

ARTICLES

The Beginnings of Vitreous Materials in the Near East and Egypt

MICHAEL TITE,* ANDREW SHORTLAND, AND SARAH PAYNTER†

Research Laboratory for Archaeology and the History of Art, 6 Keble Road, Oxford OX1 3QJ, U.K.

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ABSTRACT

In the Near East and Egypt, vitreous materials in the form of glazed stones and faience were first produced from about the 4th millennium B.C.. Subsequently, the period around 1500 BC saw major developments in the range of vitreous materials with the production of glass vessels and glazed clay objects and an extension in the range of colorants used. This paper first describes how the examination of artifacts has been used to reconstruct the processes involved in the production of these different vitreous materials. This information is then used to try to understand how the new technologies were discovered and why they were adopted.

Introduction

The appeal and high prestige of vitreous (i.e., glassy) materials in the ancient world was most probably associated with their brightly colored, smooth, and shiny surfaces similar in appearance to semiprecious stones such as turquoise and lapis lazuli. In the Near East and Egypt, such stones were valued and were considered to possess special magical powers for warding off evil spirits and for curing medical ailments.¹

The first vitreous materials were glazed stones, mainly quartz and steatite, and faience which consists of a ground quartz body coated with a glaze. In all cases, the glazes

Michael Tite (born London, 1938) M.A. (Physics) and Ph.D., University of Oxford. Lecturer in Department of Physics, University of Essex, and Keeper, Department of Scientific Research, British Museum. Currently, Edward Hall Professor of Archaeological Science and Director of Research Laboratory for Archaeology and the History of Art, University of Oxford. Major research interest is the investigation of the production technologies of vitreous materials (i.e., faience, glass, and glazed ceramics) in the Near East, Egypt, and Europe from the 4th millennium B.C. through to 18th century A.D.

Andrew Shortland (born Northampton, 1966) M.A. (Geology), M.St. (Prehistoric Archaeology), Ph.D., University of Oxford. Currently conducting research in early vitreous materials at the Research Laboratory for Archaeology and the History of Art, University of Oxford, specializing in the Late Bronze Age of Egypt and the Near East.

Sarah Paynter (born Oxford, 1972) B.A. (Materials Science), University of Cambridge, completing Ph.D., University of Oxford. Currently, archaeological scientist at the English Heritage Centre for Archaeology. Major research interest is in ancient technology, including ferrous and nonferrous metalworking and production of ceramics and vitreous materials.



FIGURE 1. Multicolored glass fragments from Amarna, Egypt (courtesy of Aegyptisches Museum, Charlottenburg, Berlin).

were of the alkali-lime type, initially with copper added to produce a blue color. Although the precise chronology and geographical origin are not known, it is clear that these vitreous materials were being used in the Near East and Egypt from the 4th millennium B.C. onward to produce small objects such as beads, scarabs, seals, and amulets.

Occasionally small glass objects are found dating from the late 3rd millennium B.C. onward. However, it was not until about 1500 B.C. that significant quantities of glass, including glass vessels, began to be produced. At about the same time the range of colorants used in both faience and glass was extended from the previously dominant copper blue to include also cobalt blue, calcium antimonate white, and lead antimonate yellow (Figure 1). Also, contemporary with the beginning of glass production, was the production in the Near East of the earliest glazed clay objects.

The aim of the present paper is to review the results of investigations into the technologies employed in the production of glazed stone, faience, glass, and glazed clay. In addition to determining the raw materials and methods of production, these technologies need to be interpreted in terms of the people producing, distributing, and using the vitreous materials. Thus, one tries to understand how a new technology was discovered and why a new technology was adopted.

Although much of the early story of vitreous materials involves Mesopotamia as the source of innovation, the present paper focuses mainly upon evidence from Egypt. This, in part, reflects the research interests of the authors but is also the result of the very much poorer preservation of vitreous materials from the Near East as compared to Egypt and hence the more limited fully quantitative analytical data available.^{2–4}

† Current address: English Heritage Centre for Archaeology, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth PO4 9LD, U.K.

