

EGYPTIAN FAIENCE: AN INVESTIGATION OF THE METHODS OF PRODUCTION

M. S. TITE, I. C. FREESTONE and M. BIMSON

British Museum, London WC1B 3DG, England

1. INTRODUCTION

The term Egyptian faience in the present context refers to a ground-quartz body with alkaline glaze which first occurs as early as the fourth millennium B.C. and has continued to be used in the Near East for the production of small objects such as beads, rings, bracelets, small figurines and bowls up to the present time.

The methods used in the production of Egyptian faience have been the subject of several previous investigations. Lucas (1962) succeeded in reproducing Egyptian faience by a two-stage process in which solid quartz pebbles were first glazed using a mixture of natron and malachite. This glaze was then chipped off, ground to a fine powder and applied to the surface of the ground-quartz body which was subsequently fired. Wulff *et al.* (1968) observed the methods currently used at Qom in Iran to produce bright turquoise donkey beads. Here the beads were formed from a mixture of finely ground quartzite and gum tragacanth dissolved in water. They were then fired to about 1000°C whilst buried in a glazing mixture which consisted of plant ash, hydrated lime, powdered quartz, copper oxide and charcoal. At the termination of firing, the glazing mixture was still friable and could be crumbled away to leave the glazed beads without any powder adhering.

On the basis of these observations, together with the scientific examination of the raw materials and finished products, Wulff *et al.* (1968) suggested that a similar technique could have been used in the production of Egyptian faience in antiquity. However, Noble (1969) did not believe that this technique was used in antiquity. Instead he succeeded in reproducing Egyptian faience by pre-mixing two of the glaze components (natron and copper oxide) with the ground-quartz body. A little water was then added in order to make the mass cohere, and after shaping, the object was left to dry freely. As this occurred, the soluble alkali salts were carried to the surface where they were deposited as efflorescence in the form of a white powdery layer which fused with the quartz to form a glaze layer when fired to about 950°C. More recently, Vandiver (1982) has attempted to reproduce Egyptian faience by the Qom technique described by Wulff *et al.* (1968), by the efflorescence technique and by direct application of the glazing mixture to the surface.

In the current work, Egyptian faience successfully produced in the laboratory using the Qom and efflorescence techniques has been characterised on the basis of microstructure and the composition of the glaze/glass phase. These reproduction beads were compared with four objects of faience from Egypt spanning the period from the New Kingdom to the Late Period (table 1). On the basis of these results, it is possible to comment further on the methods used in antiquity for the production of Egyptian faience.

Table 1 *Microstructure data*

BMRL no.*	Description	Reproduction technique or period	Surface glaze (thickness – μm)	Continuous glass-plus-quartz (thickness – μm)	Core (grain diameter – μm)
	Bead	Qom (flint)	20–50	~250	<50
	Bead	Qom (quartzite)	–	~600	50–200
	Bead	Efflorescence (flint)	20–50	~600	<50
	Bead	Efflorescence (quartz)	–	–	100–250
16319	Ring	New Kingdom	20–50	~250	<80
16321	Ring	18th Dynasty-Amarna period	~60	~350	<50
16323	Shabti-figure	21st Dynasty	20–50	~200	50–200
16322	Shabti-figure	Late Period	200–800	–	50–150

* British Museum Research Laboratory numbers

2. EXPERIMENTAL PROCEDURES

2.1 Laboratory reproduction

For the laboratory reproduction by the Qom technique, unfired objects of ground quartzite (50 – 200 μm diameter) and a sample of glazing mixture, obtained by Mr Oliver Watson from the workshop in Qom reported on by Wulff *et al.* (1968) were used. An unfired bead of ground quartzite was buried in the glazing mixture in a porcelain crucible and fired at 1000°C in air for about 2 hours in a muffle furnace. At the termination of firing, the glazing mixture was readily crumbled away to leave the glazed bead. In addition, a bead made in the laboratory from ground flint (<50 μm diameter) and formed by the addition of sufficient water to produce a paste was glazed by firing whilst buried in the Qom glazing mixture.

For the laboratory reproduction using the efflorescence technique described by Noble (1969), mixtures consisting 80 per cent by weight of either quartz sand (<250 μm diameter) or ground flint (<50 μm diameter) plus 20 per cent by weight of a glazing mixture comprised of sodium carbonate (6.5 per cent), sodium bicarbonate (6.5 per cent), calcium carbonate (4.0 per cent) and copper oxide (3.0 per cent) were prepared. Sufficient water was added to the mixture to produce a paste which could be shaped into beads. These beads were left to dry during which efflorescence of the alkalis occurred. They were then fired at 980°C for about 2 hours in air in a muffle furnace.

2.2 Examination and analysis

Samples were taken from the beads produced in the laboratory and from the faience objects from Egypt in order to provide sections through the glazes into the cores. After resin impregnation and polishing, these sections were first examined in the scanning electron microscope (SEM) in which the phases present could be distinguished on the basis of their atomic number contrast: that is, the quartz appears dark as compared with the higher atomic number glass phase which appears light (figures 1 – 8).

