co + Cu blue	Translucent	19.27	4.64	1.56	61.05	0.16	1.51	8.26	0.11	0.49	0.06	0.97	0.07	0.00
OX200	Co + Cu blue	Translucent	22.27	3.51	2.95	61.04	0.09	0.90	6.24	0.20	0.52	0.10	0.22	0.00	0.00
OX481	Co + Cu blue	Opaque	19.05	3.80	1.33	66.23	0.15	1.12	5.61	0.08	0.40	0.16	0.13	0.25	0.00
OX501	Co + Cu blue	Opaque	21.67	3.90	1.39	58.89	0.15	1.07	8.79	0.14	0.90	0.07	0.18	0.50	0.16
Co + Cu blue average			**20.51**	**3.90**	**1.69**	**62.52**	**0.13**	**1.07**	**6.87**	**0.13**	**0.58**	**0.11**	**0.33**	**0.20**	**0.04**
OX70	Cu blue	Translucent	16.69	3.98	0.83	67.27	0.17	1.46	7.29	0.02	0.46	0.00	0.45	0.02	0.05
OX103	Cu blue	Translucent	18.35	4.28	0.37	62.97	0.16	2.27	9.16	0.01	0.22	0.00	0.49	0.04	0.28
OX127	Cu blue	Translucent	18.58	3.44	0.55	64.88	0.16	1.74	7.57	0.02	0.33	0.00	0.97	0.01	0.00
OX195	Cu blue	Opaque	19.31	3.23	0.35	64.37	0.23	2.52	6.21	0.02	0.28	0.00	0.42	1.28	0.00
OX198	Cu blue	Semi-translucent	18.15	4.28	0.83	63.95	0.17	1.51	7.59	0.02	0.46	0.00	1.05	0.26	0.01
			Major and minor elements [wt %]												
High Magnesia High Potash															
As. Number	**Colour Group**	**Translucent/ Opaque**	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**K_2O**	**CaO**	**MnO**	**Fe_2O_3**	**CoO**	**CuO**	**Sb2O3**	**PbO**
OX235	Cu blue	Translucent	18.09	4.49	0.53	66.08	0.21	1.41	6.57	0.02	0.33	0.00	0.71	0.02	0.00
OX429	Cu blue	Translucent	18.69	4.80	0.73	62.77	0.21	2.44	7.75	0.02	0.41	0.00	0.76	0.00	0.00
OX442	Cu blue	Opaque	22.81	3.33	0.36	60.72	0.22	2.57	6.80	0.02	0.31	0.00	0.58	0.44	0.00
OX472	Cu blue	Opaque	19.44	4.46	0.63	61.17	0.18	1.87	8.18	0.02	0.39	0.00	1.24	0.60	0.02
OX482	Cu blue	Translucent	16.69	3.66	0.78	67.58	0.15	1.22	7.41	0.02	0.48	0.00	0.38	0.07	0.14
OX488	Cu blue	translucent	20.48	4.16	0.51	63.00	0.18	1.76	6.32	0.03	0.31	0.01	1.65	0.02	0.00
OX897	Cu blue	Translucent	18.05	4.42	1.10	65.83	0.19	1.45	6.48	0.02	0.33	0.00	0.69	0.02	0.00
Cu blue average			**18.78**	**4.04**	**0.63**	**64.22**	**0.19**	**1.85**	**7.28**	**0.02**	**0.36**	**0.00**	**0.78**	**0.23**	**0.04**
E.4486	Green	Opaque	18.54	4.72	0.39	61.34	0.20	2.42	9.07	0.01	0.28	0.00	0.01	0.16	1.46
E.4486.1	Green	Semi-translucent	20.01	3.88	0.49	65.32	0.16	1.87	6.22	0.02	0.32	0.00	0.01	0.00	0.00
OX140	Green	Semi-translucent	18.82	4.87	0.47	63.20	0.11	1.65	8.97	0.02	0.28	0.00	0.01	0.00	0.00
OX484	Green	Opaque	17.22	4.33	0.48	61.41	0.15	2.07	9.20	0.02	0.42	0.00	0.01	0.50	2.81
Green average			**18.65**	**4.45**	**0.46**	**62.82**	**0.16**	**2.00**	**8.37**	**0.02**	**0.33**	**0.00**	**0.01**	**0.16**	**1.07**
OX77	Purple	Translucent	18.28	3.65	0.57	65.04	0.20	2.26	6.98	0.75	0.71	0.00	0.05	0.00	0.00
OX85	Purple	Translucent	19.69	3.79	0.58	63.08	0.18	1.94	8.50	0.27	0.34	0.00	0.01	0.00	0.00
OX444	Purple	Translucent	19.43	3.39	0.80	63.90	0.17	1.83	7.58	0.21	0.80	0.09	0.00	0.00	0.00
Purple average			**19.13**	**3.61**	**0.65**	**64.01**	**0.18**	**2.01**	**7.69**	**0.41**	**0.62**	**0.03**	**0.02**	**0.00**	**0.00**
OX122	White	Opaque	18.43	4.01	0.48	64.60	0.21	2.34	6.70	0.03	0.28	0.00	0.18	0.85	0.01
OX641	White	Opaque	21.75	3.35	0.54	61.49	0.17	1.71	6.27	0.02	0.31	0.00	0.16	2.26	0.00
White Average			**20.09**	**3.68**	**0.51**	**63.05**	**0.19**	**2.02**	**6.48**	**0.02**	**0.30**	**0.00**	**0.17**	**1.56**	**0.01**
OX264	Yellow	Opaque	19.71	4.79	0.40	59.00	0.22	2.47	9.56	0.01	0.29	0.00	0.09	0.20	1.51
OX444	Yellow	Opaque	17.07	4.65	0.65	56.34	0.10	1.76	7.75	0.02	1.31	0.00	0.10	1.40	7.36
OX561	Yellow	Opaque	18.04	4.40	0.49	58.99	0.16	2.05	9.32	0.02	0.46	0.00	0.08	0.72	3.35
Yellow average			**18.27**	**4.61**	**0.51**	**58.11**	**0.16**	**2.09**	**8.88**	**0.02**	**0.69**	**0.00**	**0.09**	**0.77**	**4.07**
OX334	Red	Opaque	20.55	3.79	0.41	63.91	0.24	2.20	5.45	0.02	0.26	0.00	1.20	0.14	0.01
OX226	Amber	Translucent	19.91	4.23	0.38	64.74	0.26	2.80	5.43	0.03	0.25	0.00	0.01	0.00	0.00
Low Magnesia Low Potash															
OX641	Co+Cu blue	Opaque	21.80	0.49	1.00	64.94	0.03	0.91	2.69	0.01	0.69	0.08	1.33	1.08	2.76

(Shortland and Eremin, 2006; Shortland, Rogers and Eremin, 2007; Kemp, Brownscombe and Shortland, 2021). The glasses in this group are coloured with an average of 0.1 % CoO and exhibit elevated levels of associated elements Mn, Ni, and Zn and with an average of 0.15 %, 677 ppm, and 725 ppm respectively. Therefore all glasses in the Serabit CoO group are coloured with the characteristic cobaltiferous alum used exclusively in the Egyptian 18th Dynasty, known as "Type A", hence were likely manufactured between the reigns of Tuthmosis III (1479–1425 BCE) and Akhenaten (1352–1336 BCE (Kaczmarczyk, 1986; Abe et al., 2012).

4.3. Co + Cu blue

The six glasses contain between 0.06 and 0.19 % CoO and 0.13–0.97 % CuO, therefore conform to the definition of Co + Cu glasses (Shortland and Eremin, 2006; Smirniou and Rehren, 2013). All Serabit Co + Cu blue glasses contain an average concentration of 1.69 % Al_2O_3 with elevated Ni, Zn, and Mn, hence characteristic of the Type A cobalt source used

Table 3
Average results for the LA-ICP-MS trace elements analyses of the samples from Serabit (ppm).

			Trace elements (ppm)																										
High Magnesia High Potash																													
As. Number	Colour group	Translucent/Opaque	Li	Be	B	Tl	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Zr	Nb	Ag	Sn	Sb	Cs	Ba	La	Ce	Au	Pb	Th	U
OX122	Black	Opaque	5.9	0.1	54	427	7.5	5.3	186	3012	6.7	7.6	46.4	10.8	1.3	7.3	670	22.5	1.5	0.1	2.2	26.1	0.2	49.5	3.2	6.1	0.0	13.4	0.6	0.2
OX144	Black	Opaque	5.2	0.2	65	338	6.7	5.3	148	4665	1.9	4.7	926	15.1	8.5	8.1	710	29.2	1.3	6.1	7.4	3174	0.1	37.7	2.3	4.7	0.0	20991	0.6	0.2
OX299	Black	Semi-translucent	4.9	0.1	70	446	8.3	6.6	170	3010	1.9	4.1	24.8	12.6	1.2	8.8	1075	38.4	1.6	0.4	0.6	21.0	0.2	39.2	2.9	5.7	0.0	2.7	0.7	0.3
Black average			**5.3**	**0.2**	**63**	**403**	**7.5**	**5.8**	**168**	**3562**	**3.5**	**5.4**	**332**	**12.8**	**3.7**	**8.0**	**819**	**30.0**	**1.4**	**2.2**	**3.4**	**1074**	**0.2**	**42.1**	**2.8**	**5.5**	**0.0**	**7002**	**0.6**	**0.3**
OX358	Brown	Opaque	6.8	0.1	88	372	6.6	5.8	215	3165	10.9	13.6	14727	24.8	26.8	6.9	507	33.3	1.2	4.1	746	1211	0.1	42.4	2.4	4.6	0.7	7927	0.5	0.3
OX420	Brown	Opaque	4.1	0.1	72	240	5.0	4.9	128	1946	2.9	9.7	16155	223	40.4	7.2	524	27.0	0.8	4.5	1517	1574	0.1	48.5	1.8	3.4	3.7	7648	0.4	0.3
OX561	Brown	Translucent	7.2	0.1	74	237	5.5	3.9	231	2571	3.9	6.8	6972	758	37.8	6.6	593	16.8	1.0	1.6	343	423	0.1	37.9	2.3	4.4	0.4	4599	0.4	0.2
Brown average			**6.0**	**0.1**	**78**	**283**	**5.7**	**4.9**	**191**	**2561**	**5.9**	**10.0**	**12618**	**335**	**35.0**	**6.9**	**541**	**25.7**	**1.0**	**3.4**	**869**	**1070**	**0.1**	**42.9**	**2.1**	**4.2**	**1.6**	**6725**	**0.5**	**0.2**
OX189	Co blue	Translucent	9.1	2.6	84	328	6.2	4.1	1607	3059	562	369	141	698	2.3	5.0	703	32.1	1.2	0.0	6.4	217	0.1	29.4	3.0	8.2	0.0	6.9	41.9	41.9
OX193	Co blue	Translucent	7.0	0.8	148	434	7.4	4.4	646	3614	1060	1260	250	279	2.3	3.9	495	38.1	1.3	0.1	15.7	85.5	0.0	32.6	2.5	5.3	0.0	47.9	0.4	0.2
OX414	Co blue	Opaque	5.6	0.6	106	311	4.9	3.2	1398	2291	1391	820	52.4	1600	6.0	6.0	1328	29.3	1.0	0.1	1.4	2463	0.1	31.1	2.2	6.1	0.0	19.2	0.4	0.2
OX433	Co blue	Translucent	10.3	2.2	133	457	7.6	7.1	861	3262	787	877	89.6	462	3.1	5.2	1084	58.5	1.6	0.2	5.9	558	0.1	45.0	3.3	7.5	0.0	10.6	0.6	0.3
OX437	Co blue	Translucent	9.6	1.7	132	407	7.1	3.7	1274	3473	638	423	648	762	2.5	4.7	725	37.9	1.4	0.1	7.4	8.4	0.1	33.3	3.6	9.5	0.0	5.2	1.1	0.7
OX669	Co blue	Translucent	9.9	1.5	128	377	6.9	4.1	1158	3286	515	310	128	547	2.2	4.9	736	38.9	1.4	0.1	4.3	9.2	0.0	34.2	3.4	8.3	0.0	5.2	0.7	0.3
Co Blue average			**8.6**	**1.6**	**122**	**386**	**6.7**	**4.4**	**1157**	**3164**	**826**	**677**	**218**	**725**	**3.1**	**4.9**	**845**	**39.1**	**1.3**	**0.1**	**6.9**	**557**	**0.0**	**34.3**	**3.0**	**7.5**	**0.0**	**15.8**	**7.5**	**7.3**
OX84	Co+Cu blue	Translucent	10.9	0.9	134	678	11.3	8.0	1383	4967	788	634	2776	250	10.0	4.7	418	49.1	2.4	0.3	209	714	0.1	49.4	4.9	10.1	0.1	299	1.1	0.7
OX107	Co+Cu blue	Opaque	8.4	0.4	120	473	8.4	6.5	704	3015	1476	1331	1209	358	11.1	5.9	517	46.8	1.6	0.3	68.4	2346	0.1	40.3	3.2	6.6	0.2	29.0	0.4	0.9
OX183	Co+Cu blue	Translucent	7.1	0.5	98	476	8.7	6.1	857	3405	482	259	7748	664	30.7	9.4	807	38.5	1.8	1.1	789	552	0.2	42.5	3.5	7.7	0.2	43.1	0.8	0.4
OX200	Co+Cu blue	Translucent	9.9	1.8	132	474	7.2	5.8	1547	3644	781	570	1742	821	5.6	5.3	701	46.0	1.5	0.3	100	16.9	0.1	40.1	3.1	7.4	0.2	13.4	0.7	0.3
OX481	Co+Cu blue	Opaque	6.2	0.4	123	452	6.9	5.4	646	2822	1256	1186	1061	291	8.6	4.9	427	39.2	1.4	0.2	59.9	2122	0.1	36.5	2.7	5.4	0.2	26.8	0.6	0.3
OX501	Co+Cu blue	Opaque	10.6	0.7	73	585	12.4	9.9	1087	6292	527	343	1474	221	17.5	4.1	757	39.6	1.7	0.4	186	4175	0.1	46.2	3.2	7.0	0.3	1427	1.1	0.8
Co+ Cu blue average			**8.9**	**0.8**	**114**	**523**	**9.1**	**6.9**	**1037**	**4024**	**885**	**721**	**2668**	**434**	**13.9**	**5.7**	**604**	**43.2**	**1.7**	**0.4**	**235**	**1654**	**0.1**	**42.5**	**3.4**	**7.3**	**0.2**	**306**	**0.8**	**0.5**
OX70	Cu blue	Translucent	5.3	0.2	75	480	8.2	6.5	164	3241	5.7	7.0	3591	20.4	13.2	7.0	479	30.6	1.6	0.3	179	208	0.1	41.7	3.2	6.2	0.1	413	0.7	0.3
OX103	Cu blue	Translucent	6.3	0.1	83	198	3.9	2.7	82	1507	2.2	3.6	3896	149	7.5	6.5	1092	17.9	0.7	0.6	201	301	0.1	25.9	1.4	2.6	0.4	2442	0.3	0.1
OX127	Cu blue	Translucent	5.8	0.1	78	335	6.5	3.0	135	2340	3.6	7.0	7747	13.8	22.4	7.4	569	29.9	1.1	0.6	536	91.7	0.1	29.1	2.1	4.2	0.5	24.7	0.5	0.2
OX195	Cu blue	Opaque	6.2	0.1	87	194	5.5	3.7	193	1974	4.0	4.3	3352	52.2	30.2	6.6	552	12.9	0.7	1.4	104	10715	0.1	44.9	1.8	3.4	0.1	28.3	0.3	0.6
OX198	Cu blue	Semi-translucent	7.3	0.0	62	452	8.7	5.3	186	3223	7.9	10.7	8363	24.1	32.6	8.0	630	30.3	1.6	0.4	330	2188	0.1	43.0	3.3	6.4	0.2	45.8	0.7	0.3
OX235	Cu blue	Translucent	4.7	0.1	79	278	5.7	4.0	177	2297	3.6	5.9	5641	13.2	19.4	5.5	532	15.5	1.0	0.3	330	184	0.1	28.9	2.1	4.2	0.1	38.3	0.4	0.2
OX429	Cu blue	Translucent	6.3	0.1	72	459	7.6	5.4	173	2899	2.4	5.7	6089	17.6	18.8	8.5	920	41.0	1.5	0.9	414	5.5	0.1	38.4	2.7	5.3	0.9	16.7	0.6	0.3
OX442	Cu blue	Opaque	6.7	0.1	64	189	6.3	3.6	146	2141	1.8	3.1	4658	41.6	23.1	7.1	602	14.9	0.7	0.7	160	3640	0.1	42.8	2.0	3.8	0.1	16.2	0.4	0.9

			Trace elements (ppm)																										
High Magnesia High Potash																													
As. Number	Colour group	Translucent/ Opaque	Li	Be	B	Tl	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Zr	Nb	Ag	Sn	Sb	Cs	Ba	La	Ce	Au	Pb	Th	U
OX472	Cu blue	Opaque	7.9	0.1	73	379	7.6	4.8	177	2700	6.7	8.9	9879	21.2	63.2	6.5	737	30.4	1.3	0.7	366	5016	0.1	38.7	2.7	5.3	0.2	132	0.6	0.3
OX482	Cu blue	Translucent	4.1	0.2	84	485	8.1	6.5	168	3340	20.9	18.2	3049	21.1	8.8	4.4	667	26.0	1.3	0.4	269	548	0.1	44.8	2.7	5.4	0.1	1181	0.6	0.3
OX488	Cu blue	translucent	5.2	0.1	77	302	5.7	3.4	225	2159	57.4	48.1	13206	61.6	32.5	5.9	497	16.0	1.0	1.0	913	179	0.1	33.8	1.9	3.7	0.3	26.0	0.4	0.2
OX897	Cu blue	Translucent	4.2	0.1	77	272	5.5	3.9	177	2282	3.6	5.6	5527	13.0	18.7	5.6	514	14.8	0.9	0.4	322	205	0.1	28.4	2.0	4.0	0.1	40.5	0.4	0.2
Cu blue average			**5.8**	**0.1**	**76**	**335**	**6.6**	**4.4**	**167**	**2509**	**10.0**	**10.7**	**6250**	**37.4**	**24.2**	**6.6**	**649**	**23.4**	**1.1**	**0.6**	**344**	**1940**	**0.1**	**36.7**	**2.3**	**4.5**	**0.3**	**367**	**0.5**	**0.3**
E.4486	Green	Opaque	5.7	0.1	75	219	4.3	3.3	106	1980	1.4	2.5	58.1	710	2.6	11.0	1314	24.3	0.8	0.3	1.4	1322	0.1	72.4	1.7	3.3	0.0	12641	0.4	0.2
E.4486.1	Green	Semi-translucent	4.2	0.1	72	292	5.7	4.6	158	2243	1.6	3.2	43.8	12.4	1.0	8.3	535	21.2	1.0	0.1	1.1	13.0	0.1	29.4	1.7	3.3	0.0	2.4	0.4	0.2
OX140	Green	Semi-translucent	6.5	0.1	62	270	5.2	5.2	128	1948	2.1	3.3	98.2	19.8	1.2	33.1	1232	28.7	1.0	0.1	2.1	7.2	0.6	24.0	1.9	3.9	0.0	12.7	0.4	0.2
OX484	Green	Opaque	5.5	0.1	69	288	5.5	4.8	125	2966	1.8	3.5	54.2	1067	4.5	9.6	1397	36.0	1.0	0.5	2.9	4155	0.1	89.7	2.1	4.2	0.0	24358	0.5	0.4
Green average			**5.5**	**0.1**	**70**	**267**	**5.2**	**4.5**	**129**	**2284**	**1.7**	**3.1**	**63.6**	**452**	**2.3**	**15.5**	**1120**	**27.6**	**1.0**	**0.3**	**1.9**	**1374**	**0.2**	**53.9**	**1.8**	**3.7**	**0.0**	**9254**	**0.4**	**0.2**
OX77	Purple	Translucent	9.1	1.0	65	341	8.9	4.3	5795	4948	9.7	12.3	386	157	3.6	8.5	552	23.5	1.3	0.4	11.3	33.7	0.1	50.4	3.0	5.8	0.0	26.9	0.6	0.6
OX85	Purple	Translucent	6.2	0.1	58	384	7.8	5.8	2080	2389	2.2	3.3	51.6	22.9	1.7	8.2	897	37.2	1.3	0.1	3.1	0.9	0.1	57.1	2.3	4.5	0.0	4.2	0.5	0.3
OX444	Purple	Translucent	6.3	0.4	84	491	8.0	7.1	1651	5606	717	281	30.8	132	1.1	5.9	787	29.7	1.5	0.0	1.4	11.7	0.1	45.8	2.6	6.2	0.0	8.8	0.7	0.3
Purple average			**7.2**	**0.5**	**69**	**405**	**8.2**	**5.7**	**3175**	**4814**	**243**	**99**	**156**	**104**	**2.1**	**7.5**	**746**	**30.1**	**1.3**	**0.2**	**5.2**	**15.4**	**0.1**	**51.1**	**2.7**	**5.5**	**0.0**	**13.3**	**0.6**	**0.4**
OX122	White	Opaque	8.6	0.1	100	315	5.4	3.3	205	1981	1.4	2.6	1401	12.6	23.3	4.9	576	21.8	0.9	0.1	1977	7137	0.1	37.3	1.9	3.6	0.0	63.4	0.4	0.2
OX641	White	Opaque	4.5	0.1	71	335	6.7	3.3	169	2173	1.9	2.9	1304	15.1	30.5	4.9	555	13.3	1.0	0.3	1.2	18899	0.1	30.2	1.9	3.7	0.3	27.1	0.5	0.4
White Average			**6.6**	**0.1**	**86**	**325**	**6.1**	**3.3**	**187**	**2077**	**1.6**	**2.7**	**1353**	**13.9**	**26.9**	**4.9**	**565**	**17.5**	**1.0**	**0.2**	**989**	**13018**	**0.1**	**33.8**	**1.9**	**3.7**	**0.2**	**45.2**	**0.4**	**0.3**