Table 1. Analytical Data for Vitreous Materials from Egypt and the Near East

type of material ^a	phase ^b	Oxide concentrations, ^c %								
		SiO ₂	Na ₂ O	K ₂ O	MgO	CaO	Al ₂ O ₃	FeO	CuO	CoO
copper blue faience	glaze	75.7	6.5	4.3	0.5	1.2	0.4	0.2	10.3	
	IG	73.0	7.8	4.2	0.3	2.2	0.8	1.9	10.6	
cobalt blue frit	IG	78.5	12.2	0.6	2.0	1.0	4.6	0.7		0.30
	bulk	84.8	8.7	0.4	1.4	0.7	3.3	0.3		0.21
copper blue glass		64.1	17.8	2.3	4.2	8.4	1.1	0.6	1.3	
cobalt blue glass		63.8	19.6	1.0	4.3	7.6	2.5	0.6	0.2	0.13
synthetic glass ^d		76.8	12.4	1.2	2.5	3.8	2.4	0.4		0.13
Mesopotamian glass		68.8	15.0	2.8	4.4	6.9	1.2	0.9	e	
Mesopotamian pottery	glaze	63.9	15.4	4.5	3.9	6.7	2.8	2.8	e	

^a Copper/cobalt blue faience, glass, and frit from Amarna (ca. 1350 B.C.).³¹ Mesopotamian glass and pottery glaze from Nuzi, Nimrud, Nippur, and Babylon (1500–500 B.C.).³⁰ ^b IG—interstitial glass (faience) or glass matrix (frit). ^c Average concentrations normalized to 100%. ^d Synthetic glass composition for mixture 60% cobalt blue frit plus 40% colorless glass (i.e., copper blue glass less its copper oxide). ^e Copper oxide concentrations omitted.

Of particular importance in the study of early glass production in Egypt is the glass factory area at Amarna that was first excavated by Petrie⁵ at the end of the 19th century and re-excavated by Nicholson in the 1990s.⁶ Amarna was the capital of Amenophis IV later known as Akhenaten (1353–1337 B.C.). It was rapidly built on a virgin site in Middle Egypt but was inhabited for only a relatively short period of time, the royal court abandoning the site during the reign of Tutankhamen (1336–1327 B.C.). Although the site was extensively robbed of almost everything of value in antiquity, it still represents a unique snapshot of a city during one of the most interesting and controversial of all the periods of Egyptian history. The recent re-excavation of the glass factory area revealed two large furnaces with fused clay adhering to their walls and with large quantities of fused clay both within and around them. Also found in the vicinity of the furnaces was a high concentration of industrial debris associated with the production of a wide range of vitreous materials. Thus, in addition to evidence for the long-established technology for the production of faience (fragments, molds), there is clear evidence for the relatively new glass industry. As well as the glass spills, rod, and vessel fragments associated with glass working, there are shallow pans containing blue frit⁷ and cylindrical ceramic vessels with glass drips adhering that, like the furnaces, could have been associated with glass production.

It has been the scientific examination of the industrial debris from the Amarna glass factory area that has provided the focus of much of the research reported in this paper. Central to this research has been the determination of the chemical compositions of the objects in polished section using an analytical scanning electron microscope (SEM). From these data, it has been possible to infer what raw materials were used in the production of the objects and, in combination with the observed microstructures, what methods were used in processing the raw materials and fabricating the objects. Compositional data for copper blue faience, cobalt blue frit, and copper and cobalt blue glass from Amarna are summarized in Table 1, together with those for Near Eastern glass and clay glazes.

Raw Materials

The glazes and glasses produced in the Near East and Egypt prior to the Roman period are all based on silica as the network former, soda as the alkali flux, lime and magnesium oxide as the stabilizers that limit solubility and hence weathering, and, initially, copper oxide as the colorant.

The two possible sources of silica are ground quartz pebbles and quartz sand. The former contain very few impurities and therefore, other than providing the silica content, will make a negligible contribution to the overall composition of the vitreous material. Conversely, the use of quartz sand can introduce significant amounts of other elements, in particular lime and alumina. For example, typical sands from the Near East and Egypt contain some 2–18% lime and 1–4% alumina.²

The two possible sources of alkali are natron from the natural evaporitic deposit at Wadi Natrun in Egypt and the ashes obtained from burning coastal or desert plants. The former, which consists predominantly of sodium carbonate and sodium bicarbonate, contains few impurities. Therefore, other than providing the soda content, natron will make a negligible contribution to the overall composition (less than 1% each of K₂O, MgO, and CaO). However, the plant ashes can contribute significant amounts of other elements, in particular, potash, magnesium oxide, and lime.⁸ On the basis of compositional data from the Near East, it is apparent that the compositions of plant ashes can vary quite considerably, depending on the type of plant as well as the location and season of the year in which it grew.²

In summary, glazes and glasses containing low alumina levels were most probably produced using ground quartz pebbles whereas those with higher alumina levels were most probably produced from quartz sand. In the former case, the lime would have come either from plant ash or, if the source of the alkali was natron, from separately added limestone. In the latter case, the lime could also have come from the sand itself.

Because of the correlation between the copper and tin contents observed for many copper blue faience glazes and glasses, a common source of the copper colorant was probably corroded bronze.⁸ In the absence of tin, the

source of the copper colorant could have been either corroded copper metal or a copper mineral, such as malachite or azurite.