(continued on next page)

Table 3 (*continued*)

				Trace elements (ppm)																																			
	High Magnesia High Potash																																						
As. Number	Colour group	Translucent/ Opaque	Li	Be	B	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Rb	Sr	Zr	Nb	Ag	Sn	Sb	Cs	Ba	La	Ce	Au	Pb	Th	U
OX264	Yellow	Opaque	6.1	0.1	74	237	4.6	3.6	108	2058	1.4	2.7	700	914	3.0	10.9	1371	24.6	0.8	0.4	12.5	1672	0.1	72.0	1.8	3.5	0.0	13053	0.4	0.2
OX444	Yellow	Opaque	5.3	0.4	59	341	6.8	5.4	146	9148	2.0	4.7	827	23.5	23.2	7.4	687	27.3	1.2	11.3	1.6	11654	0.1	38.4	2.3	4.5	0.0	63781	0.6	0.3
OX561	Yellow	Opaque	5.7	0.1	67	295	5.6	5.3	127	3267	1.8	3.7	669	1426	5.8	9.4	1542	36.5	1.0	0.6	3.0	6037	0.1	107.7	2.2	4.2	0.0	29053	0.7	0.4
Yellow average			**5.7**	**0.2**	**67**	**291**	**5.7**	**4.7**	**127**	**4818**	**1.7**	**3.7**	**732**	**788**	**10.7**	**9.2**	**1200**	**29.4**	**1.0**	**4.1**	**5.7**	**6454**	**0.1**	**72.7**	**2.1**	**4.1**	**0.0**	**35295**	**0.6**	**0.3**
OX334	Red	Opaque	5.3	0.1	85	263	5.6	4.0	167	1853	4.2	8.0	9584	17.1	41.5	6.6	424	13.1	0.8	0.9	952	1140	0.1	32.0	1.7	3.3	0.1	45.8	0.4	0.2
OX226	Amber	Translucent	5.3	0.1	91	300	4.2	4.1	255	1719	0.8	1.6	41.9	9.3	0.8	3.9	391	19.1	1.0	0.0	0.4	3.2	0.1	32.5	1.8	3.4	0.0	1.1	0.4	0.1
Low Magnesia Low Potash																														
OX641	Co+Cu blue	Opaque	7.7	0.2	102	591	9.3	6.9	83	4819	667	12.0	10662	926	88.3	5.3	222	50.0	1.8	1.1	31.4	8998	0.1	42.4	3.0	6.0	1.6	23930	0.7	0.8

exclusively in the 18th Dynasty (Kaczmarczyk, 1986; Abe et al., 2012). Therefore, all six Co + Cu glasses were likely produced in the 18th Dynasty. In addition, several fragments from both the Co– and Co + Cu-blue groups exhibit finely applied patterns in several colours and styles, supporting the evidence that these were produced in the 18th Dynasty, likely by expert craftsmen at Malkata or Amarna (Shortland, 2012, p62).

4.4. Copper blue

All 12 Cu-blue glasses in this group are within known LBA Egyptian Cu-blue composition ranges, coloured with an average of 0.78 % CuO and contain associated elevated levels of Sn of between 104 ppm and 913 ppm, indicative of a bronze copper source (Kaczmarczyk and Hedges, 1983; Shortland and Eremin, 2006; Shortland, Rogers and Eremin, 2007). Cu-blue glasses are one of the most prevalent types of glass in the Egyptian LBA and outliers of indicative elements can make dating difficult. One dating indicator for later Cu-blue glasses is the use of lead-rich bronze used in the Ramesside period (Rademakers, Rehren and Pernicka, 2017). However, this presents challenges as atypically high lead contents are observed in several studies examining Egyptian Cu blue glasses which are firmly dated to the 18th Dynasty (Shortland and Eremin, 2006; Shortland, Rogers and Eremin, 2007; Lankton, Pulak and Gratuze, 2022).

OX195, OX198 and OX235 exhibit fine examples of feather patterns in yellow and white, therefore are stylistically typical of 18th Dynasty vessels (Nolte, 1968). Two of the Serabit Pb-rich glasses, OX70 and OX482, have basic yellow patterns applied, therefore the high lead may be due to contaminated crucibles or represent less skilful vessels produced at a later workshop using a lead rich bronze. Stylistic elements on the remaining fragments are either obscured by thick surface deposits or do not have a perceivable pattern, therefore cannot be used to further narrow the production epoch.

4.5. Yellow

Although variations are observed in Egyptian LBA yellow glasses, notably in the concentrations of Sb and Pb, the three yellow glasses are comparable with published Egyptian LBA compositions (Shortland and Eremin, 2006; Shortland, 2012; Kemp, Brownscombe and Shortland, 2021). In the 18th Dynasty, yellow glass is more commonly used for decorative elements but became more common for ground colour after the Amarna period (Nolte, 1968). OX264 and OX561 are similar in composition, but different formats; OX264 is a yellow monochrome fragment with no distinguishable pattern whereas OX561 is a brown glass fragment with an undetermined yellow pattern (possibly uneven feather?) applied. Only seven yellow vessels are described in *Die Glassgefässe im alten Ägypte*, all of which are broadly dated to between the reigns of Tutankhamen (1336–1327 BCE) to Pinodjem II (990–969 BCE) the latter whose reign stands at the end of the 21st Dynasty, therefore it is likely that OX264 is a vessel produced after the Amarna period. OX561 is described in the brown glass section.

OX444 is a rounded, opaque, yellow core formed vessel fragment with a dark and white glass twisted decoration. Two opaque yellow pilgrim flasks, described in *Die Glassgefässe im alten Ägypten*, dated between the 19th and 20th Dynasty, show strong stylistic similarities (Nolte, 1968, p75). OX444 also contains the highest Sb_2O_3, PbO, and Fe_2O_3 content of the group and exhibits significantly higher concentrations of As and Ag with significantly lower concentrations of Zn and Sr, which indicates that the lead source may have been derived from a by-product of silver production, litharge (Mass, Wypyski and Stone, 2002). This would account for the higher Ag content and the low Zn content, which would be considerably depleted during this process. The processing of litharge is a later practice, and therefore supports the proposition that this vessel was likely produced between the 19th and 20th Dynasty (Nolte, 1968). The purple glass from the same fragment (described in the later section) also provides strong evidence for

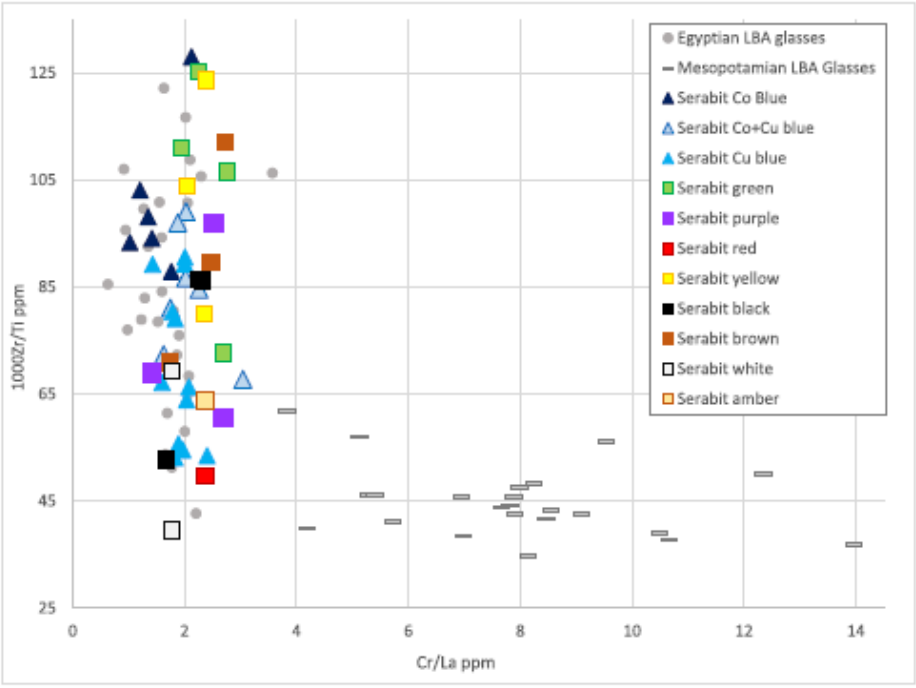

Fig. 1. Covariant plot of Cr/La vs 1000Zr/Ti comparing the glasses from Serabit. Samples are plotted against the Egyptian and Mesopotamian glasses of known origin (Shortland, Rogers and Eremin, 2007).

classification of OX444 as a Ramesside glass.

4.6. Black

The three black Serabit glasses have the highest average MgO of all the colour groups at 4.74 % and the highest Al_2O_3 concentration at 0.72 % in the study group, excluding those glasses containing significant cobalt. The Serabit black glasses contain very low levels of Co, Cu and Mn and therefore reflect the colouring strategy that achieves a dark/black hue without the apparent deliberate addition of colourants (Turner, 1956; Sayre and Smith, 1974). OX122 and OX299 are similar in composition and both appear closer to LBA Egyptian colourless glasses (Shortland, Rogers and Eremin, 2007) compared with early black glasses from the reigns of Tuthmosis III and Amenhotep II, that achieved black hues by colouring the glass a very deep blue or purple using copper, cobalt, manganese or a combination of colourants (Lilyquist et al., 1993, p36; Jackson and Nicholson, 2007, p107). Interestingly, the composition of OX144 is comparable with green samples E.4486 and OX484, which also contain trace levels of CuO and elevated Sb_2O_3 and PbO with lower concentrations of Fe_2O_3 and Al_2O_3, indicating that both glasses were manufactured according to an exacting process, possibly at the same workshop.

The Fe-black colouring strategy is identified in other black glasses from Amarna and in later glasses from Lisht, Gurob and Timna (Brill, 1999; Shortland and Eremin, 2006; Lankton, Pulak and Gratuze, 2022). Therefore, the black Serabit glasses represent later Fe-black glasses, which appear from the reign of Akhenaten. A particularly skilful feather pattern is applied to OX122 which could indicate that this was an early Fe-black glass vessel produced at Amarna.

4.7. Green

The four Serabit green glasses fall into two distinct groups: The first group, E.4486 and OX484, contain 0.16 % and 0.5 % Sb_2O_3, high concentrations of 1.46 % and 2.81 % PbO respectively, and notably elevated zinc which suggests that they were opacified with lead antimonate (Shortland, 2002). The second group, E.4486.1 and OX140, contain below 50 ppm of Zn, Sb_2O_3 and Pb. All four glasses contain trace CuO, therefore the green hue is likely achieved from natural impurities in the raw materials (Schreurs and Brill, 1984; Varberg, Gratuze and Kaul, 2015).

Remarkably, SEM-WDS analysis of 15 green glasses (working debris, rods and vessel fragments) from the LBA Egyptian sites of Malkata and Amarna (Shortland and Eremin, 2006), and LA-ICP-MS analysis of 10 green glasses from Amarna (Lankton, Pulak and Gratuze, 2022) showed that all 25 samples were coloured using CuO, 24 of which were opacified using lead antimonate. Research undertaken by Varberg et al. identified green glass rods from Amarna that showed three distinct compositions and were of both Egyptian and Mesopotamian origin, confirming not only the exchange of glass between the two regions, but also that both Cu and non-Cu green colouring strategies were worked contemporaneously at Amarna (Varberg et al., 2016). E.4486.1 and OX140 specifically are comparable with a green glass rod from the Varberg study, 7412, which is of Egyptian provenance and exhibits similar low concentrations of Sb, Pb, and Zn all below 50 ppm with low levels of CuO (Varberg et al., 2016).

Therefore, the four green Serabit glasses are likely produced from the Amarna period onwards, however, one of the green fragments, OX484, has a distinctive rounded edge with a yellow rim, likely a "leaf" from the neck of a pomegranate vessel. A green pomegranate vessel with a yellow rim is described in *Die Glasgefässe im alten Ägypten* (Accession Number AF 1571, p133, plate number XXVII) and a virtually identical vessel is currently held at the Metropolitan Museum of Art, New York (Accession Number 44.4.52). Pomegranate vessels are broadly dated between the reigns of Tutankhamen (1336–1327 BCE) to Pinodjem II (990–969 BCE) (Nolte, 1968), therefore OX484 represents a later non-Cu green glass

Table 4
Summary of Serabit glass production periods.

As. Number	Proposed production date
High Magnesia High Potash glass fragments	
Black	
OX122	Amarna period onwards, from the reign of Akhenaten (1352–1336 BCE) to Rameses VI (1143–1136 BCE).
OX144	
OX299	
Brown	
OX358	Amarna period onwards, from the reign of Akhenaten (1352–1336 BCE) to Rameses VI (1143–1136 BCE).
OX420	
OX561	
Co blue	
OX189	18th Dynasty, between the reigns of Tuthmosis III (1479–1425 BCE) and Akhenaten (1352–1336 BCE).
OX193	
OX414	
OX433	
OX437	
OX669	
Co + Cu blue	
OX107	18th Dynasty, between the reigns of Tuthmosis III (1479–1425 BCE) and Akhenaten (1352–1336 BCE).
OX183	
OX200	
OX481	
OX501	
OX84	
Cu blue	
OX195	Stylistically dated to 18th Dynasty between the reigns of Tuthmosis III (1479–1425 BCE) and Akhenaten (1352–1336 BCE) owing to the fine examples of pattern application.
OX198	
OX235	
OX70	Composition potentially indicates post-Amarna production due to high lead content and basic pattern application. From the reign of Akhenaten (1352–1336 BCE) to Rameses VI (1143–1136 BCE).
OX482	
OX103	Dated to between the reigns of Tuthmosis III (1479–1425 BCE) and Rameses VI (1143–1136 BCE).
OX127	
OX429	
OX442	
OX472	
OX488	
OX897	
Green	
E.4486	Amarna period onwards, from the reign of Akhenaten (1352–1336 BCE) to Rameses VI (1143–1136 BCE).
E.4486.1	
OX140	
OX484	Pomegranate vessel produced between the reigns of Tutankhamen (1336–1327 BCE) and Rameses VI (1151–1143 BCE).
Purple	
OX77	Dated to between the reigns of Tuthmosis III (1479–1425 BCE) and Rameses VI (1143–1136 BCE).
OX85	
OX444	19th-20th Dynasty - Rameses I (1295–1294 BCE) and Rameses VI (1143–1136 BCE).
White	
OX122	Amarna period onwards, from the reign of Akhenaten (1352–1336 BCE) to Rameses VI (1143–1136 BCE).
Yellow	
OX264	Amarna period onwards, from the reign of Akhenaten (1352–1336 BCE) to Rameses VI (1143–1136 BCE).
OX561	
OX444	19th-20th Dynasty - Rameses I (1295–1294 BCE) and Rameses VI (1143–1136 BCE).
Red	
OX334	Dated to between the reigns of Tuthmosis III (1479–1425 BCE) and Rameses VI (1143–1136 BCE).
Amber	
OX226	Dated to between the reigns of Tuthmosis III (1479–1425 BCE) and Rameses VI (1143–1136 BCE).
Low Magnesia Low Potash Co + Cu blue and white glass fragment	
OX641	Likely represents one of the last glass offerings made to the temple, therefore (later) 20st Dynasty.

produced after the Amarna period (Nolte, 1968).

4.8. Brown

The three brown Serabit glasses are compositionally similar and follow the same colouring strategy, containing between 0.87 % and 2.02 % CuO and likely opacified using lead antimonate. They contain the associated high levels of Sn and As at 867 ppm and 33 ppm respectively, indicating a bronze Cu source was used. The Serabit brown glasses are therefore compositionally different to brown glasses analysed in the 2006 Shortland et al. study which include an early glass, twelve glasses from Malkata and Amarna, and two glasses from Lisht, all of which have no deliberately added colourant (Shortland and Eremin, 2006). Brown vessels are rare and are broadly dated from the reign of Tutankhamun to Pinodjem II (Nolte, 1968), although some brown glasses are known from Amarna (Jackson and Nicholson, 2007). OX561 has a yellow glass applied which appears to be a later composition from the by-product of litharge practiced in the Ramesside period (Mass, Wypyski and Stone, 2002). Therefore, the three Cu-brown glasses may represent a new colouring strategy at a specialist workshop.

4.9. Amber

OX226 is a pale amber hue with no apparent colourant deliberately added, therefore this glass is comparable with published amber/colourless glasses from the LBA (Shortland and Eremin, 2006; Shortland, 2012, p104). Notably, this glass falls within the Lisht compositional criteria.

4.10. Purple

The Serabit purple glasses show some variation between the colouring strategies, however all three are comparable with known Egyptian LBA manganese-purple glass compositions (Shortland and Eremin, 2006; Kemp, Brownscombe and Shortland, 2021). Both OX77 and OX444 exhibit a visibly deeper hue than OX85, which contains 0.27 % MnO with no additional colourants added. OX77 contains 0.75 % MnO, the highest concentration in the Serabit glasses, in addition to an elevated Fe_2O_3 concentration of 0.71 %.