Copper Blue Glazed Stones and Faience

The discovery of a process for producing a blue glaze most probably occurred during the smelting of copper that started in the Near East sometime during the late 5th to early 4th millennium B.C.,⁹ at more-or-less the same period as the production of the first glazed stones. Thus, a colored glaze could have been formed on a sandstone furnace wall as the result of reaction between soda from the fuel plant ash, copper from the ore, and silica from the sandstone.

The first material to be deliberately glazed was probably quartz. Glazing was subsequently extended to steatite, a hydrated magnesium silicate, which was much softer and more easily carved than quartz but which hardened during firing due to the conversion of steatite to enstatite. In addition, faience objects started to be produced using forming and firing processes characteristic of this soft-stone technology.¹⁰ By the middle of the 3rd millennium B.C. faience predominated over steatite as the favored material for small objects.¹¹ An advantage of faience was that its production by modeling or molding moistened ground quartz was a more rapid process than carving steatite. Further, faience glaze tended to be a clear blue (Figure 2) whereas the steatite glaze was more greenish.

Since quartz, steatite, and faience are all rich in silica, the bodies themselves can provide the silica needed for the glaze. Therefore, glazing is possible through the application of a paste or slurry of alkalis, derived from plant ash or natron, and a copper compound to their surfaces and firing to a temperature in the range 900–1000 °C. An alternative method is cementation glazing, in which the bodies are buried in a glazing mixture consisting of alkalis, a copper compound, and sometimes additional lime and/or quartz. On firing, the glazing mixture reacts with the surface of the stone or faience, forming a glaze. The presence of lime has been shown to make removal of the glazed object easier after firing.

For faience, efflorescence glazing provides a third possible method. In this method, alkalis and copper compound are mixed with the ground quartz. The mixture is moistened to form a paste that is then shaped by modeling or by molding. As the body subsequently dries, a proportion of the different glazing components are carried to the surface by capillary action and precipitate as a powdery layer from which the glaze is formed on firing.

A further method of glazing involves first producing a frit or a glass by firing a mixture of quartz, alkali, and a copper compound. The ground frit or glass can be applied as either a slurry or a powder to the surface of steatite or faience bodies, which are then fired. On the basis of present evidence, it is not entirely clear whether this method of glazing preceded glass production or was adopted as a result of glass production. If the former, then application faience glazing could have provided the



FIGURE 2. Copper blue faience shabti figures and rings from Egypt (copyright of the British Museum, London).

inspiration for producing core-formed glass vessels by similarly applying the powdered glass used for glazing to a clay-based core.¹²

Examination with a low-power binocular microscope to identify, for example, drips of glaze or firing marks is an essential first step in determining which of the possible glazing methods was used.^{11,13} This macroscopic evidence should then be supplemented by microstructural evidence, obtained with a SEM.^{14,15} For example, with cementation glazing of faience, the glazing mixture interacts with the surface of the quartz body but there is minimal penetration of the glazing components. Thus, there is negligible interstitial glass bonding together the quartz particles within the body (Figure 3a). Similarly, application of a prefritted glazing mixture results in minimal interstitial glass within the quartz body but, in this case, the glaze layer tends to be much thicker (Figure 3b). Conversely, with efflorescence glazing, alkali and copper compound survive throughout the quartz body after drying and react with the quartz to form fairly extensive interstitial glass (Figure 3c).

Information on the raw materials used in the production of faience can be inferred from the compositions of the glaze and interstitial glass, the average values being given for copper blue faience from Amarna in Table 1. The low alumina contents of the glaze and interstitial glass, together with the angularity of the quartz particles