OX444 contains 0.21 % MnO, 0.80 % Fe_2O_3, and interestingly 0.09 % CoO which likely contributes to the darker hue. Purple glasses enhanced with cobalt and/or elevated concentrations of Fe have been observed in the LBA, therefore OX444 exhibits a known colouring strategy (Shortland and Eremin, 2006). OX444 contains significantly lower alumina than New Kingdom glasses containing cobalt and has depleted Zn with elevated Ni, therefore comparable with the "Type R" source used during the 19th-20th Dynasty (Abe et al., 2012). This date is consistent with the yellow glass from the same fragment described earlier, and therefore can be confidently dated to the Ramesside period.

4.11. Red

OX334, the only red glass from the selected Serabit material, is a standard high magnesia LBA Egyptian red glass coloured with 1.2 % CuO and opacified with 0.14 % Sb_2O_3 with an associated elevated concentration of Sn (952 ppm), As (42 ppm) but notably very low lead (46 ppm). Red is one of the rarest Egyptian LBA glasses and published compositions from the 18th Dynasty show wide variations in base composition and colouring strategy (Lilyquist et al., 1993; Shortland and Eremin, 2006; Pusch and Rehren, 2007; Kemp, Brownscombe and Shortland, 2021; Lankton, Pulak and Gratuze, 2022). The red glass from Serabit also falls within the Lisht compositional criteria.

4.12. White

OX122 is a standard white LBA glass opacified with antimony (Shortland and Eremin, 2006; Kemp, Brownscombe and Shortland, 2021) and applied to a Fe-black vessel, the composition of which indicates a later glass as discussed.

4.13. Ox641

OX641 is a white core-formed vessel fragment, with a dark blue (possibly garland) pattern applied. The white glass is of standard LBA composition but contains notably high soda, and is low in lime, alumina, and iron oxide, consistent with glasses produced at Lisht (Smirniou, Rehren and Gratuze, 2018). The blue Co + Cu decoration from the same fragment contains 0.49 % MgO and 0.91 % K_2O, therefore consistent with natron glasses produced in the IA which are characterised by MgO and K_2O concentrations between 0.5 and 1.5 % (Lilyquist et al., 1993, p56). The blue glass contains 2.7 % CaO which is significantly lower than the lime content of the other Serabit glasses in addition to containing a high concentration of CuO with low Sn, indicating the use of a pure copper source. The blue OX641 glass also contains 1.0 % Al_2O_3 and low levels of nickel, zinc and manganese, therefore compares with "Type N1" cobalt, characterised as having "lack of nickel and depletion of zinc" with low MnO, and used in natron glasses during the Late Period (Abe et al., 2012). Therefore, OX641 represents the first identified example of a vessel composed of a plant ash body with a natron glass decoration.

The OX641 Co + Cu blue glass is similar in composition to those from the tomb of Nesikhons, containing between 0.3 and 1.2 % MgO, 0.4–0.9 % K_2O and 1.3–4.8 % CaO (Schlick-Nolte and Werthmann, 2003). These glasses are considered to be among the last glass vessels produced in Pharaonic Egypt, manufactured in the early 10th century BCE. OX641, therefore, was the last glass offering made to the temple in the study group and likely corresponds with the culmination of Egyptian presence at Serabit in the 20st Dynasty.

5. Conclusion

All glasses in the Serabit study group, excluding fragment OX641, are high magnesia plant ash glasses of Egyptian provenance. Excluding OX641, the 12 blue glasses containing cobalt can be confidently dated to the 18th Dynasty by the characteristic cobaltiferous alum, therefore likely produced in the workshops of Malkata and Amarna. Fragment OX444, containing both purple and yellow glass, can also be confidently dated to the 19th-20th Dynasty by the distinctive Type R cobalt signature and likely use of litharge for the lead source. Unlike early compositions of green and black glasses, the Serabit green and black glasses appear to have no deliberate colourant added and therefore compare with later glasses made during the Amarna period and after. The Serabit glass group exhibit differing strategies for producing 'rarer' ground colours, which became more commonly used in the Ramesside period, therefore reflective of the increase in activity at Serabit during this time. Where present, the stylistic features of vessel types provided production period 'milestones' and were used in conjunction with compositional information to narrow the dates of production; this is exemplified by the green fragment OX484 which is likely a leaf from a pomegranate vessel.

OX641 is a unique example of a vessel using early natron Co + Cu blue glass, coloured with the later N1 cobalt source, to decorate a white vessel made of high magnesia plant ash glass, with both glasses falling clearly within the Egyptian provenance range. That the Co + Cu natron blue glass is applied to a white glass body of standard LBA plant ash glass confirms that the two glass technologies were worked contemporaneously.

Three periods of Egyptian core-formed vessel glassmaking are therefore represented at Serabit: 18th Dynasty plant ash glass, plant ash Ramesside glass and natron Ramesside glass, which corresponds with the known periods of Egyptian activity at Serabit.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2023.103920.

References

Abe, Y., Harimoto, R., Kikugawa, T., Yazawa, K., Nishisaka, A., Kawai, N., Yoshimura, S., Nakai, I., 2012. Transition in the use of cobalt-blue colorant in the New Kingdom of Egypt. J. Archaeol. Sci. 39 (6), 1793–1808.
Aldred, C., 1971. Jewels of the pharaohs: egyptian jewellery of the dynastic period. Thames and Hudson Ltd, London.
Aston, B., Harrell, J., Shaw, I., 2000. Stone. In: Nicholson, P.T., Shaw, I. (Eds.), Ancient Egyptian Materials and Technology. Cambridge University Press, Cambridge, pp. 195–226.
Barrois, A., 1932. 'The Mines of Sinai', *The Harvard Theological Review*. Cambridge University Press 25 (2), 101–121.
Brill, R.H., 1999. Chemical analyses of early glasses, Volume 1 (tables) and 2 (catalogue). Corning Museum of Glass, Corning, NY.
Caelen, V., 2013. Ceramics from the mining site of Serabit el-Khadem, Sinai, stored at the Harvard Semitic Museum - Revisiting of an old collection through petrographic and chemical analysis. KU Leuven.
Eckenstein, L., 1921. A History of Sinai. The Macmillan Co., London; New York.
Giveon, R., 1978. The impact of Egypt on Canaan: iconographical and related studies. Vandenhoeck & Ruprecht, Freiburg.
Grimal, N., 1992. A History of Ancient Egypt. Blackwell, Oxford.
Jackson, C.M., Nicholson, P.T., 2007. Brilliant Things for Akhenaten: The Production of Glass, Vitreous Materials and Pottery at Amarna Site O45.1. Egypt Exploration Society, London.
Jochum, K.P., Weis, U., Stoll, B., Kuzmin, D., Yang, Q., Raczek, I., Jacob, D.E., Stracke, A., Birbaum, K., Frick, D.A., Günther, D., Enzweiler, J., 2011. Determination of reference values for NIST SRM 610–617 glasses following ISO guidelines. Geostand. Geoanal. Res. 35 (4), 397–429.
Kaczmarczyk, A., Hedges, R.E.M., 1983. Ancient Egyptian faience: an analytical survey of Egyptian faience from predynastic to Roman times. Aris and Phillips, Warminster.
Kaczmarczyk, A. 1986 'The source of cobalt in ancient Egyptian pigments', in Olin, J. S. and Blackman, M. J. (eds) *Proceedings of the 24th International Archaeometry Symposium*. Washington: Smithsonian, pp. 369–376.
Keller, C.A., 1983. Problems of dating glass industries of the Egyptian New Kingdom: examples from Malkata and Lisht. Journal of Glass Studies 25, 19–28.
Kemp, V., Brownscombe, W., Shortland, A.J., 2021. The investigation and provenance of glass vessel fragments attributed to the tomb of Amenhotep II, KV35, Valley of the Kings. Archaeometry 64 (1), 147–160.
Lankton, J.W., Pulak, C., Gratuze, B., June 2021. (2022) 'Glass ingots from the Uluburun shipwreck: Glass by the batch in the Late Bronze Age', *Journal of Archaeological Science: Reports*. Elsevier Ltd 42, 103354. https://doi.org/10.1016/j.jasrep.2022.103354.
Lilyquist, C., et al., 1993. Part 2. Glass. In: Lilyquist, C., Brill, R.H. (Eds.), Studies in Ancient Egyptian Glass. Metropolitan Museum of Art, New York, pp. 23–58.
Mass, J.L., Wypyski, M.T., Stone, R.E., 2002. Malkata and Lisht glassmaking technologies: towards a specific link between second millennium BC metallurgists and glassmakers. Archaeometry 44 (1), 67–82.
Mumford, G.D., 1999. Serabit el-Khadim. In: Bard, K. (Ed.), Encyclopedia of the Archaeology of Ancient Egypt. Routledge, London, pp. 722–725.
Mumford, G., 2006. Egypt's New Kingdom Levantine Empire and Serabit El-khadim, including a newly attested votive offering of horemheb. J. Soc. Study of Egyptian Antiquities 33.
New, S., 1932. 'The Temple of Hathor', *the harvard theological review*. Cambridge University Press 25 (2), 122–129.
Nolte, B., 1968. *Die Glasgefasse im alten Ägypten, Münchner Ägyptologische Studien*. Verlag Bruno Hessling, Berlin.
Petrie, W.M.F., 1904. 'The Sinai Expedition', *Archaeological Report (Egypt Exploration Fund)*. Egypt Exploration Soc. 10–12.
Petrie, W.M.F., 1906. Researches In Sinai. John Murray, London.
Pusch, E., Rehren, T.h., 2007. Hochtemperatur-Technologie in der Ramses-Stadt: Rubinglass für den Pharao - Teil 2. Gerstenburg, Hildesheim.
Rademakers, F.W., Rehren, T.h., Pernicka, E., 2017. Copper for the Pharaoh: identifying multiple metal sources for Ramesses' workshops from bronze and crucible remains. J. Archaeol. Sci. 80, 50–73.

Redford, D. 1992 *Egypt, Canaan, and Israel in ancient times*. Princeton: Princeton University Press.
Rehren, T.h., Pusch, E., 2005. 'Late Bronze Age glass production at Qantir-Piramesses. Egypt', *Science* 308, 1756.
Rehren, T.h., Pusch, E., Herold, A., 2001. Problems and possiblities in workshop reconstruction: Qantir and the organisation of LBA glass workshops. In: Shortland, A. J. (Ed.), The Social Context of Technological Change. Oxbow books, Oxford.
Sayre, E.V., Smith, R.W., 1961. Compositional catagories of ancient glass. Science 133, 1824–1826.
Sayre, E.V., Smith, R.W., 1974. Analytical studies in ancient Egyptian glass. In: Bishay, A. (Ed.), Recent Advances in the Science and Technology of Materials. New York.
Schlick-Nolte, B., Werthmann, R., 2003. 'Glass Vessels from the Burial of Nesikhons', *Journal of Glass Studies*. Corning Museum of Glass 45, 11–34.
Schreurs, J.W.H., Brill, R.H., 1984. Iron and sulfur related colors in ancient glasses. Archaeometry 26 (2), 199–209.
Shortland, A.J., 2002. The use and origin of antmonate colorants in early Egyptian glass. Archaeometry 44 (4), 517–531.
Shortland, A.J., 2012. Lapis lazuli from the kiln : glass and glassmaking in the late bronze age. Leuven University Press, Leuven.
Shortland, A.J., Eremin, K., 2006. The analysis of second millennium glass from Egypt and Mesopotamia, Part 1: new WDS analyses. Archaeometry 48 (4), 581–605.
Shortland, A.J., Nicholson, P.T., Jackson, C.M., 2001. Glass and Faience at Amarna: different methods of both supply for production, and subsequent distribution. In: Shortland, A.J. (Ed.), The Social Context of Technological Change. Oxbow Books, Oxford, pp. 147–160.
Shortland, A.J., Rogers, N., Eremin, K., 2007. Trace element discriminants between Egyptian and Mesopotamian Late Bronze Age glasses. J. Archaeol. Sci. 34 (5), 781–789.
Simpson, P., 1990. 'Egyptian Core Glass Vessels from Sinai', *the journal of egyptian archaeology*. Egypt Exploration Soc. 76 (1), 185–186.
Smirniou, M., Rehren, T.h., 2013. Shades of blue - cobalt-copper coloured blue glass from New Kingdom Egypt and the Mycenaean world: a matter of production or colourant source? J. Archaeol. Sci. 40 (12), 4731–4743.
Smirniou, M., Rehren, T.h., Gratuze, B., 2018. Lisht as a new kingdom glass-making site with its own chemical signature. Archaeometry 60 (3), 502–516.
Turner, W.E.S., 1956. Studies in ancient glasses and glass making processes. Part IV. the chemical composition of ancient glasses. J. Soc. Glas. Technol. 40, 162–184.
Van Elteren, J.T., Tennent, N.H., Šelih, V.S., 2009. Multi-element quantification of ancient/historic glasses by laser ablation inductively coupled plasma mass spectrometry using sum normalization calibration. Anal. Chim. Acta 644 (1–2), 1–9.
Varberg, J., Gratuze, B., Kaul, P., 2015. Between egypt, mesopotamia and scandinavia: late bronze age glass beads found in denmark. J. Archaeol. Sci. 54, 168–181.
Varberg, J., Gratuze, B., Kaul, P., Hansen, A.H., Rotea, M., Wittenberger, M., 2016. Mesopotamian glass from Late Bronze Age Egypt, Romania, Germany, and Denmark. J. Archaeol. Sci. 74, 184–194.
Vicenzi, E.P., et al., 2002. Microbeam characterisation of Corning archaeological reference glasses: new additions to the Smithsonian Microbeam standard collection. J. Res. National Institute Standards and Technol. 107, 719–727.
Wagner, B., Nowak, A., Bulska, E., Hametner, K., Günther, D., 2012. Critical assessment of the elemental composition of Corning archeological reference glasses by LA-ICP-MS. Anal. Bioanal. Chem. 402 (4), 1667–1677.
Wilkinson, R.H., 2017. The complete temples of ancient egypt. Thames & Hudson Limited, London.

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DATING AND PROVENANCE OF GLASS ARTEFACTS EXCAVATED FROM THE ANCIENT CITY OF TALL ZIRĀʿA, JORDAN*

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Fourteen glass objects recovered from excavations at the ancient city of Tall Zirāʿa, Jordan, were analysed using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to determine the period and origin of manufacture. The composition of glasses manufactured in the Late Bronze Age (LBA) and Iron Age are distinctly different, therefore major element analysis can be used to distinguish between the groups relatively easily. The LA-ICP-MS analysis provided quantitative trace element data which were used to determine the provenance of those glasses identified as LBA. This research discusses the implications of the presence of both Egyptian and Mesopotamian LBA glasses and examines the varying compositions and colour strategies employed in both the LBA and Iron Age objects. Specifically, glass in the LBA was considered to be one of the highest status items attainable, playing an instrumental role in diplomatic gift-giving. When considered with the archaeological information, the significance of these finds at Tall Zirāʿa indicates that this city was a settlement of high status, not primarily a convenient trading stop on the Transjordan route.

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KEYWORDS: TALL ZIRĀʿA, GLASS, LATE BRONZE AGE, IRON AGE, LA-ICP-MS, EGYPT, MESOPOTAMIA

INTRODUCTION

The first deliberate manufacture of glass occurs in the 16th century BCE, although the origin of the material is still a focus of debate—Egypt or Mesopotamia being the most likely innovator. The conventional approach is that glass technology first developed in Mesopotamia (Barag 1970, 131–4; Moorey 1994, 192; Shortland *et al.* 2017) and that the subsequent transfer to Egypt could be ascribed to tribute associated with the successful military campaigns in the Levant by the Egyptian king Tuthmosis III (1479–1425 BCE). Although there is textual and iconographic evidence for the production, supply and transport of glass between Egypt, its vassal Levantine states and Mesopotamia, it is very rare to find Egyptian glass in Mesopotamia, or vice versa (Walton *et al.* 2009). The exceptions to date are two green glass rods found in Amarna, Egypt, which have trace element compositions consistent with Mesopotamian glass, and a collection of blue glass beads and a scarab recovered from a tomb in Gurob, Egypt, which also showed compositional consistency with glasses of known Mesopotamian origin (Varberg *et al*. 2016; Kemp *et al*. 2017, 2019). Although ubiquitous in modern life, glass in the Late Bronze Age (LBA) was meticulously controlled by the Egyptian royal court (Moorey 2001, 4). Glass in the LBA denotated high status and had sufficient value and importance to be a gift appropriate for the upper Egyptian elite, therefore playing an instrumental role in the etiquette of diplomatic gift-giving and tribute (Na'aman 2000; Shortland *et al.* 2001). To date, no glass of Egyptian trace element composition has been identified in the Levant or Mesopotamia. However, Egyptian glass has been identified in the Uluburun shipwreck, a vessel which sank in the late 14th century off the south-west Turkish coast with a large consignment of internationally sourced goods, including ebony, pottery from several states, elephant and hippopotamus tusks, copper ingots, tin ingots, and 175 glass ingots (Pulak 2001; Jackson and Nicholson 2010). Glass of both Egyptian and Mesopotamian compositions has also been identified at Tiryns in Mycenae (Walton *et al.* 2009; Smirniou and Rehren 2013; Varberg *et al*. 2016).

These observations strongly suggest that Egyptian and Mesopotamian glasses were extensively traded outside of their production areas, and this paper attempts to identify such glasses at Tall Zirāʿa, Jordan. When referring to glasses as 'Mesopotamian', it should be noted that the samples analysed by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analysis in Shortland *et al.* (2007) were excavated from the sites of Nuzi and Tell Brak specifically, therefore the term 'Mesopotamia' is used here to describe the collective LBA Near Eastern states that ruled the lands near the Euphrates and Tigris, including Assyria and Babylonia (Oppenheim 1977, 35–48). LA-ICP-MS provides a quantitative analysis of geologically relevant trace elements including, most importantly, Cr, La, Ti and Zr, which form a 'compositional fingerprint' that can be used to ascertain the region of manufacture (Shortland *et al.* 2007). Samples analysed from Tall Zirāʿa are compared with glasses from known centres of LBA glass production: Egypt and Mesopotamia.

When considered with the contextual and historical data of the Tall Zirāʿa site, the provenance data of early glass technology is pertinent to key research questions such as exchange mechanisms between foreign states, and relationships between proximate and distant areas of a single state. Therefore, the provenance information can be used to investigate the connections and diplomatic affiliations that this ancient city maintained with both Egypt and Mesopotamia through the LBA and Iron Age (IA). In addition, the presence of LBA glass would infer that Tall

Zirāʿa was more than a convenient stopping point on a trading route, but an important city in its own right, which was rewarded with the one of the highest accolades in the LBA.

The Levant

The Levant became the centre of an LBA international communication system, with long-distance trade routes playing an integral part (Pfälzner 2012, 770). The relationship between LBA Levantine potentates of the 'city-states' and the Egyptian royal administration can be perceived from the Amarna Letters, cuneiform tablets which contained the diplomatic correspondences between states (Moran 1992). From the language used in the Amarna Letters, the Levant was considered as a subordinate vassal state and was persistently subjected to the competing, dominating influences of the Egyptians, Mitanni and Hittites, and endured routine military campaigns which maintained Egyptian and then other supremacy over the Levant (Reader 2003, 349). However, trade and improved diplomatic relations between Egypt and Mesopotamia provided the Levant with stability, peace and prosperity, with only minor quarrels forming between neighbouring Levantine cities. The political landscape changed in 1350–1200 BCE when the Hittites conquered northern Syria by defeating the Mitanni, thereby initiating critical civil and political disorder.

After the Battle of Qadesh (1275 BCE) between the Egyptian and Hittite armies, and the subsequent collapse of the LBA, the southern Levant endured an extended period of complex social change during the IA; the great powers of Egypt and Mesopotamia withdrew, resulting in urban decline. The resulting power vacuum allowed the Levantine elite to re-establish their power and assume positions of rule, subsequently allowing the city-states to assert their independence and expand their international connections (Joffe 2002). Some central Levantine cities also continued in a contracted state but were quickly reoccupied by the Philistines, Teukrians and incumbent tribal factions that joined to form the states of Israel (Redford 1992, 289, 298). The Levant accumulated independent wealth and the Egyptian nation rekindled its interest in goods provided by the lucrative Phoenician trade, maintaining relations to secure the supply of imported and luxury commodities (Goedicke 1975).

Tall Zirāʿa

Tall Zirāʿa is located in the Wādī al-_x0201B;Arab situated in northern Jordan, approximately 5km from the ancient Decapolis city of Gadara in modern-day Umm Qēs (Fig. 1). Excavations were carried out by the German Protestant Institute of Archaeology, Amman (GPIA), and the Biblical Archaeological Institute in Wuppertal (BAI), University of Wuppertal. The current excavations are supported by the Department of Antiquities of Jordan and financed by the German Archaeological Institute (DAI).

The site is located in the middle of the Wādī al-_x0201B;Arab, providing excellent living conditions with its numerous springs, fertile soil and temperate climate (Hanbury-Tenison 1984). The Tall measures approximately 200m in diameter, with the highest point located 17m below sea level. The significance of the site can be directly attributed to the artesian spring situated in the centre. The advantageous settlement conditions meant that Tall Zirāʿa was consistently occupied from the Early Bronze Age to the Islamic period, providing the singular opportunity to examine an unbroken comparative stratigraphy (Steuernagel 1926; Vieweger and Häser 2017, 16–19). Notably, Tall Zirāʿa was located on an LBA and IA trade route, which connected the Jordan Valley with the Mediterranean coast via the Jezreel plain and Tall al-_x01E24;iṣn

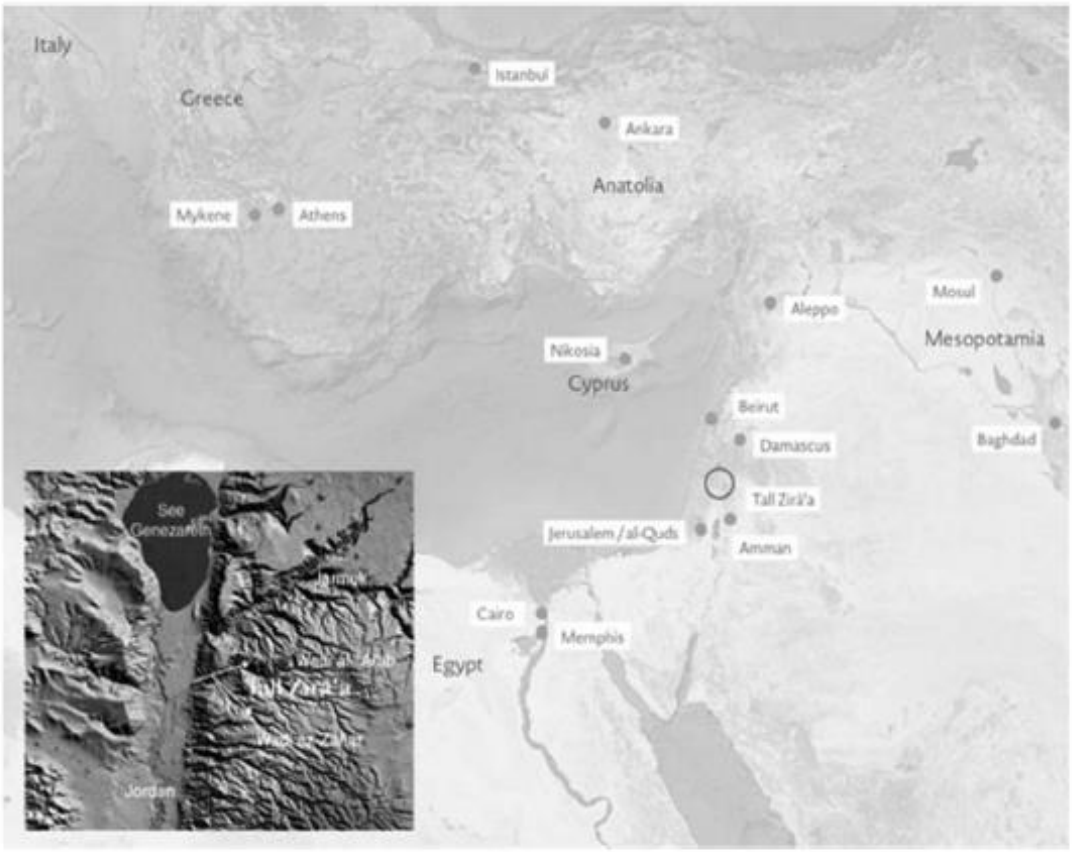

Figure 1 *Location of Tall Zirāʿa in the Wādī al-ʿArab. Design: after Walter, in Vieweger and Häser (2019), 29, fig. 1.5.*

(Beth Shean) in the west and with the Jordanian highlands in the east (Fig. 1). Owing to this favourable geography as well as to numerous finds that testify to the trade between the inhabitants of Tall Zirāʿa with neighbouring regions, the excavators infer that the Wādī al-_x0201B;Arab was part of an important trade route connecting Egypt with Syria and Mesopotamia (Vieweger and Häser 2017, 14, 21–22).

SAMPLES AND METHODOLOGY

The glass objects analysed were excavated from Area I on the western slope of the Tell. Overall, approximately 142 pieces of glass from the LBA (stratum 14, 1500/1450–1200/1150 BCE) and approximately 287 pieces from the IA period were recovered: 92 from IA I (stratum 13, 1200/1150–1000/980 BCE) and 195 from IA IIA-C (stratum 12–10, 1000/980–520 BCE) period.

The LBA settlement (strata 16–14) consists of agglutinating domestic buildings and a casemate wall with an attaching tower. The LBA temple (complex D) was built on a terrace in the last phase of the LBA period; the radiocarbon samples from the *cella* of the temple indicating a date between 1450 and 1300 BCE. The discovery in this area of a scarab with the cartouche of Egyptian king Amenhotep III (1388–1351 BCE) confirms this date (Vieweger and Häser 2019, 57–59). The final LBA phase can be attributed to *c.*1200–1150 BCE, again according to radiocarbon dating (Soennecken 2017, 223).

The temple consists of a rectangular *cella* (2.15×3.40m) with a central column to carry the roof, a portico, a staircase (numbered D2), a large well-paved courtyard (D4) (150 m^2) and four small rooms in the east (D5–8). The solid foundations of the temple, as well as the staircase, indicate that the building had at least two stories (Soennecken 2017, 171–88, 327; Vieweger and Häser 2017, 56). Five of the glass objects analysed were found in deposition layers in the temple *cella*, and one was excavated from the courtyard area (Table 1).

Unfortunately, many contexts around the temple area which yielded glass finds appear to be disturbed by later building activities, and thus do not provide a precise date, for example: contexts 4674, 6343 and 2726. Around 1200 BCE, the LBA temple together with the entire city was destroyed; shortly after but still during the IA I period, the temple was re-erected, but changed its outline. In the IA II period, the temple was abandoned and residences were built directly on the former IA I temple using its foundation walls. The two glass finds from the IA II period (stratum 12) were found in a deposition layer (locus 2650) of one of these domestic building complexes, complex B (room B3) (Soennecken 2017, 588–90).

The 15 glass or related objects selected for LA-ICP-MS analysis were chosen primarily to represent a range of object types and periods from the site, with the emphasis on the LBA period. Second, these objects were selected as they appeared to show a good level of preservation, the criteria of which included no obvious degradation or weathering, strong colour and clarity. Previous experience of work by inductively coupled plasma mass spectrometry (ICP-MS) on glass has shown that weathered, white, powdery glasses (which is often the norm) rarely produce interpretable results and should be avoided.

Small samples around a few millimetres across were clipped from the 15 glass objects and fragments with a pair of wire cutters. The samples were mounted in resin blocks and polished flat. The samples were subjected to LA-ICP-MS analysis at the Natural History Museum, London. The instruments used were an Agilent 7700 ICP-Q-MS mass spectrometer coupled to an ESI NWR193 with laser type ArF excimer with an ablation spot of 50µm, as detailed in the in the additional supporting information.

Each sample was analysed at different 12 spots, avoiding any obvious weathered areas. Rarely, where low Na values suggested that weathered areas were sampled, these points have been removed to standardize the consistency of the samples and ensure the accuracy of the results. Corning A standard was run throughout the LA-ICP-MS analysis to check for accuracy and drift. The results are shown in Table 2, where they are compared with established values for the standards. The values for the major elements for Corning A were taken from Vicenzi *et al.* (2002). The results show good agreement for the most elements, with the standards averaging < 10% error on accuracy. Elements that greatly exceed these values can be split into two groups: elements where the standard only contains parts per billion and it is not well determined (e.g., Au and Cs) and elements where the ICP struggles because of interferences, monoisotopic elements and/or other factors (e.g., P).

RESULTS

The average compositions of the major elements in Table 3 show that 14 samples were glasses, and that they fall into three distinct compositional groups: high magnesia/high potash (HMHK), high magnesium/low potash (HMLK) and low magnesia/low potash (LMLK). The remaining sample (16622a) was not glass and is discussed below.

Table 1 *Summary of the objects excavated at Tall Zirā'a, Jordan*

Sample number	*Find number*	*Object description*	*Colour*	*Locus*	*Context*
Iron Age context					
15329	TZ 015329-001	Fragment of a spacer bead	Opaque turquoise	4674	Stratum 10 (IA IIC) Deposition layer located in the area above the Late Bronze Age (LBA) temple courtyard
16753	TZ 016753-001	Core-formed vessel fragment	Opaque (?), black/dark blue and white	5410	Stratum 12 (IA IIA/B) Deposition layer located in 'complex A', room A3
10047	TZ 010047-001	Fragment of a spacer bead	Translucent turquoise	2726	Stratum 12 (IA II A/B) Deposition layer located west of the large complex B; most probably mixed with earlier layers that belong to the LBA temple
10048	TZ 010048-001	Fragment of a round bead	Translucent yellow/ brown	2728	Stratum 13 (IA I) Round silo in complex G; domestic context with storage facilities and working areas
18802	TZ 018802-001	Core-formed vessel fragment	Translucent dark blue	5942	Stratum 13 (IA I) Filling layer located in 'complex C' east of the paved temple courtyard C1
16622b	TZ 016622-001	Irregular fragment	Translucent colourless	5105	Stratum 13 (IA I) Floor level of area B2, on the outside
16622a	TZ 016622-001	Fragment of a hemisphere bead	Translucent yellow	5105	(north) of the IA I temple
Late Bronze Age context					
10779	TZ 010779-001	Fragment of a naked female figurine pendant	Translucent turquoise	2796	Stratum 14 (LBA) Deposition layer in the *cella* of the temple
10772	TZ 010772-001	Irregular fragment, probably a piece of raw glass	Opaque white with opaque blue centre	2777	Stratum 14 d (final LBA)
10170	TZ 010170-001	Fragment of a disc pendant	Opaque turquoise		Deposition layer in the *cella* of the temple
10762	TZ 010762-001	Fragment of a bead	Translucent dark blue		Stratum 14 d (final LBA)
10765	TZ 010765-001	Fragment of a spherical bead	Opaque turquoise		Deposition layer in the *cella* of the temple
16759	TZ 016759-001	Irregular lump	Translucent light green	5520	Stratum 14 d (final LBA) Deposition layer in courtyard D4 of the LBA temple complex
19322	TZ 019322-001	Fragment of a spacer bead	Translucent turquoise	6416	Stratum 16, 15, 14 (Middle Bronze Age (MBA) C-LBA) 'Complex A', room 4, mixed filling layer
19320	TZ 019320-001	Fragment of a bead	Opaque turquoise	6343	Stratum 16 (MBA C) Deposition layer in the area of room 9 'complex B'

Table 2 *Average results of the Corning A standard compared with two sets of reference values*

Analyte measured	*Atomic mass*	*Average Corning A values from Tall Zirā'a (n = 15)*	*Shortland* et al. *(2007) and Vicenzi* et al. *(2002)*		*Wagner* et al. *(2012)*	
			Accepted value (mg kg^{-1})	*Relative error*	*Accepted value (mg kg^{-1})*	*Relative error*
Na_2O	Na23	14.3	14.3	−0.1	13.4	6.2
MgO	Mg24	2.4	2.7	−11.4	2.5	−4.7
Al_2O_3	Al27	0.9	1.0	−9.0	0.8	10.6
SiO_2	Si29	67.2	66.5	1.1	67.8	−0.8
P_2O_5	P31	0.1	0.1	24.3	0.1	17.6
K_2O	K39	3.0	2.7	8.8	3.5	−15.6
CaO	Ca43	5.2	5.0	2.8	4.9	4.5
MnO	Mn55	1.0	0.9	10.1	1.1	−13.7
FeO	Fe57	0.8	0.8	−1.0	0.9	−5.7
CoO	Co59	0.2	0.2	12.2	0.2	1.3
CuO	Cu65	1.2	1.0	19.4	1.1	9.7
Sb_2O_3	Sb121	1.6	1.3	18.8	1.7	−6.8
PbO	Pb208	0.1	0.1	18.1	0.1	n.r.
Li	Li7	51.3	46.0	51.0	10.3	0.5
Be	Be9	0.1	0.1	n.r.	31.8	n.r.
B	B11	751	537	851	28.5	−13.3
Ti	Ti47	4867	4226	4428	13.2	9.0
V	V51	36.0	34.0	39.0	5.5	−8.4
Cr	Cr52	21.2	18.0	21.0	14.9	0.8
Ni	Ni60	186	160	181	13.8	2.5
Zn	Zn66	413	410	386	0.8	6.6
As	As75	30.7	25.0	n.r.	18.5	n.r.
Rb	Rb85	85.8	82.0	82.0	4.5	4.5
Sr	Sr88	935.0	860.0	897.0	8.0	4.1
Zr	Zr90	38.2	40.0	37.0	−4.8	3.1
Nb	Nb93	0.6	0.6	n.r.	−6.3	n.r.
Ag	Ag107	17.2	14.0	n.r.	18.4	n.r.
Sn	Sn118	1482	1194	1357	19.4	8.4
Sb	Sb121	13,109	10,649	14,002	18.8	−6.8
Cs	Cs133	0.3	0.2	n.r.	26.4	n.r.
Ba	Ba137	4651	3905	4122	16.0	11.4
La	La139	0.3	0.3	n.r.	−6.5	n.r.
Ce	Ce140	0.2	0.2	n.r.	19.3	n.r.
Au	Au197	0.2	0.1	n.r.	41.4	n.r.
Bi	Bi209	9.1	7.8	9.0	14.4	1.3
Th	Th232	0.3	0.3	n.r.	−6.8	n.r.
U	U238	0.2	0.2	n.r.	−5.8	n.r.

Note: Oxides values (wt%); elemental values (ppm). n.r., Not reported.Sources: Vicenzi *et al.* (2002); Shortland *et al.* (2007); Wagner *et al.* (2012).

DISCUSSION

LBA glasses found in Egypt and Mesopotamia that date from the mid-second millennium typically have high soda (15–20%) and significant magnesia (2–5%) and potash (2–4%) (Lilyquist *et al.* 1993, 41; Shortland and Eremin 2006), suggesting they were produced using

Table 3 *Results of the laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analyses of the major and minor elements of the Tall Zirā'a's samples (wt%)*

Sample number	*Na_2O*	*MgO*	*Al_2O_3*	*SiO_2*	*P_2O_5*	*K_2O*	*CaO*	*MnO*	*FeO*	*CoO*	*CuO*	*Sb_2O_3*	*PbO*
High magnesia/high potash													
10772	15.8	3.9	0.93	58.5	0.19	3.4	9.9	0.03	0.73	0.01	1.04	5.21	0.02
10170	14.1	3.4	0.43	65.3	0.12	2.9	10.4	0.02	0.19	0.00	1.19	1.75	0.02
19322	17.6	3.8	0.54	66.6	0.18	4.4	5.5	0.02	0.35	0.00	0.93	0.00	0.00
10048	19.3	4.8	0.72	65.6	0.19	3.7	5.1	0.05	0.24	0.00	0.00	0.00	0.00
10079	18.2	5.0	0.66	66.8	0.11	3.0	4.7	0.03	0.29	0.00	1.13	0.00	0.00
15329	12.4	3.2	0.39	69.0	0.18	2.4	9.2	0.02	0.16	0.00	1.15	1.72	0.00
19320	12.4	3.1	0.38	69.1	0.18	2.3	9.2	0.02	0.16	0.00	1.16	1.78	0.00
10765	18.2	4.0	1.76	67.2	0.10	2.9	4.1	0.04	0.33	0.00	1.20	0.00	0.00
10047	17.63	5.34	0.70	65.38	0.17	3.48	5.70	0.03	0.19	0.00	1.24	0.00	0.00
Low magnesia/low potash													
18802	17.0	0.6	2.16	65.8	0.11	1.0	8.1	1.20	1.31	0.19	0.32	0.68	1.35
16759	16.5	0.6	2.33	68.7	0.23	1.0	9.0	0.58	0.51	0.00	0.01	0.29	0.02
16622b	11.83	0.94	2.25	72.65	0.06	0.56	11.31	0.01	0.05	0.00	0.00	0.00	0.00
High magnesia/low potash													
16753	18.0	3.5	1.63	66.0	0.12	0.9	8.2	0.16	0.39	0.09	0.10	0.26	0.04
10762	20.6	2.7	2.35	64.6	0.11	1.3	6.2	0.21	0.49	0.14	0.33	0.37	0.02
Non-glass													
16622a	0.2	0.0	0.33	99.2	0.00	0.0	0.1	0.00	0.1	0.00	0.00	0.00	0.00

plant ash glass as the principal source of soda, perhaps from the genera *Salicornia* or *Salsola*, which are both found in Egypt and the Middle East. Later glasses from the first millennium BCE, or IA, used a different source, for example, Na-rich evaporite minerals which occur in Wadi el-Natrun or Beheira province both located in Egypt (Turner 1954, 1956; Henderson 1985). Natron glasses are characteristically low in both magnesia and potash, with both components at levels of approximately 0.5%, and therefore compositionally distinct from plant ash glasses (Sayre and Smith 1974). The elemental composition of both plant ash and natron glasses are well published and can be used to distinguish between these glass-making periods (Sayre and Smith 1961; Lilyquist *et al.* 1993; Brill 1999; Henderson 2000; Shortland and Tite 2000).