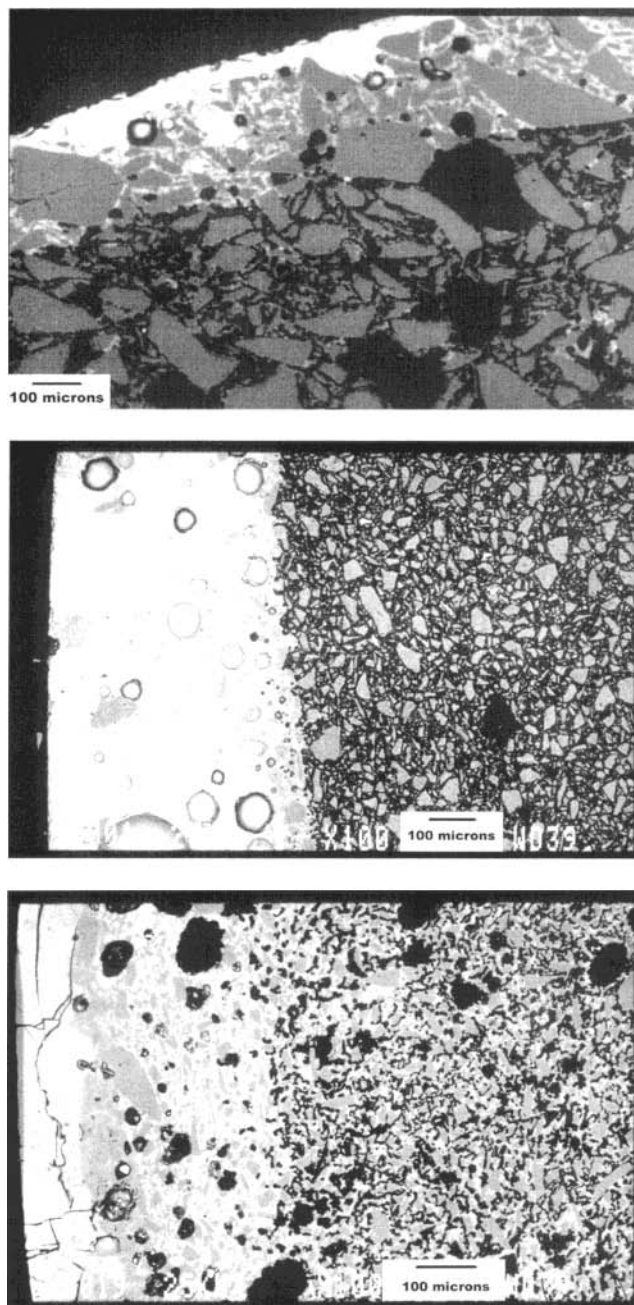


FIGURE 3. SEM photomicrographs of sections through (a) a faience shabti figure from Egypt glazed by the cementation method showing a thin surface glaze (white), an interaction layer of quartz (grey) in a glass matrix, and a core of quartz particles containing no interstitial glass; (b) replicate faience glazed by the application method showing a thick glaze layer (white) with a scatter of quartz particles (grey) at glaze–core interface and a core of quartz particles containing no interstitial glass; (c) faience shabti figure from Egypt glazed by the efflorescence method showing the surface glaze (white), an interaction layer, and a core of quartz particles (grey) bonded together by interstitial glass (white).

in the faience cores, suggest that ground quartz pebbles were the source of the silica. The high potash and lime contents (11.9% K_2O and 6.1% CaO for the interstitial glass after normalization to 18% Na_2O) confirm the use of plant ash as the source of the alkali, even though the magnesium oxide content is low (1.6% MgO after normalization).

However, the composition of this plant ash differs significantly from the plant ash used in the production of copper blue glass in Egypt, for which the potash content is lower (2.3% K_2O) and the lime and magnesium oxide contents are higher (8.4% CaO and 4.2% MgO) (Table 1).

The Beginnings of Glass Production

The initial discovery of glass most probably arose through poor compositional or temperature control (i.e., excess alkali or heat) during the production of faience. In attempting to explain the delay of more than 2000 years between the production of glazed stones and faience and that of glass, Peltenburg¹⁶ suggested that an important factor was that the production of the former materials involved only cold-working. Thus, the stone was carved before firing and, in faience production, the raw materials were first mixed together, moistened, and modeled or molded to shape. Similarly, the occasional glass objects produced in the period prior to about 1500 B.C. were also produced using cold-working lapidary techniques, in this case, after firing.

In contrast the routine production of glass vessels and other objects involved the manipulation of hot, viscous fluids, a process that was more akin to metal working. Thus glass vessels were produced either by melting a series of layers of ground glass applied to a clay-based core or by trailing molten glass around the core.¹² The glass was then reheated in order to be able to smooth the surface and, when cool, the core was removed. Therefore, although the production of glazed stones, faience, and glass involved the same combination of basic raw materials, the change from cold-working for glazed stone and faience to hot-working for glass may not have been a logical progression or an easy transition.

The transition would therefore probably have required input from metal workers. Thus, it can be argued that the discovery of the techniques necessary for hot-working glass was the result of contacts between glazed stone and faience workers and metal workers. Further, it is possible that these contacts were achieved through the changing control over and organization of artisans following the political upheavals occurring in Egypt and the Near East during the 16th century B.C. As a result, during this period, experts in different crafts could have been brought into close proximity in workshops and craft centers dedicated to producing objects for the elite. In such an environment, the transfer of technologies between crafts, and thus the discovery of glass production, would have been facilitated. Further evidence for contact between glass and metal workers is provided by the frequent use of bronze for the copper colorant⁸ together with the possibility that antimony-rich litharge from the cupellation of silver was the source of the lead antimonate yellow colorant.¹⁷ More direct evidence is provided by the industrial complex excavated at Qantir-Pirameses at which, during the early 13th century BC, there was large-scale bronze casting as well as the production of copper red glass.¹⁸

Similarly, the climate of change created by these same political upheavals probably encouraged the demand for this new and exotic prestige material, with the availability of an extended range of colorants perhaps being as important as glass itself. At the same time, the Harappan civilization also went into decline and the trade routes, via which lapis-lazuli and etched carnelian stones were imported to Mesopotamia from the Indus valley, were severed.¹⁹ Therefore, a further driving force for the adoption of glass could have been the declining availability of lapis lazuli and other semiprecious stones from the Indus valley at this period.

It is now generally accepted that the glass was first produced in any significant quantity in Mesopotamia from about 1500 B.C. The glass industry was subsequently introduced into Egypt during the reign of Tuthmosis III (1479–1425 B.C.) through a combination of glass objects and ingots being imported as tribute and the bringing back of captive Mesopotamian glass workers. However, whether Egypt subsequently relied on imported raw materials, in the form of ingots and cullet, or whether glass was being produced in Egypt rather than merely worked is less well-established.

A distinctive feature of early glass from Egypt, as well as contemporary frit and faience, was the extensive use of a dark blue cobalt colorant. These cobalt blue vitreous materials are characterized by higher alumina and magnesium oxide contents than the equivalent copper blue materials, together with the trace amounts of nickel, manganese, and zinc. On the basis of these data, Kaczmarczyk²⁰ argued that the most probably source of the cobalt colorant was the cobalt bearing alums from the Kharga Oasis in the Western Desert of Egypt. This discovery that the cobalt blue colorant in glass found in Egypt originated from an Egyptian source is very important in that it strongly suggests that glass was being produced in Egypt from as early as the reign of Tuthmosis III (1479–1425 B.C.).²¹ The alternative explanation that the cobalt-rich alum was exported to Mesopotamia and the glass thus produced was re-imported to Egypt seems less likely. First, a significant proportion of the very much rarer cobalt blue glass found in Mesopotamia³ does not contain the high alumina characteristic of Egyptian cobalt, suggesting an alternative cobalt source, possibly in Iran. Second, by the Amarna period (1353–1337 B.C.), there is fairly definite evidence for glass production in Egypt.

Comparison in the SEM of the microstructures of fragments from the walls of the two furnaces excavated at Amarna with those of samples of Nile silt fired in the laboratory to temperatures in the range 950–1250 °C indicated that the furnaces must have reached temperatures in the range 1100–1200 °C. Such temperatures are far in excess of those required for the production of contemporary pottery. Therefore, since there is no evidence for metal production on the site, it is most probable that the furnaces were used in glass production. Support for this hypothesis was provided by an experimental firing of a replicate version of these furnaces that established that such furnaces could be used to produce glass from

quartz sand and seaweed ash,²² temperatures of 1150 °C being fairly easily reached.²³

Further evidence for glass production in Egypt is provided by the glass ingots found on the Uluburun shipwreck off the Turkish coast that is dated toward the end of the 14th century BC. Analysis of the cobalt blue ingots from the shipwreck has established that the source of the cobalt colorant is again the cobalt rich alums from the Kharga Oasis.² In addition, the size and shape of these ingots match the cylindrical vessels found in abundance at Amarna. This match together with the frequent presence of traces of glass suggests that the cylindrical vessels were used to produce glass ingots.^{24,25}

Cobalt Blue Frit and Glass

One important question relating to the use of cobalt-rich alum is how it was first discovered that a slightly pinkish powder could be used to produce a dark blue glass. It seems probable that this discovery is related to the fact that the cobalt-rich alum occurs as small deposits within massive beds of alum and that alum was used by the Egyptians as a mordant in dyeing and natron as a natural detergent in laundering textiles.²⁶ The addition of natron to a pinkish colored solution of the cobalt rich alum results in the precipitation of a mixture of aluminum, magnesium, and cobalt hydroxides which takes on a blue color when dried. It therefore seems possible that such a color change was first observed on some occasion during the dyeing process.

The second question relates to the method used to incorporate the cobalt colorant into the glass. One hypothesis is that the distinctive coarse blue frit found at Amarna surviving in shallow “fritting pans”⁵ (Figure 4) represents an intermediate stage between the cobalt-rich alum and the final glass. Support for this hypothesis comes from the fact that no artifacts made from the frit itself, which consists of coarse quartz particles (100–500 μm across) in a glass matrix (Figure 5), have been found.

In attempting to identify the raw materials used from the chemical compositions of the frit, the contributions to the total alumina and magnesium oxide contents from the quartz and alkali, respectively, must be separated from the contributions from the cobalt colorant. This is possible using the plots of the concentrations of alumina and magnesium oxide in the glass matrix of the frits with increasing cobalt oxide concentration (Figure 6). The intercepts at zero cobalt oxide concentration then provide a measure of the contributions to the total alumina and magnesium oxide contents from the quartz and alkali, respectively.