HMHK and HMLK

The HMHK group is consistent with the typical composition of high magnesia glasses produced in the LBA using a plant ash flux, glasses that are relatively common through Egypt, Mesopotamia and the Greek world. These glasses are low in Al, indicating that a relatively pure source of silica was used, such as ground quartz pebbles. The HMHK glasses coloured with Cu are relatively low in Sn, indicating that an unalloyed source of copper was used. This Sn-free copper source is more consistent with Mesopotamian Cu-coloured glasses from sites such as Nuzi and Tell Brak (Walton *et al.* 2012), than Egyptian Cu-coloured glasses which tend to have higher Sn contents, although not always (Shortland and Eremin 2006). Four of the Cu-coloured glasses contain Sb, which was used to make opaque glasses in this period (Nicholson and Henderson 2000, 197; Shortland and Eremin 2006). The addition of an Sb compound creates Ca antimonate crystals in the glass which render it opaque, and at least two different methods of achieving this are known in this period. In Egypt, an Sb compound alone appears to be added to the glass, whereas in Mesopotamia, both a Ca compound and an Sb compound (perhaps combined before addition) are added. This means that whilst in Egyptian sourced glasses the lime content of both the non-opacified and opacified glasses are very similar, in Mesopotamia, the lime content of Sb-opacified glasses tends to be greater than that of the non-opacified glass (Shortland 2002; Shortland and Eremin 2006; Shortland *et al.* 2017). In the blue glasses from this site, it can clearly be seen that the lime content of the opacified glass (averaging 9.7% CaO) is higher and distinct from the translucent glass (averaging 4.9% CaO). This once again suggests that at least the four opaque blue glasses are more consistent with Mesopotamian technology than Egyptian. The composition of 10765 is consistent with the HMHK group, but shows an elevated Al and Nb content and is discussed further below.

The single yellow-brown glass, 100488, is the only non-blue glass in the HMHK group. Yellow-brown glasses are relatively rare, but analyses are available from Amarna, Malkata and Lisht (Shortland and Eremin 2006) and from Nuzi (Kirk 2009). These glasses range in colour from very pale amber to deep brown due to the presence of relatively low levels of Fe in varying oxidization conditions. The yellow-brown glass in the HMHK group is consistent with the composition of other LBA brown glasses, containing low concentrations of Fe (< 0.25% FeO) and no other colouring elements in significant concentrations.

Interestingly, two objects of the HMHK group, 15329 and 19320, both spacer-beads, exhibited almost identical compositions for all elements. The compositions are so close that this cannot be mere chance; indeed, the variation is so small as to fall within the range that would be expected if the analysis were carried out on the same piece of glass. It is probable, therefore, that the objects were made from the same glass ingot or glass batch. The contexts in which they were found are different, however, as discussed below. The composition of the HMLK glasses, 16753 and

10762, is consistent with Cu-Co coloured plant ash glass manufactured in Egypt in the LBA (Shortland and Eremin 2006). The HMLK group exhibits elevated levels of Al, Mn, Fe, Ni, and Zn with accompanying low levels of K (> 1.6% K_2O), which is characteristic of Egyptian Co-coloured glasses, made from an Egyptian Oasis-sourced Co alum-based colourant (Sayre and Smith 1961; Kaczmarczyk 1986; Shortland and Eremin 2006; Walton *et al*. 2012). The HMLK glasses were also coloured with Cu and contained elevated levels of Sn, indicating that a Sn-bearing source of copper was used, such as bronze. Sb is present once again as an opacifier and at consistent levels compared with the Cu/Co-coloured glasses analysed previously (Shortland and Eremin 2006).

As mentioned above, concentrations of Cr, La, Ti and Zr can be used to discriminate between glasses produced of Egyptian and Mesopotamian origin (Shortland *et al*. 2007); Egyptian glasses have relatively low Cr and La concentrations with elevated, but varying, Zr and Ti concentrations, whereas Mesopotamian glasses have the opposite (Table 4). Figure 2 shows the HMHK and HMLK groups plotted against data from Shortland *et al*. (2007). The HMHK group shows compositional similarities with the glasses from Mesopotamia, whereas the HMLK group showed a strong correlation with Egyptian compositions. This is consistent with the different colouring strategies discussed above and the evidence from the major elemental compositions. The analysis strongly suggests that the nine HMHK glasses, blue and yellow-brown, come from Mesopotamia, whereas the two HMLK Co/Cu-coloured glasses come from Egypt. HMHK glass 10765 exhibits the lowest concentrations of Cr with the highest concentrations of La in the HMHK group, which are comparable with Egyptian composition; however, the Ti and Zr levels are consistent with Mesopotamian composition. However, this could be an outlier and without a larger sample group, it cannot be said that this sample represents a Levantine glass composition.

LMLK

The LMLK group is compositionally consistent with low magnesia glasses produced in the IA and later using natron as an alkali flux and sand as a silica source. The LMLK group has significantly higher levels of Al compared with the HMHK group, but comparable with that of the HMLK group (where alumina is introduced with the Co colourant). The Co-coloured glass (18802) has relatively high levels of a range of elements including Co, Cu, Mn, Fe, lead, Sb, Sn and even Ag when compared with the other HMLK glasses and such glasses in general. This trace element pattern for the Co used to colour the glass has been identified before in other glasses found in Europe from the early IA until the end of the 12th century CE (Gratuze 2013). It is very distinct from the standard, Egyptian Oasis-sourced Co used in the HMLK glasses and bears compositional similarities with the 'Type N' Co colourant defined by Abe *et al*. (2012). Cobalt Type N is recognized as the Co colorant used after the Late Period, and in distinguished by its relatively low amounts of Zn and a deficiency of Ni. Both levels of Zn and Ni in the Co-coloured glass 18802 conform with this composition (Abe *et al*. 2012).

The pale translucent green and colourless translucent glasses appear to have no deliberate colourant added, but in detail they are very different glasses. The translucent green glass (16759) has significant Mn (4469ppm Mn) and Sb (2381ppm Sb), suggesting that the glass may have been deliberately decolourized with these elements. The occurrence of both Mn and Sb at intentional levels could also indicate a Roman glass composition. The colourless translucent glass 16622b contains only a 10th of the Fe (352ppm Fe) of 16759 and only traces Mn and Sb. The Zr content is also high in 16622b. It does, however, contain significant As at 1130ppm. The Rb/Sr ratio of the two-colourant-free LMLK glasses are very different, with

Table 4 *Results of the laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analyses of the trace elements of the Tall Zirā'a's samples (ppm)*

Sample no.	*Li*	*Be*	*B*	*Ti*	*V*	*Cr*	*Mn*	*Fe*	*Co*	*Ni*	*Cu*	*Zn*	*As*	*Rb*	*Sr*
								ppm							
High magnesia/high potash															
10772	15.4	0.2	163	352	11	18	260	5662	48.8	151	8309	78.4	463.7	22.9	554
10170	16.0	0.1	104	163	5	17	167	1466	4.5	35.5	9507	15.7	137.5	10.5	443
19322	19.5	0.0	125	198	6	14	166	2756	7.1	18.6	7442	24.4	29.7	15.3	411
10048	26.7	0.1	168	190	6	17	360	1863	1.2	9.2	15.0	16.0	1.18	12.7	501
10079	19.4	0.1	172	249	6	19	229	2293	19.4	14.6	9014	20.2	20.2	6.3	342
15329	16.2	0.0	95	147	4	14	119	1220	1.3	13.8	9227	15.1	82.4	18.4	605
19320	14.6	0.1	95	146	4	14	118	1231	1.3	13.7	9310	14.7	81.7	17.7	601
10765	24.8	0.4	215	271	8	10	320	2557	7.9	13.9	9628	18.3	19.6	18.7	312
10047	11.9	0.1	119	286	8	23	201	1439	4.2	16.8	9898	24.3	4.5	16.7	337
Low magnesia/low potash															
18802	5.6	0.3	146	390	17	10	9307	10197	1527	50.3	2575	78.6	36.4	11.6	556
16759	4.6	0.3	183	528	20	15	4468	3928	5.3	10.7	41.7	29.6	9.9	9.6	459
16622b	24.6	12.9	20.9	272	6	10	47	352	2.5	4.5	7.3	16.9	1130	149	51
High magnesia/low potash															
16753	8.0	1.6	149	589	8	7	1250	3050	735	695	816	2316	10.1	5.7	631
10762	11.2	1.4	243	636	11	9	1655	3789	1063	710	2638	1904	27.7	7.5	511
Non-glass															
16622a	0.0	0.0	67	269	4	1	1	662	0.9	0.4	1.9	5.8	0.0	0.2	8.1

Sample no.	*Zr*	*Nb*	*Ag*	*Sn*	*Sb*	*Cs*	*Ba*	*La*	*Ce*	*Au*	*Pb*	*Bi*	*Th*	*U*
							ppm							
High magnesia/high potash														
10772	13.6	1.0	0.9	17.9	43516	0.65	104	2.4	4.6	0.1	209	0.1	0.6	0.3
10170	5.9	0.4	3.9	31.7	14607	0.41	33.3	1.1	2.1	0.6	147	1.0	0.2	0.1
19322	7.0	0.5	1.1	3.97	9.3	0.37	43.8	1.4	2.8	0.4	5	0.3	0.3	0.1
10048	9.6	0.7	0.1	1.81	0.2	0.31	37.8	1.9	3.8	0.0	5	0.0	0.4	0.2
10079	7.8	0.7	0.5	2.59	3.3	0.18	33.8	1.9	3.7	0.1	3	0.1	0.4	0.2
15329	6.5	0.4	1.1	2.44	14408	0.52	42.1	1.2	2.4	0.1	21	0.2	0.2	0.1
19320	6.4	0.4	1.1	2.48	14868	0.48	41.9	1.2	2.4	0.1	20	0.2	0.2	0.1
10765	12.1	2.0	0.4	3.75	6.30	0.31	55.0	2.9	5.9	0.1	9	0.3	1.2	0.6
10047	9.6	0.7	1.8	2.1	32.6	0.3	40.5	1.7	3.5	0.3	9	0.4	0.4	0.2
Low magnesia/low potash														
18802	34.8	1.3	1.24	113.5	5707	0.1	255	5.91	10.6	0.11	12496	0.3	0.8	0.8
16759	45.6	1.8	0.09	60.4	2381	0.1	269	6.0	10.8	0.0	206	0.0	0.9	1.1
16622b	247	7.8	0.1	12.9	9.2	11.8	597	8.5	11.5	0.0	41	0.5	6.8	2.7
High magnesia/low potash														
16753	48.3	1.8	0.4	41.5	2176	0.1	64.1	3.5	8.2	0.1	362	0.1	0.9	0.6
10762	48.9	1.8	0.6	38.2	3102	0.1	63.4	3.4	8.5	0.2	151	0.2	1.0	1.0
Non-glass														
16622a	40	0.9	0.0	1.8	0.9	0.0	0.7	0.0	0.2	0.0	0.84	0.0	0.2	0.0

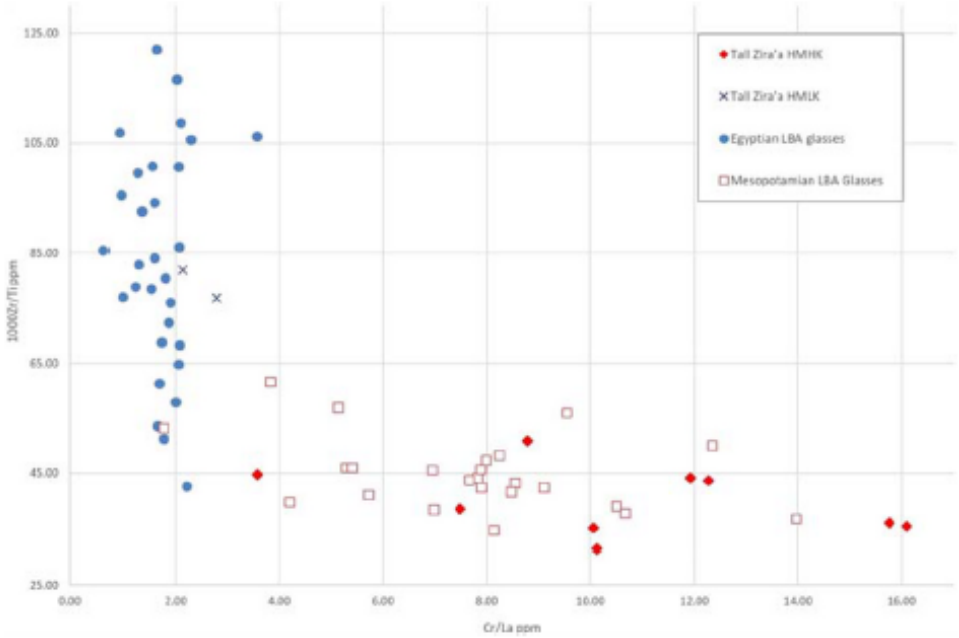

Figure 2 *Covariant plot of 1000 Zr/Ti with Cr/La of the Tall Zirā'a high magnesia/high potash (HMHK) and high magnesium/low potash (HMLK) groups compared with Egyptian and Mesopotamian glasses of known origin. Source: Shortland et al. (2007). [Colour figure can be viewed at wileyonlinelibrary.com]*

16759 having a ratio of 0.02 and 16622b much higher at 2.9. 16622b was excavated from an IA context; however, the composition is comparable with late nineteenth-century CE glasses decolourized with As.

Archaeological implications

The trace elements of the nine Tall Zirā'a glasses in the HMHK group match the composition of LBA glasses originating from Mesopotamia, whereas the two HMLK glasses analysed match the composition of LBA glasses originating from Egypt. The pieces belonging to the HMHK group allow good parallels to glass finds from Mesopotamia (e.g., disc pendant, spacer bead) and partly also from the Levant (e.g., naked female figurine pendant). The findings as well as the analysis show that Tall Zirā'a was the recipient of glass exports from both Egypt and Mesopotamia. The Egyptian and Mesopotamian origins of the glasses are furthermore also reflected in other finds from the *cella*, for example: 24 cylinder seals which can be attributed to the Syrian or Syro-Palestinian style of the Mitanni glyptic (Syro-Palestine), a silver pendant depicting a goddess with parallels in Ugarti, Tall al-'Ajjul and Megiddo, a scarab with the cartouche of Amenhotep III, and various faience objects (scarabs, vessel fragments) which originate from Egypt.

Only one other LBA site has been identified to contain glasses from both Egypt and Mesopotamia: Mycenae. Beads excavated from the palatial centre of Tiryns, Mycenae, were analysed and identified as coming from both Egypt and Mesopotamia (Walton *et al*. 2009). No other site in the Levant has yet been identified with a similar pattern, although further work would surely indicate that this was the case. Tall Zirā'a was on a significant trading route connecting Egypt with Mesopotamia. The trading route started in Egypt, traversed the Sinai Peninsula, diverted north along

the Mediterranean further on to Damascus to arrive at the Euphrates in Mesopotamia. Therefore, it can be inferred that high-value items such as glass and other materials were transported via this route and, at least partly, arrived at Tall Zirā'a as tribute to the temple.

Seven of the 12 glass objects identified as being LBA plant ash glass were excavated from the LBA stratum 14 and are therefore consistent with the stratigraphy. Five were found in the *cella* of the temple or in close proximity: a fragment of a naked female figurine pendant (10779), a disc pendant (10170) (Fig. 3), a fragment of a bead (10762), a suspected piece of raw glass (10772), and a spherical bead (10765). These pieces can also be dated according to typological comparisons: for example, 10779 can be identified as the arm of a typically LBA naked female figurine. The best comparable pieces comes from Tall Zirā'a itself (Schmidt 2019, 46), as well as from Tall al-Fukhar (Jensen 2015, 331), Lachish (Tufnell 1958, pl. 27: 3), and Tall al-_x01E24;iṣn (Beth Shean) (Rowe 1940, pl. LXVIIIA: 7). In addition, a large number of sites are known to yield naked female figurine pendants (Brill 1970, appendix II). Owing to the thickness and rounded shape, it is credible to identify 10170 as part of disc pendant, as they were similarly found in LBA contexts in Nuzi, where they were decorated with stars (Starr 1939, pl. 120; Barag 1970, figs 100, 101). In Nuzi, the star-pendants are connected with the cult of the Goddess Ishtar, a similar function as temple dedication can also be suggested for the piece from Tall Zirā'a.

Glass beads, amulets and pendants could be purchased by those who could afford them and were eminently tradable as objects of elevated status. Numerous glass fragments identified as parts of disc pendants found at the site supporting the inference that smaller glass objects were transported from Mesopotamia to Tall Zirā'a.

According to chemical analysis, four LBA glass objects were primarily classified to have been retrieved from IA deposition layers. However, in each case it was observed by the excavators that probable mixing of the deposition layers had occurred. The production of plant ash glass continued into the IA; however, the HMHK glasses excavated from the IA contexts exhibit

Figure 3 *Fragment of a disc pendant (10170). [Colour figure can be viewed at wileyonlinelibrary.com]*

characteristic LBA composition: the spacer bead fragment 15329 was found in the IA deposition layer in close proximity to fragment 19320, which has an almost identical composition but originates in an adjacent LBA context. The HMHK composition of 15329, typical of an LBA glass, therefore adds credence to the excavators' interpretation that these contexts were mixed during later construction works. Likewise, another fragment of a spacer bead (10047) of LBA composition was found in IA stratum 12, again thought to be disturbed by the digging of a later pit. The round bead 10048 of LBA plant ash composition was excavated from an IA I stratum; however, there is evidence yet again of later works on this area, including the conversion of the structure into a residence. The core-formed vessel fragment (16753) was located north of the former temple (IA II A) and can also be identified as being excavated from a mixed stratum, and has a typical LBA Egyptian Co glass composition. Once again, this supports the excavators' interpretation that these contexts were mixed.

The presence of Egyptian composition LBA core-formed vessels (16753) at the site also implies that Tall Zirāʿa was connected with influential individuals, equivalent to the second-rank elite of Egypt. Although the Levant was considered as vassal, and subject to the influences of Egypt and Mesopotamia, the presence of core-formed vessels indicates that Tall Zirāʿa was considered to be an LBA city of particular significance.

Object 16759, a translucent light green object described as an 'irregular lump', is consistent with IA natron glass, but was excavated from the deposition layer in the courtyard of the LBA temple complex. However, stratum 14d is described as being a very late phase of the LBA, therefore it can be inferred that this is an early example of IA glass at Tall Zirāʿa. The natron glass core-formed vessel fragment (18802) was excavated from stratum 13 (IA I), which is attributed to the 13th–12th centuries BCE, and therefore the composition of this glass is consistent with the date of the phases. The translucent, colourless glass fragment (16622b) was excavated from the north outside area of the temple also from stratum 13 (IA I); however, the composition is atypical for LMLK glass.

16622a, a yellowish, translucent hemisphere, likely quartz, and 16622b, a translucent, colourless glass fragment, were found mixed, and in large number, on a floor to the north of the IA I temple (stratum 13) of an area identified as a possible workshop. The composition of the translucent, colourless glass fragment 16622b is however atypical for LMLK glass. The area was interpreted as workshop area indicated by the presence of a large number of working stones, slags and fireplaces, but containing no vessels associated with cooking or food preparation. The presence of these numerous glass fragments and quartz pebbles suggest that craftsmen at Tall Zirāʿa may have used these quartz pebbles as raw material and incorporated glass fragments as part of the glassworking process. Further evidence for glassworking at the site comes from 10772, identified as a piece of raw glass (or part of an ingot) of plant ash composition. This suggests that glassworking may have occurred on-site from the LBA and continued into the IA. The continued presence of glass at Tall Zirāʿa during the IA suggests that the city was affluent enough to sustain the trade of luxury items after the collapse of the LBA and had sufficient resources to support a craft industry encompassing vitreous materials.