From Figure 6a, it can be seen that the contribution to the total alumina content from the quartz is small (~1.3% Al₂O₃), suggesting that ground pebbles were the source of the quartz. This interpretation is supported by the fact that large angular quartz particles survive in many of the frits. Similarly, the contribution to the total magnesium oxide content from the alkali is small (~0.8% MgO) (Figure 6b). Since both the potash content (average 0.6% K₂O) and

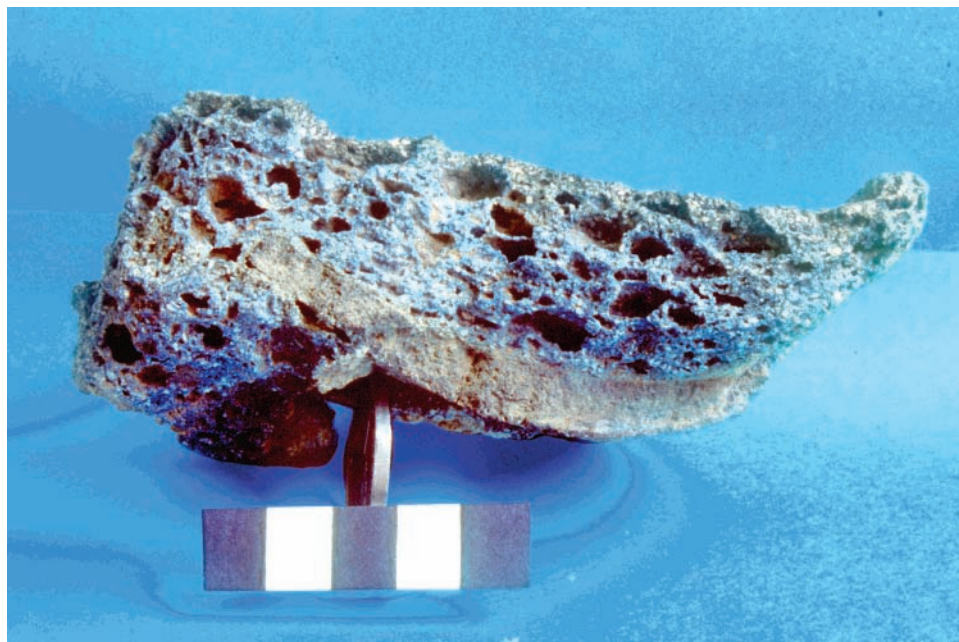


FIGURE 4. Fritting pan from Amarna, Egypt, showing a fused mass of cobalt blue frit in a partially melted ceramic pan (copyright of the Petrie Museum of Egyptian Archaeology, London, UC36457).

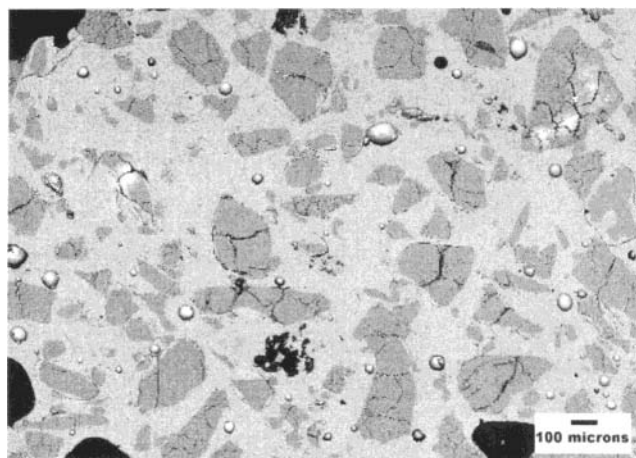


FIGURE 5. SEM photomicrograph of section through cobalt blue frit fragment from Amarna, Egypt, showing quartz particles (grey) in a homogeneous glass matrix (light grey).

the lime content (about 1% CaO when not contaminated by adjacent lime-rich slip) are also low, natron was most probably the predominant source of the alkali in the cobalt blue frit. This use of natron, rather than plant ash as for both copper blue glass and faience, strongly suggests that the cobalt colorant was added in the form of hydroxides precipitated from a cobalt-rich alum solution.^{20,27}

In considering how the cobalt blue frit might have been used to produce cobalt blue glass, Petrie⁵ suggested that the frit was added to a colorless glass of the composition of the copper blue glass less its copper oxide. To achieve the observed cobalt oxide content in the final glass (0.13% CoO), the mixture would need to include some 60% bulk frit (0.21% CoO). However, from the data presented in Table 1, it can be seen that the glass resulting from this mixture, although more-or-less correct in its cobalt oxide,

alumina, and potash contents, would be too high in silica and too low in soda, lime, and magnesium oxide. To achieve the increase in soda, lime, and magnesium oxide with respect to silica necessary for a match in composition, additional plant ash would need to be added to the frit–colorless glass mixture. However, since the potash content of the copper blue glass (2.3% K₂O) is significantly higher than that of the cobalt blue glass (1% K₂O), the potash content would then be too high if plant ash of the same composition as that used in the copper blue glass was added.

In summary, it seems possible that the cobalt blue glass was produced from a mixture of cobalt blue frit, plant ash, and either colorless glass or quartz. However, the plant ash used would have been different in composition than that used for the copper blue glass (i.e., lower in potash but remaining high in magnesium oxide and lime). This conclusion is consistent with the earlier suggestion by Lilyquist and Brill,²⁸ re-enforced by Rehren,²⁹ that plant ashes of different composition were used in the production of copper and cobalt blue glasses.

Glazed Clay

The production of the earliest glazed clay objects occurred in Mesopotamia some 2000 years after the first production of glazed stone and faience and coincided with the beginnings of glass vessel production. A possible explanation for why the glazing of clay objects was thus delayed is that the methods used to glaze stone (that is, quartz and steatite) and faience before the beginnings of glass production were not suitable for glazing Mesopotamian alluvial clays.³⁰ For glazing stone and faience, only alkali and colorant are required, the silica needed to react with the alkali to form a glaze coming from the body materials. However, Mesopotamian clays contain only about 50%

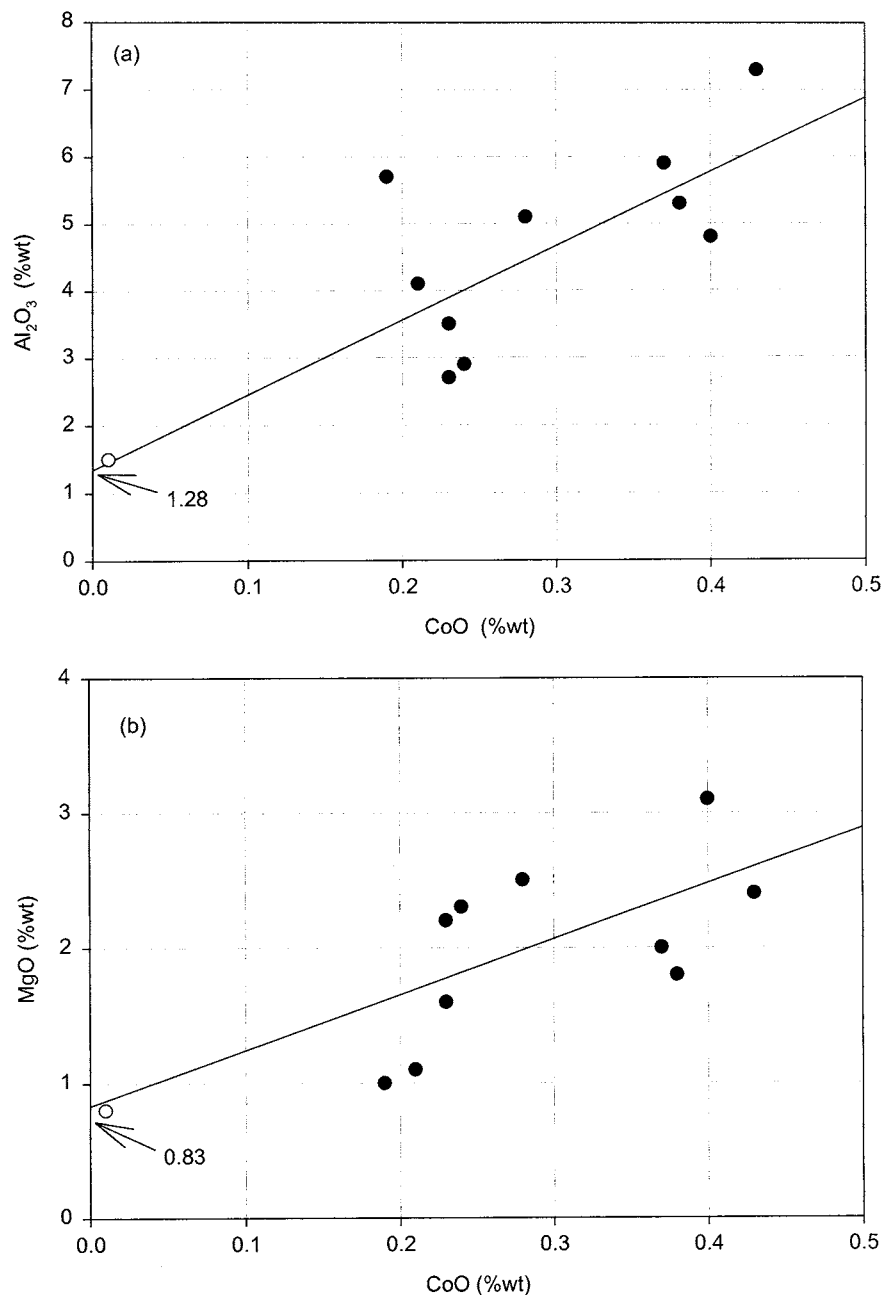


FIGURE 6. Plots for glass matrixes of cobalt blue frits (filled circles) and a single copper blue frit (open circles) of (a) alumina versus cobalt oxide concentrations and (b) magnesium oxide versus cobalt oxide concentrations.

silica. When a mixture of only alkali and colorant is applied to bodies made from these clays and fired, the remaining clay components cause the resulting glaze to be highly viscous at earthenware firing temperatures and, when cool, largely crystalline. The copper colorant fails to dissolve and there is severe blistering.

Therefore, before clay bodies could be satisfactorily glazed, a different glazing technology to that possible for glazing stones and faience needed to be developed. The close similarity in chemical composition observed for both early clay glazes and early glasses from Mesopotamia (Table 1) suggests strongly that clay objects were glazed by the application of a ground frit to their surfaces. However, the slight compositional differences between the glazes and glasses suggest that the potters made the glaze

frit independently from glass producers, although using a derivative technology. Therefore, it was the introduction of glass production that provided the necessary technological development for the successful glazing of clay objects. Further, because of their similarity in form, it is possible that the production of glass vessels provided the inspiration and created the market demand for glazed clay vessels.¹⁶

Because glass production began in Egypt at much the same time as it began in Mesopotamia, one might expect glazed clay objects to have been produced in Egypt at the same time as in Mesopotamia. Instead the earliest glazed clay objects in Egypt are produced around the 1st century B.C. and have lead-fluxed glazes. One possible explanation is that the clays available in Egypt were intrinsically less