CONCLUSIONS

The chronological classification of the glass finds from Tall Zirāʿa shows that glass analyses can be used as a method for dating finds. This is an additional source of information in view of the stratigraphic contexts, which are often difficult to date, as they are often strongly mixed. Of the 14 glass objects analysed, nine plant ash glasses show a positive correlation with the

composition of LBA glasses manufactured in Mesopotamia. The remaining two plant ash glasses are consistent with the composition of LBA Egyptian-made glasses. Therefore, Tall Zirāʿa represents one of only two LBA sites which are known to have received glass objects from both Egypt and Mesopotamia. This goes hand in hand with the archaeological findings, both with the glass objects themselves as well as with the other finds made in the *cella* of the LBA temple. There is also some evidence of glassworking at the site, suggesting that raw glass, possibly in the form of ingots, was transported to the city. The presence of an LBA core-formed vessel with an Egyptian composition indicates and affiliation directly or indirectly with the upper elite of Egypt. The presence of natron glass confirms that the trade of luxury goods continued at Tall Zirāʿa into the IA after the collapse of the LBA, and that the city was prosperous enough to sustain craftsmen who probably provided glassworking. The presence of these three types of glass demonstrates that Tall Zirāʿa was a well-connected settlement of significant social importance during the LBA, maintaining affluence and trade links into the IA.

REFERENCES

Abe, Y., Harimoto, R., Kikugawa, T., Yazawa, K., Nishisaka, A., Kawai, N., Yoshimura, S., and Nakai, I., 2012, Transition in the use of cobalt-blue colorant in the new kingdom of Egypt, *Journal of Archaeological Science*, **39**(6), 1793–808.

Barag, D., 1970, Mesopotamian core-formed glass vessels (1500–500 BC), in *Glass and glass-making in ancient Mesopotamia* (eds. A. L. Oppenheim et al.), Corning Museum of Glass, New York.

Brill, R. H., 1970, The chemical interpretation of the texts, in *Glass and glass-making in ancient Mesopotamia* (eds. A. L. Oppenheim et al.), Corning Museum of Glass, New York.

Brill, R. H., 1999, *Chemical analyses of early glasses: Volume 1, the tables*, Corning Museum of Glass, Corning, NY.

Goedicke, H. (1975) *The report of Wenamun*. Johns Hopkins Press (Near Eastern studies).

Gratuze, B., 2013, Provenance analysis of glass artefacts, in *Modern methods for Analysing archaeological and historical glass, volume I* (ed. K. Jannsens), 311–43. Chichester: John Wiley and Sons.

Hanbury-Tenison, J. W., 1984, Exploration du Wadi el-Arab, *Chronique Archéologique, RB*, **91**, 230–1.

Henderson, J., 1985, The raw materials of early glass production, *Oxford Journal of Archaeology*, **4**(3), 267–91.

Henderson, J., 2000, Chemical analysis of ancient Egyptian glass and its interpretation, in *Ancient Egyptian materials and technology* (eds. P. T. Nicholson and I. Shaw), 206–24, Cambridge University Press, Cambridge.

Jackson, C. M., and Nicholson, P. T., 2010, The provenance of some ingots from the Uluburun shipwreck, *Journal of Archaeological Science*, **37**(2), 295–301.

Jensen, L. W., 2015, Basalt and small finds, in *Tall al-Fukhār* (eds. J. Strange and F. G. Andersen), 329–65, Results from excavations 1990–93 and, Vol. **2002**, Aarhus University Press, Aarhus.

Joffe, A. H., 2002, The rise of secondary states in the iron age Levant, *Journal of the Economic and Social History of the Orient*, **45**(4), 425–67. Available at. http://www.jstor.org/stable/3632872

Kaczmarczyk, A., 1986, The source of cobalt in ancient Egyptian pigments, in *Proceedings of the 24th international Archaeometry symposium* (eds. J. S. Olin and M. J. Blackman), 369–76, Smithsonian, Washington.

Kemp, V., McDonald, A., Brock, F., and Shortland, A. J., 2019, LA-ICP-MS analysis of ll Bronze Age blue glass beads from Gurob, Egypt, *Archaeometry*, **62**(1), 42–53. https://doi.org/10.1111/arcm.12501

Kemp, V., McDonald, A., and Shortland, A. J., 2017, Ancient biographies: Trace element analysis to investigate provenance and transportation mechanisms of Late Bronze Age glass, *Archaeological and Environmental Forensic Science*, **1**(2), 161–74.

Kirk, S. (2009) The vitreous materials from the 2nd millennium BC City of Nuzi: Their preservation, technology and distribution. Cranfield University.

Lilyquist, C., Brill, R. H., and Wypyski, M. T., 1993, *Studies in early Egyptian glass*, Metropolitan Museum of Art.

Moorey, P. R. S., 1994, *Ancient Mesopotamian materials and industries*, Oxford University Press, Oxford.

Moorey, P. R. S., 2001, The mobility of artisans and opportunities for technology transfer between Western Asia and Egypt in Late Bronze Age, in *The social context of technological change* (ed. A. J. Shortland), 39–58, Oxbow books, Oxford.

Moran, W. L., 1992, *The Amarna letters*, The Johns Hopkins Press, Baltimore.

Na'aman, N., 2000, The Egyptian–Canaanite correspondence, in *Amarna diplomacy: The beginnings of international relations* (eds. R. Cohen and R. Westbrook), 125–38, Johns Hopkins University Press, Baltimore.

Nicholson, P. T., and Henderson, J., 2000, Glass, in *Ancient Egyptian materials and technology* (eds. P. T. Nicholson and I. Shaw), 195–226, Cambridge University Press, Cambridge.

Oppenheim, A. L., 1977, in *Ancient Mesopotamia: Portrait of a dead civilization* (ed. E. Reiner), Revised edn, University of Chicago Press, Chicago.

Pfälzner, P., 2012, Levantine kingdoms the Late Bronze Age, in *A companion to the archaeology of the ancient Near East* (ed. D. T. Potts), 770–96, Blackwell, Oxford.

Pulak, C., 2001, The cargo of the Uluburun ship and evidence for trade with the Aegean and beyond, in *Italy and Cyprus in antiquity 1500–450 BC: Proceedings of an international symposium held at the Italian academy for advanced studies in America at Columbia University, November 16–18, 2000* (eds. L. Bonfante, V. Karageorghis, and Costakis and Leto Severis Foundation Nicosia, C), 13–60, The Costakis and Leto Severis Foundation, Nicosia.

Reader, A. (2003) *Near eastern archaeology: A Reader*. Ed. S. Richard. Pennsylvania State University Press.

Redford, D., 1992, *Egypt, Canaan, and Israel in ancient times*, Princeton University Press, Princeton.

Rowe, A., 1940, *The four Canaanite temples of Beth-Shan. 1. The temples and cult objects*, The University Museum, Philadelphia.

Sayre, E. V., and Smith, R. W., 1961, Categories of ancient glass, *Science*, **133**, 1824–6.

Sayre, E. V., and Smith, R. W., 1974, Analytical studies in ancient Egyptian glass, in *Recent advances in the science and Technology of Materials* (ed. A. Bishay), New York.

Shortland, A. J., 2002, The use and origin of antmonate colorants in early Egyptian glass, *Archaeometry*, **44**(4), 517–31.

Shortland, A. J., Kirk, S., Eremin, K., Degryse, P., and Walton, M., 2017, The analysis of Late Bronze Age glass from Nuzi and the question of the origin of glassmaking, *Archaeometry*, **60**(4), 764–83.

Shortland, A. J., and Eremin, K., 2006, The analysis of second millennium glass from Egypt and Mesopotamia, part 1: New WDS analyses, *Archaeometry*, **48**(4), 581–605.

Shortland, A. J., Nicholson, P. T., and Jackson, C. M., 2001, Glass and faience at Amarna: Different methods of both supply for production, and subsequent distribution, in *The social context of technological change* (ed. A. J. Shortland), 147–60, Oxbow Books, Oxford.

Shortland, A. J., Rogers, N., and Eremin, K., 2007, Trace element discriminants between Egyptian and Mesopotamian Late Bronze Age glasses, *Journal of Archaeological Science*, **34**(5), 781–9.

Shortland, A. J., and Tite, M. S., 2000, Raw materials of glass from Amarna and implications for the origins of Egyptian glass, *Archaeometry*, **42**(1), 141–53.

Smirniou, M., and Rehren, T., 2013, Shades of blue-cobalt-copper coloured blue glass from new kingdom Egypt and the Mycenaean world: A matter of production or colourant source? *Journal of Archaeological Science*, **40**, 4731–43.

Soennecken, K. A. P. (2017) *Kulturelle Umbrüche in der südlichen Levante. Der Übergang von der Bronze- zur Eisenzeit unter besonderer Berücksichtigung des Tall Zirā□a*. Universitätsbibliothek Wuppertal.

Starr, R. F., 1939, *Nuzi. Report on the excavations at Yorgan tepa near Kirkuk, Iraq, conducted by Harvard Univ. in conjunction with the American Schools of Oriental Research and the Univ. Museum of Philadelphia 1927–1931*, With app. by Ruth Sears Chute and others, Harvard University Press, Cambridge, MA.

Steuernagel, C., 1926, Der 'Adschlūn, in *Zeitschrift des Deutschen Palästina-Vereins*, 13–62.

Tufnell, O., 1958, *Lachish (tell ed-Duweir): The Bronze Age. Text and plates*, Oxford University, London.

Turner, W. E. S., 1954, Studies in ancient glasses and glass making processes. Part I. crucibles and melting temperatures employed in ancient Egypt at about 1370 BC, *Journal of the Society of Glass Technology*, **38**, 436–444.

Turner, W. E. S., 1956, Studies in ancient glasses and glass making processes. Part IV. The chemical composition of ancient glasses, *Journal of the Society of Glass Technology*, **40**, 162–84.

Varberg, J., Gratuze, B., Kaul, F., Hansen, A. H., Rotea, M., and Wittenberger, M., 2016, Mesopotaln glass from Late Bronze Age Egypt, Romania, Germany, and Denmark, *Journal of Archaeological Science*, **74**, 184–94.

Vicenzi, E. P., Eggins, S., Logan, A., and Wysoczanski, R., 2002, Microbeam characterisation of corning archaeological reference glasses: New additions to the Smithsonian microbeam standard collection, *Journal of Research of the National Institute Standards and Technology*, **107**, 719–27.

Vieweger, D. and Häser, J. (2017) *Tall Zirā'a The Gadara Region Project (2001–2011) Final Report*. Gütersloh.

Vieweger, D., and Häser, J., 2019, Tall Zirā□'—Mirror of Jordan's history, in *Tall Zirā□a* (eds. J. Häser and K. Schmidt), 12–53, Wichern Verlag, Berlin.

Wagner, B., Nowak, A., Bulska, E., Hametner, K., and Günther, D., 2012, Critical assessment of the elemental composition of corning archeological reference glasses by LA-ICP-MS, *Analytical and Bioanalytical Chemistry*, **402**(4), 1667–77.

Walton, M., et al., 2009, Evidence for the trade of Mesopotamian and Egyptian glass to Mycenean Greece, *Journal of Archaeological Science*, **36**, 1496–503.
Walton, M., Eremin, K., Shortland, A., Degryse, P., and Kirk, S., 2012, Analysis of late Bronze Age glass axes from Nippur—a new cobalt Colourant, *Archaeometry*, **54**(5), 835–52.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Data S1: Operating conditions of the ESI NWR193 laser ablation system and the Agilent 7700 ICP-Q-MS mass spectrometer.

Data S2: Plan of the Late Bronze Age settlement, stratum 14d.

Data S3: Plan of the Late Bronze Age temple, stratum 14d, complex D.

17 Appendix F Publication 6

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Identifying and Evaluating Atypical Traits in Ancient Egyptian Glass Vessels attributed to the New Kingdom using Raw Data Analysis and Expert Assessment

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The descriptive data pertaining to the remaining, largely intact, glass vessels produced in ancient Egypt between the reigns of Tuthmosis IV (1401–1391 BCE) and Pinudjem II (959–945 BCE) contained in *Die Glasgefäße im Alten Ägypten* [The Glass Vessels in Ancient Egypt], was extracted and standardized to create a dataset that could be analysed to determine the most typical and atypical features of vessels attributed to the New Kingdom in the corpus. Seven descriptive categories were assessed based on the percentage of incidence to determine if a vessel could be defined as statistically "atypical." An expert's evaluation was employed as a second assessment method. The two methods identified 76 vessels from a total number of 320 vessels and agreed on 16 vessels considered as atypical, all of which had little or no provenance information. The resulting 76 vessels identified as "atypical" by the combined methods were subsequently compared with the respective provenance information and current location to determine patterns of collection and distribution throughout the world. The data showed that the Americas held the largest number of vessels that had little or no provenance data, including those held in private collections. The combined atypical tests identified that the Americas hold the largest proportion of atypical vessels. It is not the intention of this research to undermine the authenticity of vessels but to determine if data methods can be used to identify atypical traits in archaeological collections and to encourage the application of archaeometric testing to provide supporting information on statistically rare objects.

Introduction

Die Glasgefäße im Alten Ägypten [The Glass Vessels in Ancient Egypt], produced by Birgit Schlick-Nolte in 1968, is a catalogue of 344 remaining, largely intact vessels from ancient Egypt produced between the eighteenth and twenty-first Dynasties (between approximately 1550 to 945 BCE). Each vessel is recorded in detail, describing the mor-

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phology, colour, decoration, and specific features, such as the handles, feet, neck, and rim. Very few vessels have been added to the corpus since this time, therefore the information contained in Schlick-Nolte's catalogue continues to represent a relevant data set. Although many other vessels were produced in, and excavated from, ancient Egypt, these vessels cannot be reliably restored from the fragments, however, it is reasonable to expect that the corpus described in *Die Glasgefäße* represents the corpus of vessels that were created overall. Using the Schlick-Nolte catalogue, the descriptive information pertaining to the colour of the body, the shape of the vessel, opacity, colour of the neck rim, handles, pattern colour and pattern design was extracted and standardized to create a data set that could be used to quantify and assess patterns in the attributes of the vessels. The data was used to identify the number of incidences of certain characteristics, thereby distinguishing what could have been the most common usages of colours, preferred shapes, and favoured decorative patterns. Using the same data, vessels that present statistically rare attributes can be identified as "atypical" and when compared with the provenance information, these vessels can be the subject of further investigation. This study also seeks to compare the current location of the post-study data set vessels with the provenance information and to use the results of the atypical study to examine the distribution of this particular subset of vessels throughout the world.

Although a novel technology in the Late Bronze Age (LBA), glass was rapidly assimilated by the ancient Egyptian elite to become an important symbol of high status. The ensuing production of glass was strictly regulated by the Egyptian royal courts and administered according to a rigid distribution model. Ingots of raw glass were exchanged between royal courts at the highest level, while glass vessels were an exclusive commodity suitable for high-level gift-giving between rulers of LBA states and preferred members of the domestic court (Na'aman 2000, 130; Shortland, Nicholson and Jackson 2001, 153). Early vessels were created using the "cold-working technique" by which glass would be poured into a cast, and then shaped using lapidary techniques (Broschat and Rehren 2017). The invention of core-forming represented a significant advance in glass vessel production technology (Shortland 2001, 212), transforming how glass vessels could be created, shaped and decorated. A "core" made from a mixture of clay and dung was moulded to form the interior shape of the vessel around a long pole called a "handling piece." The core was heated and rolled in powdered glass, then worked in the form of a "pasty mass," upon which layer after layer was applied to create the vessel (Nicholson 1993, 53). The foot, handles and decoration were added before the vessel was left to slowly cool, after which the core and handling piece was removed (Nicholson and Henderson 2000, 203).

Establishing a reliable timeline for early glass vessels has proven to be problematic: reburials, destruction and transference of goods caused by extensive looting or the actions undertaken by the priests of the necropolis administration to preserve their charges has rendered the context of items in these tombs unreliable in several instances (Reeves and Wilkinson 2008, 125). Glassworking was undertaken by multiple glass workshops, who based their work on the modes of the time. The workshops of Malkata and Amarna represent the peak of Egyptian glass production, pre-

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dominantly in the number of vessels produced, the technical accomplishment of the craftsmen and the stylistic uniformity; namely the iconic vessels of blue glass with yellow and white threads applied to create feather or garland patterns (Petrie 1894, 25). In *Die Glasgefäße*, Schlick-Nolte assigns the vessels into groups and subgroups: The first group comprises of the vessels that can be reliably dated to a specific time of manufacture, having either come from a reliable archaeological context such as the tomb of Amenhotep II, or are stylistically dated with confidence. Even though this group is comparatively small, the author emphasizes the archaeological importance of having such pieces recorded from reputable investigations (Nolte 1968, 46). The second, and largest group comprising of 213 vessels, are divided into "*Werkkreis*"; this term is often used to refer to an Old Master artist and his associated assistants and followers—"circle of workshops" is perhaps the nearest translation. The vessels in the *Werkkreis* groups have been approximately dated according to the stylistic features and some are attributed to known workshop locations such as Malkata and Amarna. At the beginning of the 14th Century BCE, a more uniform approach to style was taken for the production of glass vessels, however, subtle changes in features such as the diameter of the neck, the shape of a spout, handles and the shape and size of the feet provided key elements that narrow estimates for the period of production. As such, the *Werkkreis* are divided into six groups, the largest of which, *Werkkreis* 6, contains 43 vessels and dates between the reigns of Tutankhamun (1333–1323 BCE) and Pinudjem II (959–945 BCE), an era of approximately 390 years, thereby making any speculation pertaining to periodical trends somewhat tenuous. Of the vessels contained in the *Werkkreis* groups, only 15% are of known origin, 19% are of unknown origin, 32% are of ambiguous origin and the remaining 35% belong to private collections. Two additional groups are also described: the *Kohlpalmsäulchen*, or kohl palm vessels, that contain 58 vessels and "special shapes" that contain 19 vessels. The vessels in both groups are dated from Amenhotep III (1391–1353 BCE) to the Ramesside period (ending in 1070 BCE), spanning approximately 320 years.

Methodology

To accurately assess the characteristics that exemplify typical and atypical features of the New Kingdom, this paper concentrates on the vessels that were attributed to between the reigns of Amenhotep II (1427–1401 BCE) and Rameses III (1194–1163 BCE). The 15 early vessels that are reliably dated between the reign of Tuthmosis III (1479–1425 BCE) to Amenhotep II were excluded from the data set as they exhibit unusual shapes, colours and morphology that have been attributed to the experimental phase of early glassmaking1 (Nolte 1968, 5). The six vessels that are reliably dated to the 21st Dynasty and the three vessels, recorded as lost, are also excluded the data set.

The descriptive information of the remaining 320 vessels exactly as reported by Schlick-Nolte was collated into a working database using Microsoft Excel. Seven

1. These vessels are: 24391, 47620 (British Museum), 19657 (University College London), 23.9, 26.7.1175, 26.7.1179 (Metropolitan Museum of Art), ÄS 630 (Bavarian State Collection of Egyptian Art, Munich), E 2451 (Ashmolean Museum), 24761, 24761 bis, 24768, 24804, 24808, J 33827 (Cairo Museum), E 6201 (Brussels Royal Art and History Museum).

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attributes were chosen to assess typical and atypical features for the purposes of the study: the colour of the body, or "ground colour," the vessel shape, neck rim colour, handle colour, the pattern colour and the pattern type on the neck and body. The foot colour and foot rim colour were not included in the data as the information did not provide sufficient discrimination between the vessels; over a third of vessels were not made with a foot. The pilgrim flask, for example, is the second most common vessel shape in the corpus, and the majority of the remaining vessel feet were created using the ground colour.

For clarity, colours are standardized into the main colour groups, rather than listing individual hues as described by the author; for example, "olive green" is noted in the dataset as green. As the most prevalent colour, blue is standardized into three main groups: light blue (which contains the colours described as light blue, sky blue and turquoise), mid blue (blue, bright blue, copper blue, grey-blue and lapis lazuli blue) and dark blue (black blue, cobalt blue, dark blue, deep blue and ultramarine).