suitable for glazing than the calcareous clays used in Mesopotamia. An important advantage of calcareous clays is that, as a result of their higher thermal expansion coefficient and greater interaction with the glaze, glaze crazing is minimized. In addition, calcareous clays fire to a buff color rather than the red color of noncalcareous clays so that the glaze appears brighter and is less "discolored" by the underlying body. Certainly Nile silt, one of the clays used extensively in Egypt in antiquity, is noncalcareous and therefore less suitable for glazing than calcareous clays. However, marl clays whose glazing properties are similar to those of calcareous Mesopotamian clays are widely available in Egypt and were extensively used in antiquity for pottery production. Therefore, one must probably look to cultural factors for the reason for the delay in the introduction of glazed clay objects in Egypt.

In Mesopotamia, stone was a rare commodity and therefore clay, both fired and unfired, was used extensively to build structures as well as for statues and figurines. Therefore, the ability to glaze clay was an important technological development in Mesopotamia in the context of architectural details (e.g., glazed clay nails, wall plaques, and bricks), as well as for glazed pottery vessels. In contrast, in Egypt, stone was employed on a large scale for many applications including monumental buildings and statues. Therefore, clay glazing may not have been such a directly applicable or desirable technology. In addition, in the period when glass began to be produced, the extremely skilled Egyptian artisans were able to extend both their range of colorants and their glazing methods for faience. As a result, faience, with its vivid colors and uncrazed glaze, would have been preferred over glazed clay as the material for religious and votive applications.

Conclusions

An important conclusion to emerge from the above study of vitreous materials is that a crucial factor in the discovery of new technologies was close contact between artisans involved in a range of different technologies. Thus, it is suggested that the possibility of producing a colored glaze on stone was discovered as a result of observations made during copper smelting, that the beginning of glass production was strongly influenced by input from metalworking, and that the technology used for glazing clay objects was derived from glass production technology. Similarly, the discovery of the cobalt blue colorant introduced at the same time as glass production probably resulted from the use of alum and natron for dyeing and laundering textiles.

However, despite the need for such contacts and the fact that artisans in different crafts were often working, as in the Amarna glass factory area, in close proximity, different traditions in, for example, the choice of raw materials seems to have been retained. Thus, plant ashes of different composition, and therefore from a different source, appear to have been used in the production of copper blue faience and copper blue glass. Similarly, it

seems probable that different plants ashes were used in the production of copper blue and cobalt blue glass and, finally, that potters produced their glazing frit independently from glass producers.

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