The vessels are categorized into 14 main shape types using the terminology described in *Die Glasgefäße*. The origin of these names are mainly derived from traditional ceramic vessels:

- Krateriskos refers to vessels that have a wide, cylindrical, crater-like neck with a short spherical body, usually with a foot attached.
- The thick walled krateriskoi exhibit a broader neck and have thicker, less defined handles that do not protrude far from the body of the vessel.
- The simple krateriskoi is a basic version of the krateriskos and may not contain handles, feet, or decoration.
- The pilgrim flask has a small cylindrical neck with a round, lenticular body. Pilgrim flasks can be large or small; specifically between 45mm and 145mm tall, with no, or two to three handles attached.
- Kohl tubes are modelled on the Egyptian palm columns and have a rounded or flat base with a long, narrow body and an opening that is fashioned into leaves surrounding the rim.
- Amphoriskos vessels are composed of a cylindrical, narrow, or conical neck with board shoulders and a tapered base.
- Jug-shaped vessels have narrow neck with a wider, oval body with a handle attaching the neck and shoulder.
- The spherical vessel is defined by the orbicular body but can have a long or short neck with various handle types and a stand.
- The flask or bottle type is generally composed of a long and narrow neck with an oval body and rounded base without handles.
- The beaker has no handles or rim applied and tapers to a flat base.
- The pomegranate vessel exhibits a distinctive pomegranate shape with a spherical body, no handles and a narrow, cylindrical neck that opens into several small leaf shapes.
- The lotus beaker is modelled after the lotus flower and contains a small foot and no handles (Loat, 1905 pl 4–30; Nolte 1968, 149).

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- One vessel described in *Die Glasgefäße* is identified as "pilgrim flask and pomegranate vessel"; this vessel consists of a pilgrim flask and a pomegranate vessel which appears fused at the body, most likely accidentally, and is therefore described as one vessel throughout.
- The category of "special shapes" consists of glass objects that cannot be classified into the main shape groups; these include fish-shaped vessels, curved and flat bowls and the alabastron style vessels.

The colour of the neck rim and handles are also described in the main colour groups. Where two or more colours are used, this is described as polychrome. It should be noted that no colour combination in the polychrome group exceeds 5% of instances in the respective category, therefore all polychrome combinations used for the neck, rim and handles are classified as atypical for the study.

The colours of the patterns were assessed by counting the total number of instances that a single colour occurred across the corpus of vessels overall. The colour combinations of patterns used for each vessel were also assessed to determine frequency of colour combinations. The vessel patterns in *Die Glasgefäße* are described in detail to convey information about the style and aesthetic of the vessel, such as: "Especially generous, even garlands" and "Garlands turning into a regular feather pattern, irregular feather pattern." For clarity when comparing the data, the patterns were standardized into basic types: garland, feather, arcades, zigzag, other, unknown and none. Where multiple patterns were used on the body or neck, these were added as a separate category, for example "arcades merging into feather pattern" was described in the data as "arcades > feather." Where the vessel type did not comprise a neck, such as the beaker shape, the kohl tubes, and the special shapes, this was shown in the data as "not applicable." In some instances, more than one type of pattern was applied to the vessel on the body and neck, thereby adding another feature for trend comparison. It was noted whether the patterns on the body and neck were the same pattern, two distinctly different patterns, or had the same pattern on the body and neck with an additional pattern emerging, for example, one vessel (67.1, Toledo Museum of Art) is described as having a feather pattern applied to the body and a feather pattern, that turns into garlands on the neck (Nolte 1968, 85).

Characteristics that represented less than 5% of the whole category were identified as an atypical trait, for example, yellow represented 3% of vessel ground colour, thereby classifying it as an atypical trait for the purposes of the study. If a vessel exhibited three or more atypical traits, the vessel as a whole was classified as atypical for the purposes of the study.

Finally, the information pertaining to the provenance and the location of the vessel were reviewed with the post study data set. Four categories were given to describe the origin of each vessel: "Origin known" describes a vessel that is recorded as being excavated from a specific archaeological context, i.e. a grave or tomb, whereas "Origin ambiguous" indicates that the vessel is recorded as coming from a specific region or town, such as "Malkata," "Cairo" or more generally "Egypt." It is possible (indeed probable in many cases) that the object was bought rather than found there. "Origin unknown" refers to the vessels that have no provenance information, or that

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the information refers only to the date or location of acquisition. Finally, "Private collection" refers to those vessels where only the collection name is listed, but there is no information regarding the actual origin, and such pieces usually having been bought or exchanged through the art market. During the research for this paper, it was apparent that the locations of some vessels have changed, for instance, where vessels that have been purchased by museums from private collections. While these locations were updated, no active investigation to confirm the current location of each vessel was undertaken as part of this research. For clarity, the regions of Egypt and the Levant, Europe and the Americas were used to define locations, rather than individual countries, unless pertinent to the information.

In addition to using the raw data approach, a second test method using "connoisseurs' eye" was employed. A specialist in the area of ancient Egyptian glass, Professor Andrew Shortland, was asked to use their expert opinion to appraise each vessel using black and white images without context. The specialist was asked to categorize each vessel as typical or atypical based on shape, design, and discernible pattern type. The two methods were designed to provide virtually opposite techniques of assessment; the "connoisseurs' eye" method was intended to assess the vessels using a minimal amount of visible data, compared with the raw data approach which presented attribute categories, but with no stylistic description. Each method was performed independently.

Results

Blue was revered above all colours by the ancient Egyptians and utilized extensively in painted reliefs, protective amulets, and jewellery; it symbolized many significant spiritual meanings, including representing the embodiment of divine truth and justice (Birren, 1950, p37). It is unsurprising, therefore, that 80% of the vessels described in *Die Glasgefäße* were produced with a ground colour of either dark, mid, or light blue glass. The next most prevalent colour is black which represents a significantly smaller group of 6% of the vessels. Some 'black' vessels are actually very dark blue vessels coloured with cobalt, or very dark purple glasses coloured by manganese, however as mentioned previously the characteristics of each vessel are reported as described by Schlick-Nolte. The remaining colours used for the body in descending frequency are white, green, yellow, grey, brown, purple, unknown, polychrome, and red, representing between 5% to less than 1% per colour. Also, 86% of vessels in the dataset are described as opaque, rather than translucent, making this by far the most typical trait of ancient Egyptian vessels. However, because the incidences of translucent vessels are above 5%, they are not classified as an atypical trait for this study. It should also be noted that the classification of atypical vessels in this study is performed using the data as unrelated variables and no attempt is made to link stylistic characteristics, however, where it is appropriate, the style and date is considered in the discussion section.

The most common four vessel shapes are the krateriskos, the pilgrim flask, the kohl tube, and the amphora. The remaining vessel shapes accounted for 6% or less per vessel shape type (Figure 1). With the exception of the thick-walled krateriskos,

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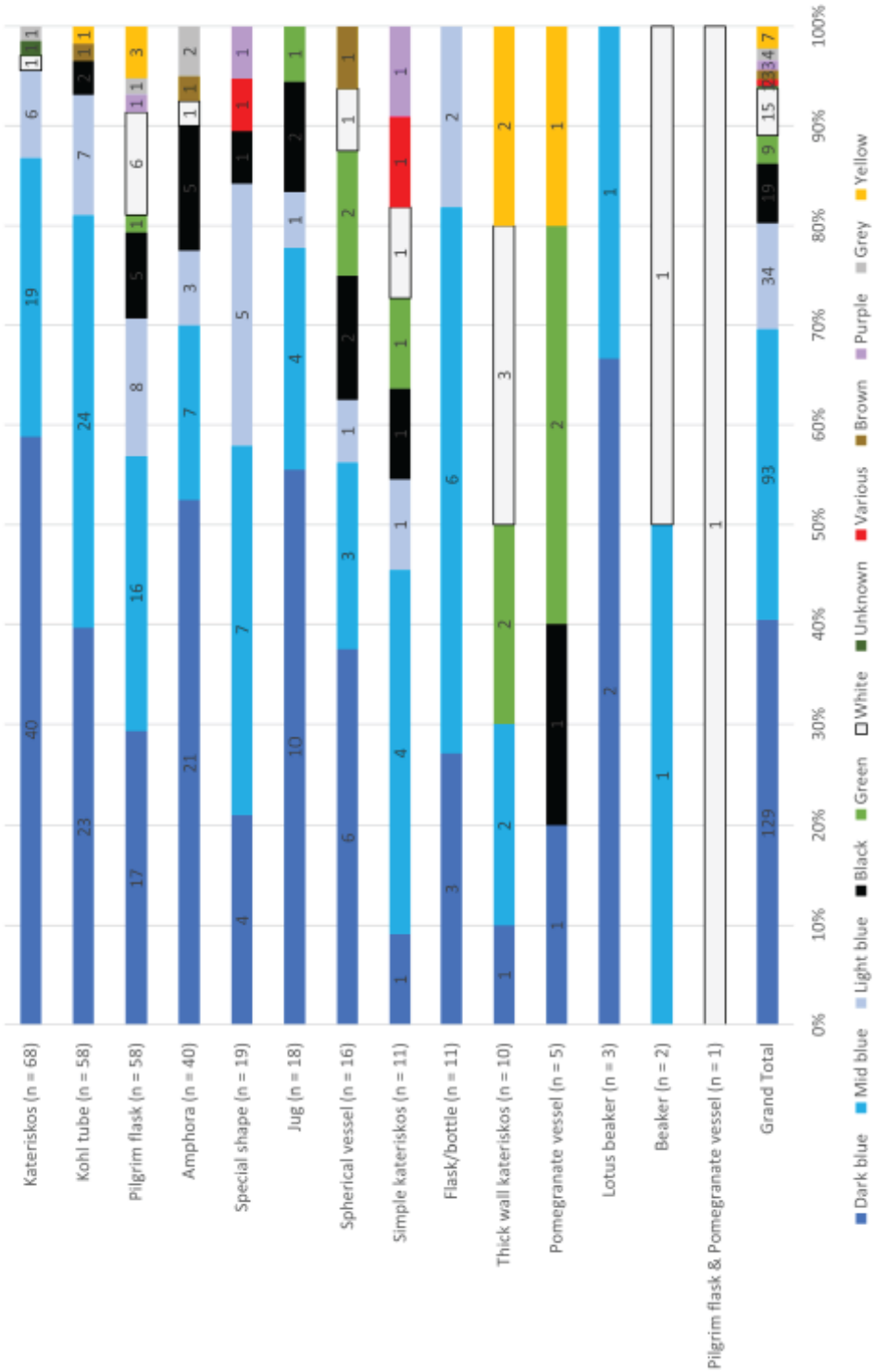

Figure 1 Chart illustrating colour prevalence in each vessel type attributed to the New Kingdom. Centre bar labels indicate number of vessels.

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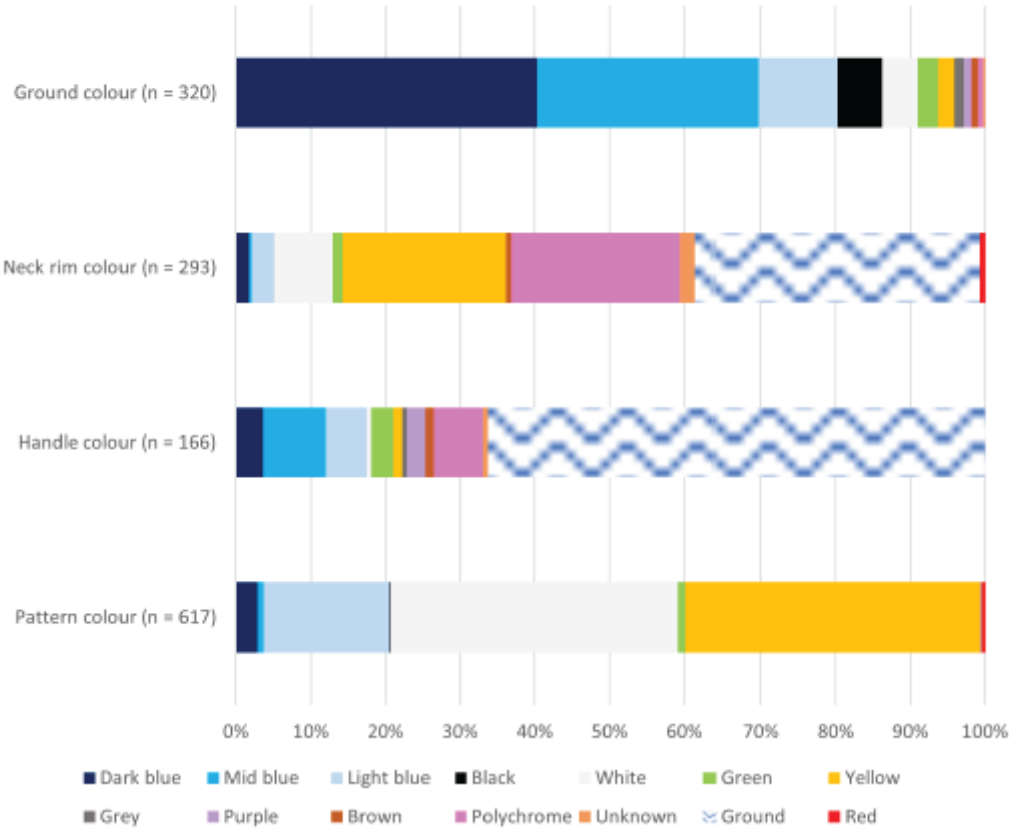

Figure 2 Distribution of colours used in vessels attributed to the New Kingdom to create patterns, handles, neck rim and the vessel body. Where vessels do not contain a neck rim or handles, or are recorded as "not present," these have been removed from the figure.

the beaker shape, pomegranate vessels and the unusually merged pilgrim flask and pomegranate vessel, blue is the most predominant colour for all vessel types.

Of the 320 vessels observed, 92% of vessels have a rim which is still preserved. Thirty-five percent of these vessels presented rims created from the same tone as the ground colour, 20% of vessels used yellow and 21% of vessels were recorded as polychrome, exhibiting 22 different colour combinations of two or more colours (Figure 2). The most common polychrome combination being black and white, occurring in 4% of instances. 8% of vessels were observed as having no rim, broken from the body of the vessel.

Thirty-four percent of ancient Egyptian vessels were produced without handles, with the same percentage of vessels exhibiting handles made from the same tone as the ground colour used for the body of the vessel. Fourteen percent of vessels are recorded as once having had handles, however, these have been broken and are missing from the vessel thereby preventing colour determination. The remaining 18% of handles equate to 29 different colour combinations; therefore, classified as

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atypical. Eleven handles are described as translucent and appear to be made in a different colour to the vessel ground colour, making this an unusual trait. However, it should be noted that the translucency of a vessel may be more difficult to discern due to the thickness of the glass used for the body, any weathering of the vessel and any core remaining inside the vessel. The hue of the handles, therefore, may appear optically distinct from the vessel body. As discussed, for the purposes of the study, the colours are reported as stated in *Glasgefäße*.

The three most frequently used colours for pattern application across the corpus of the 320 glass vessels are yellow, white, and light blue. Seventy-six percent of vessels had a yellow pattern applied, and 74% of vessels had a white pattern applied; light blue is the third most common pattern colour, used on 33% of vessels. However, it is the combination of colours which were the most statistically significant when identifying atypical pattern traits. Patterns applied using yellow and white combined comprised of the 35% vessels in the dataset, with the second most common combination of pattern colours being yellow, white, and light blue at 28%. The third-largest group totalling 20% of vessels have no decoration applied to the body. The remaining pattern colours were mid or dark blue with yellow or white, and the use of green, red, purple, or black in various colour combinations. Thirteen percent of vessels exhibited combinations of yellow or white with one or multiple other colours such as green, red, or purple. These "atypical" colours and combinations presented 18 separate incidences of single and polychrome combinations, comprising the remaining 17% of vessels, hence less than 1% per incidence.

The garland pattern followed by the feather pattern are the two most likely patterns to be applied to both the body and neck of a vessel; the third most common pattern type is "no pattern" applied. Combinations and fusions of feather, garland, and arcade patterns, zigzag, or other patterns occur in 5% or less of vessels per pattern type. Although not assessed as part of the atypical traits, it was noted that 61% of vessels that are created with the garland pattern have the same pattern on the neck and body, and 63% of vessels created with the feather pattern have the same pattern on the neck and body. Eight percent of vessels showed a combination of patterns that merged on the neck or body, for example, a vessel that is described as having a feather pattern on the body and a neck pattern that showed both a garland and feather pattern. Twenty-two percent of vessels from the dataset do not comprise necks and were described as "not applicable." Thirty-five percent of vessel rims were created using the ground colour, followed by 20% of vessels using yellow. Eight percent of vessels are recorded as the rim not being present, either from damage or because of the vessel design, for example, fish-shaped vessels in the "special shapes" category, white composed 7% of rim colours. The remaining 30% of vessels exhibit multiple different single colour or polychrome combinations, less than 1% per incidence.

Provenance review

From the corpus, 17% of vessels are of known origin, having been excavated from a specific archaeological context such as a tomb or grave. Thirty-four percent are described as "Origin ambiguous," 18% are "Origin unknown" and finally, 32% have

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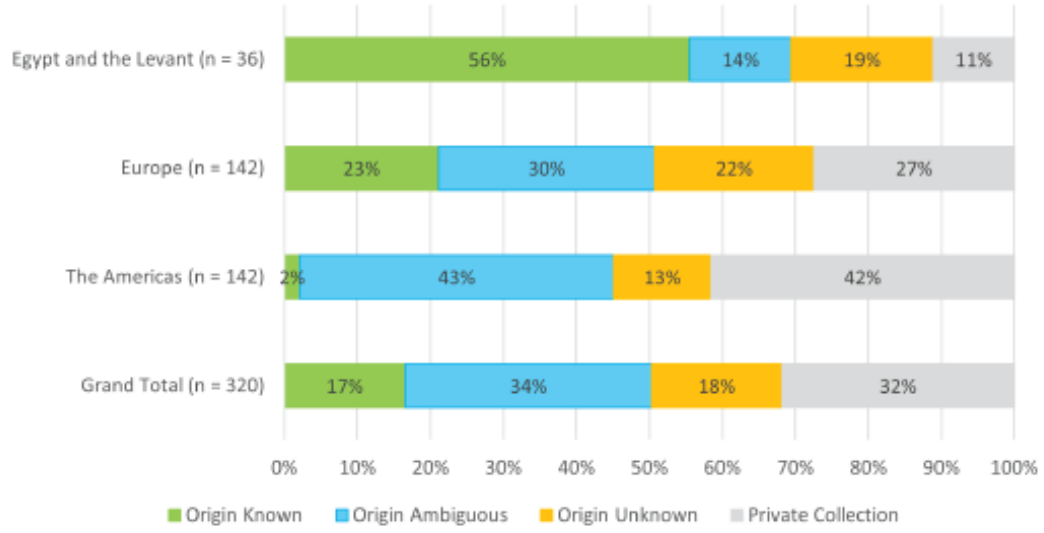

Figure 3 Vessel provenance category by current regional location.

been or are still part of a private collection where virtually no information is known about the origin of the vessel (Figure 3). The distribution of vessels was assessed by comparing the region with the provenance category; the vessels of known origin in the post-study group equate to 53 vessels; the country with the largest number of known vessels is the United Kingdom with 15 vessels. Egypt holds the second largest number equating to 13 vessels, followed by Israel with 6 vessels of known origin. The remaining 19 vessels of known origin are distributed throughout 9 different countries.

The data also showed that although the Americas contained the same number of ancient Egyptian glass vessels as Europe, 142 vessels each in total, only 3 vessels are of known origin with the remaining 139 vessels having very little or no recorded information about the provenance. Of the vessels located in the Americas, 42%, equating to 59 vessels, are recorded as belonging to private collections, meaning that the Americas have the largest number of privately owned ancient Egyptian glass vessels in the world, also representing 18% of the total number of vessels in the world. By comparison, the number of vessels in private collections in Egypt and the Levant is 4, equating to 10% of the total number of vessels in this region. Europe has 39 vessels in private collections, equating to 27% of the total number of vessels in this region.

Discussion

Using the raw data approach, 44 vessels were identified as having three or more atypical traits according to the test criteria, thereby classifying them as atypical vessels. The expert identification method distinguished 48 vessels as atypical. Both methods combined identified 76 vessels in total, with 16 vessels being identified as atypical by both methods.

The largest group of shape type distinguished in the raw data atypical test is the pilgrim flask, formerly the third most frequent vessel type in the corpus; the frequency of this vessel increased from 18% to constitute 27% of the atypical vessels.

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The second most prevalent shape in the atypical group is the spherical vessel, composing 16%, previously it occurred in only 5% of the corpus. The third most frequent is the thick-walled krateriskos, that comprises 11% in the atypical group, but only 3% in the corpus. The amphora shape was the fourth most common vessel shape in the corpus at 13% and occurs in 9% of the raw data atypical group. The most prevalent vessels from the corpus, the krateriskos and the kohl tube represented 21% and 18% respectively, however, in the atypical group they represented 7% and 5% of the vessels identified as atypical. Therefore, the krateriskos and the kohl tube show the largest decreases in frequency in the atypical raw data group, and the pilgrim flask and the spherical vessel show the largest increases in frequency in the atypical raw data group. The only two vessels not detected in the atypical group are the merged pilgrim flask & pomegranate vessel and the lotus beaker shape. The expert assessment differed to the raw data test by identifying the amphora shape, krateriskos, kohl tube and pilgrim flask as being the four most prevalent atypical vessel types (in this order) but did not identify any thick-walled krateriskos shape or beaker shaped vessels as being atypical.

The most prevalent ground colour distinguished by the raw data atypical test is dark blue comprising 27%, compared with the pre-test corpus which comprises 40%. The remaining ground colours distinguished in the atypical test differ in frequency to the corpus order; the second most prevalent ground colour is green, which represents 14% of the ground colour, the third being white and light blue at 11% each. Therefore, the incidences of green more than triple in the raw data atypical group, white more than doubles in the atypical test, whereas light blue represents almost the same percentage in the atypical group. Mid blue, the second most prevalent corpus ground colour at 29% is seen in only 5% of atypical vessels. The remaining colours ranged from 9% to 2% which included two polychrome vessels and one vessel of unknown colour, meaning that at least one of each colour category is represented in the raw data atypical test. The expert test identified atypical vessels which were primarily dark blue vessels at 54%. The remaining vessels were light blue, mid blue, black, white, green, and yellow: almost identical to the order of prevalence seen in the corpus.

The polychromatic combinations of the neck rim colour in the raw data test were most prevalent at 61%, whereas it accounted for 21% in the corpus; the two most prevalent colour combinations in the polychromatic group being black and white and blue and white in both the corpus, the raw data test and the expert test. By comparison, the ground colour accounted for 11% of the neck rim colour of the raw data atypical test but accounted for 35% in the corpus. Yellow accounted for 20% in the whole corpus but only accounts for 11% in the raw data atypical group. The expert test also identified vessels that had polychrome neck rims (31%), ground colour (27%), yellow (21%) and white (13%) and respectively as the most prevalent groups in the neck rim category.

Twenty-seven percent of handles in the atypical raw data group are made from the ground colour and are therefore the most prevalent. "No handles" in the atypical group represented the second largest group at 20%. In the corpus, the "no handle"

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group and the ground colour group were the most frequent at 34% each. Vessels which were recorded as handles "not present," i.e. vessels which showed evidence of comprising handles, but were no longer surviving on the vessel, was the third largest group at 14% in the corpus, however, in the raw data atypical group, only 5% of vessels are recorded as having handles "not present." Dark blue represented 11% in the raw data atypical group, while only comprising 2% in the corpus. The polychrome group represented 18% of the handle occurrence in the raw data test, the most prevalent colour combination was blue and white, comprising of 5% of the handle colour. The most prevalent handle colour of atypical vessels indicated in the expert assessment were made from the ground colour then "no handles" at 35% and 31% respectively, but the remaining nine categories were seen at 6% or less.

The most common pattern colours in the raw data atypical group were the combinations of white, yellow, and light blue occurring in 25% of the atypical vessels, compared with 28% in the corpus. Vessels that were reported with no pattern applied were noted at 23% in the raw data atypical group and 20% in the corpus. The most prevalent colour combination of pattern in the corpus is the combination of white and yellow, which occurred in 35% of the corpus compared with 18% in the raw data atypical group. Patterns applied singly in white or yellow occur in 5% and 2% of the atypical vessels respectively but each occurred in 2% of the whole corpus. The remaining colours and combinations are noted at 6% or below in the atypical group. In the expert assessment, the two most prevalent patterns were yellow and white at 38% and yellow, white, and light blue at 31%. "No decoration" and yellow, white, and dark blue both accounted for 8% each of the expert pattern identification, the remaining six categories accounting for 4% or less.

The most prevalent body pattern in the raw data atypical group was the feather pattern at 23%, "other" and "no pattern" are the second most common representing 18% of the atypical vessels each, with the garland pattern comprising 17% of the atypical group. In comparison the most common three pattern types in the main corpus were garlands (35%), feather (33%) and "no pattern" (19%); all other pattern types represented 5% or less. Patterns described as "other" represented 5% in the vessel corpus. The expert test indicated a total of seven body pattern categories in contrast to the raw data method that indicated nine; the three most prevalent patterns in the expert test were garland, feather, and "other" at 40%, 27% and 13% respectively, with the remaining four categories accounting for 8% or less per pattern type.

The most common neck decoration group in the raw data atypical vessels group was "no pattern" and garlands at 20% each, and "other" at 16%. Zigzag represented 14% of the atypical vessels, with the feather pattern appearing on 11% of atypical vessels. The corpus by comparison showed that the neck pattern fell into four major categories; garlands were most prevalent at 27%, feather 23%, "no neck" at 22% and "no pattern" at 19% all others occurred in under 3% of incidents, including "merged" patterns. The expert assessment for the neck decoration showed the garland and feather patterns being the most prevalent respectively at 31% and 27%, with "no neck" accounting for 21% and "no pattern" accounting for 10%. Only two other pattern types, "zig-zag" and "other," were identified by the expert assessment.

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The raw data approach identified four vessels of known origin as atypical whereas the connoisseur's eye method identified only one, equating to a total of five vessels identified of known origin. Overall, the raw data approach identified more atypical vessels as being from the 'origin ambiguous' category, whereas the connoisseur's eye method indicated more atypical vessels as being from private collections (Figure 4 and Figure 5).

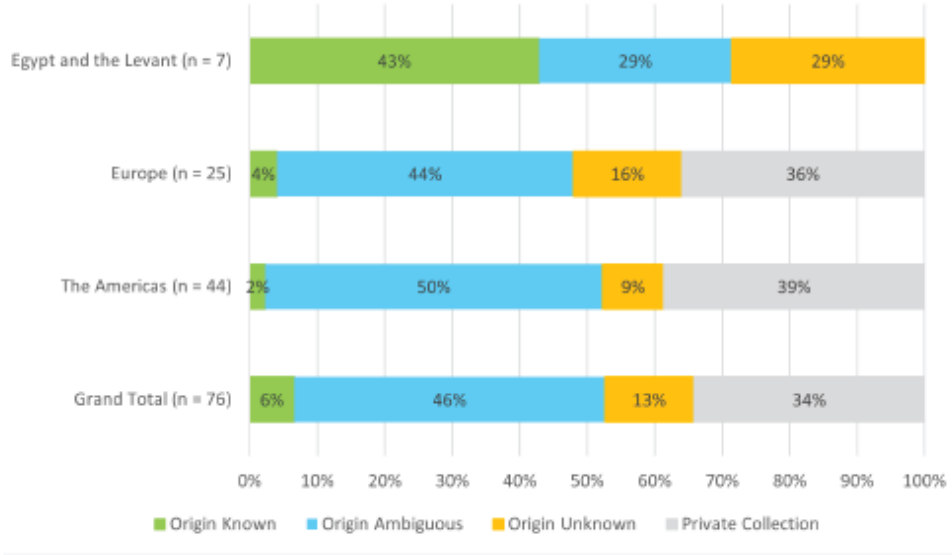

Figure 4 Combined percentages of provenance type by region of atypical vessels using both the raw data method and the connoisseur's eye method.

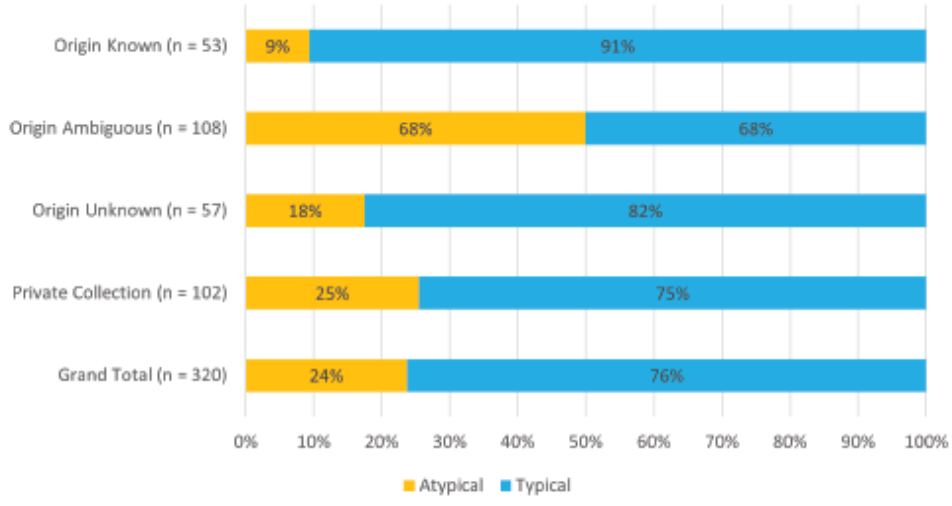

Figure 5 Percentage of provenance category: typical, atypical, and total number of vessels in the experimental group using the connoisseur's eye and raw data methods combined.

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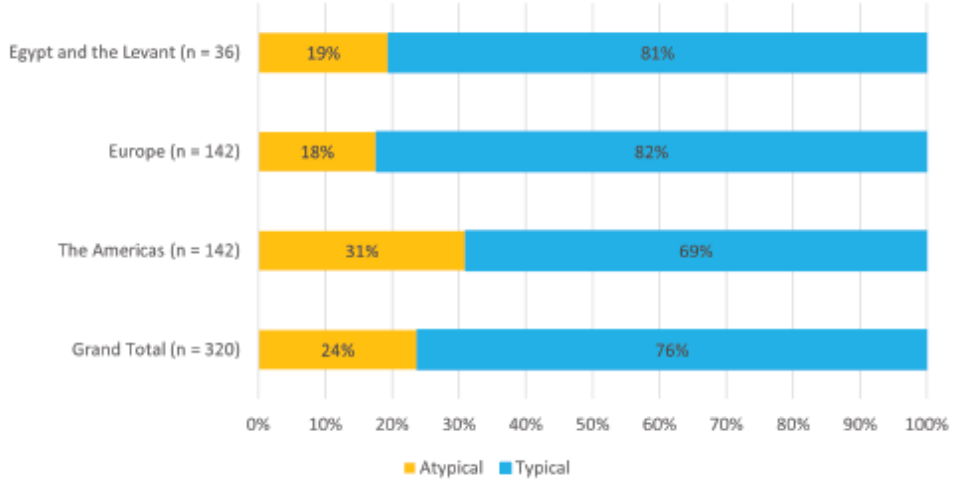

Figure 6 Percentage of atypical and typical vessels by region. Atypical vessels identified by the raw data method and connoisseur's eye method combined.

Using the combined methods, it was observed that 31% of the total number of vessels reported as being located in the Americas were identified as atypical, constituting 56% of the total number of atypical vessels in the world. Also, 33% of the atypical vessels are located in the Americas and are of ambiguous or unknown origin. Only 1% of the vessels identified as atypical located in the Americas (constituting one kohl tube vessel), was of known origin, and this was indicated by the connoisseur's eye method. The Americas also has the largest percentage of atypical vessels held in private collections at 22%. compared with the private collections in Europe that hold 10%, and Egypt and the Levant that have only 1% of atypical vessels (Figure 6).

Egypt has the smallest number of vessels identified as atypical, although three vessels of known origin were indicated by the raw data method. The raw data method identified four vessels of known origin in total: the remaining vessel being located in the United Kingdom, Europe. Three of these vessels have been dated approximately, and are described as having white, brown and polychrome ground colour respectively with two additional atypical features. The remaining vessel of known origin (Cairo museum, 46955) was excavated from the main site of the city of Amarna is arguably a typical 18th Dynasty style vessel: described as a dark blue jug with trailed decoration in the feather /garland pattern applied in yellow and white. Dated to the reign of Amenhotep IV (Cairo Museum, 46955), this vessel was noted as atypical from the three "atypical" features: the colour combination of yellow, white and blue on the rim and handles and the pattern merging from feather to garlands on the body.

The 16 vessels that were indicated as atypical by both methods were all described as having little or no provenance information: nine vessels being from the origin ambiguous group, four vessels from origin unknown and three vessels from private collections. No vessels from the known origin group were identified from the combined methods. By country, 11 of the atypical vessels indicated by the combined methods are located in the Americas, four in Europe and one in Egypt and the Levant.

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Dating and stylistic trends

This paper seeks to discuss the viability of using datasets to detect and assess atypical characteristics for comparison with the respective provenance of vessels attributed to the New Kingdom period. Taking the example of the thick-walled krateriskos (n=10) and the pomegranate vessel (n=5) the most prevalent colours are white and green, respectively. Two of these vessels were reliably dated to between the 19th dynasty and the 20th dynasty, with 13 assigned to *Werkkreis* 4 to 6, spanning a total reign of Tutankhamun to Pinudjem II, therefore it cannot be said if these represent a link between a colour preference for these specific vessel types. Likewise, vessels that exhibit multiple colours in patterns may denote a trend for polychromatic vessels, however, these vessels are relatively evenly distributed over the known reigns of production and *Werkkreis* 1 to 5. The largest group of polychrome patterned vessels belongs to *Werkkreis* 4 that spans the reigns of Tutankhamun (1333–1323 BCE)—Rameses II (1290–1224 BCE), therefore showing little statistical significance. Hence, it can be claimed that these epochs are too broad and span considerable periods of political and social change to reliably assign trends to specific reigns or even Dynasties and may not recognize periods of experimentation as seen in early glass vessel production, of which some vessels are of known origin and can be reliably dated. Therefore, assessing a dataset that spans discrete periods of glassworking institutions and styles, where dating is largely equivocal, is challenging. Including all data prevents cognitive bias that could be introduced by attempting to refine the dataset, however, this presents limitations which should be considered for future study design.

The composition of ancient glass and associated colourants are well documented and analytical techniques have proven extremely effective in determining the period of glass production from their raw materials. Establishing the period of production would help narrow dating epochs of ancient Egyptian glass vessels, specifically the vessels which are categorized in the broader *Werkkreis* groups that span both the Late Bronze Age (LBA) and Iron Age. Where vessels are of known origin and date, elemental analysis could offer new insights regarding raw material trading including colourants and variances in composition, which would be particularly valuable when examining translucent vessels and those with statistically rare colours. Although non-destructive techniques, such as X-ray fluorescence, are currently used, this is not sensitive enough to detect trace elements which are used to determine provenance in LBA vessels, however, as non-destructive analysis techniques develop to provide greater sensitivity, compositional data can be obtained with little sample preparation and with no risk to the vessel. However, analytical analysis may not be a pragmatic solution for items located in countries with strict legislation, such as Egypt, which strictly regulates scientific investigation.

Conclusion

Using the information from *Die Glasgefäße* and applying the raw data test, an ancient Egyptian vessel is statistically more likely to present characteristics typified by vessels produced during the height of the glassmaking industry in the 18th dynasty. However, some vessels of known origin do not conform to this "statistical ideal" and

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should be highlighted and investigated as particularly rare stylistic pieces. Overall, the "connoisseurs' eye" method appeared to be more discriminatory, identifying fewer attributes per category than the raw data atypical test. This was apparent in the higher percentages (>30%) seen in the top two to three most prevalent attributes per vessel, rather than the raw data atypical test that showed a lower percentage (<30%) in the top four to five categories. Therefore, raw data extracted from detailed descriptions can be useful to help define typical and atypical traits, but it does not take into account the aesthetic properties of each vessel or any potential trends throughout the ancient Egyptian glassmaking and glassworking era, therefore, an expert visual analysis should be also be used for appraisal. However, the combined methods were by no means conclusive, only "agreeing" on 16 vessels of the 78 vessels identified as atypical and identifying five vessels of known origin. Therefore, any vessels to be examined should also be subjected to compositional analysis, where appropriate. The Americas were identified as containing the largest number of atypical vessels and the largest proportion of vessels with little or no provenance information, including those vessels that are contained within private collections. Finally, it is not the intention of this research to undermine the authenticity of the vessels identified in this study as atypical, but to articulate the value of the information that has been lost during as a result of poor documentation during historical excavations, and how important information may be gained by subjecting these pieces to archaeometric study.

About the authors

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References

Birren, F. 1950. *Color Psychology and Color Therapy: A Factual Study of the Influence of Color on Human Life*. McGraw-Hill.

Broschat, K. and Th. Rehren. 2017. "The glass headrests of Tutankhamen." *Journal of Glass Studies* 59: 377–380.

Loat, W.L.S. 1905. *Gurob*. London: British School of Archaeology in Egypt/Egyptian Research Account 10.

Na'aman, N. 2000. "The Egyptian-Canaanite correspondence." In *Amarna Diplomacy: The Beginnings of International Relations*, edited by R. Cohen and R. Westbrook, 125–138. Baltimore, MD: Johns Hopkins University Press.

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Nicholson, P. T. 1993. *Egyptian Faience and Glass*. Shire Egyptology. Bucks: Shire Archaeology.

Nicholson, P. T. and J. Henderson. 2000. "Glass." In *Ancient Egyptian Materials and Technology*, edited by P. T. Nicholson and I. Shaw, 195–226. Cambridge: Cambridge University Press.

Nolte, B. 1968. *Die Glassgefässe im alten Ägypten, Münchner Ägyptologische Studien*. Berlin: Verlag Bruno Hessling.

Petrie, W.M.F. 1894. *Tell el-Amarna*. London: Methuen.

Reeves, N. and R. H. Wilkinson. 2008. *The Complete Valley of the Kings: Tombs and Treasures of Egypt's Greatest Pharaohs*. Thames & Hudson.

Shortland, A. J. 2001. "Social influences on the development and spread of glass and glazing technologies." In *The Social Context of Technological Change—Egypt and the Near East 1650–1150 BC*, edited by A. J. Shortland, 211–223. Oxford: Oxbow Books.

Shortland, A. J., P. T. Nicholson and C. M. Jackson. 2001. "Glass and faience at Amarna: Different methods of both supply for production, and subsequent distribution. In *The Social Context of Technological Change—Egypt and the Near East 1650–1150 BC*, edited by A. J. Shortland, 147–160. Oxford: Oxbow Books.

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