The glass phases were then quantitatively analysed using a Cambridge Geoscan electron microprobe fitted with a Link Systems energy dispersive spectrometer. The accelerating potential was 15 kV and the specimen current 5 nA. The accuracy and precision of a similar

instrument have been discussed by Dunham and Wilkinson (1978). There are several analytical problems which may be encountered when examining alkali-rich material such as glass and faience. Firstly, analytical totals may be reduced when analysing irregular and porous surfaces such as are encountered with ceramics (Tite *et al.* 1982). This is unlikely to be a significant effect in the analysis of the smooth glazed surfaces of the faience (except possibly No. 16322), but the analytical totals are in some cases disturbingly low (table 2). Some other explanation

Table 2 *Microprobe analyses of glass phase*

Oxide (% wt)	Ring (16319)		Ring (16321)			Shabti (16323)		Shabti (16322)		Lab. bead (Qom) (Efflorescence)	
	Glaze	Glass matrix	Glaze (outer)	Glaze (inner)	Glass matrix	Glaze	Glass matrix	Glaze (outer)	Glaze (inner)		
Na ₂ O	—*	>11.6**	3.3*	16.0	>13.3**	17.5	>13.5**	—*	18.6†	16.0	17.0
MgO	0.2	0.5	—	0.2	—	0.3	—	1.2	1.1	0.3	—
Al ₂ O ₃	—	1.5	—	—	0.4	0.8	0.4	3.2	4.8	1.8	0.4
SiO ₂	73.1	70.5	70.0	69.3	70.6	70.4	74.0	63.7	61.0	63.3	74.0
K ₂ O	—	3.2	1.5	5.7	5.5	1.4	1.6	—	0.6	6.8	0.4
CaO	1.4	2.8	0.4	0.2	—	4.7	3.4	4.9	4.3	5.4	2.7
FeO	0.3	0.9	—	0.3	—	0.5	—	1.0	1.7	0.6	—
CuO	9.7	6.5	9.5	7.4	5.8	3.2	2.9	3.9	2.8	2.9	5.1
P ₂ O ₅	0.5	0.5	0.4	—	—	0.7	0.5	0.4	—	—	—
Cl	1.0	0.5	1.2	1.0	1.0	1.0	1.4	1.6	1.8	0.9	0.1
Total	86.2	98.5	86.3	100.1	96.6	100.5	97.7	79.9	96.7	98.0	99.7

* Low Na₂O and low analytical total due to weathering

** Low Na₂O and low analytical total due to probe damage

† Low analytical total probably due to porous surface

must therefore be sought for this feature of the data. Loss of alkalis, particularly sodium, from silicates during microprobe analysis is a well-known effect (Lineweaver 1963, Autefage and Couderc 1980). In the present case the relatively low specimen current of the microprobe will have reduced but not eliminated this problem. For the glaze layers, the electron beam was therefore progressively defocused and the counting time reduced until a constant value for sodium was obtained and this was taken as close to the true sodium value. Unfortunately this procedure could not be followed for the interstitial glasses between the quartz grains in the body of the objects which occupied too small pockets to accommodate a spot size of greater than a few μm without interference from the surrounding quartz. Therefore sodium contents of the interstitial glasses (table 2) are low due to probe damage. Probe damage cannot, however, account for the low analytical totals of the surface glaze layers, for in some cases no alkalis were detected in spite of the efforts to reduce damage during analysis. The low totals of these layers are attributed to weathering and replacement of alkalis by water, an effect which is well known in glasses (Caley 1962). We have observed similar effects and similar analysis shortfalls on the weathered surface layers of approximately contemporary glass fragments of similar compositional ranges, but these fragments give good analytical results from their unweathered interiors.

In summary, because of probe damage, the alkalis (especially Na) in the analysed interstitial glasses are low. The ratios of the other components are, however, expected to be approximately correct. On the other hand the low totals and low alkali contents of the glaze layers are due to weathering. Thus, for all analyses the alkali contents should be regarded as minimum values. However, they closely approach the original concentration in the case of the ring (No. 16321 – inner glaze) and the shabti figure (No. 16323) where the Na_2O concentrations are high and the analytical totals approach 100 per cent, and also in the shabti figure (No. 16322 – inner glaze) where the Na_2O concentration is high although the analytical total is slightly low (table 2).

3. RESULTS AND DISCUSSION

3.1 Microstructure

The SEM examination of the beads produced in the laboratory and the ancient objects showed that, typically, they consist of a fragmented core of quartz with varying amounts of interstitial glass. The fragmented quartz core is encased in a layer of quartz embedded in a continuous matrix of glass with a surface layer of quartz-free glaze present in some cases. Data on the grain size of the quartz and the thicknesses of the surface glaze and continuous glass-plus-quartz layers are given in table 1, together with details on the ancient objects examined. From this data and from the photomicrographs (figures 1 – 8) it can be seen that, in spite of the general similarity, there are clear differences between the microstructures of the various objects.

The two beads made from coarse- and fine-grained quartz (i.e. ground quartzite and ground

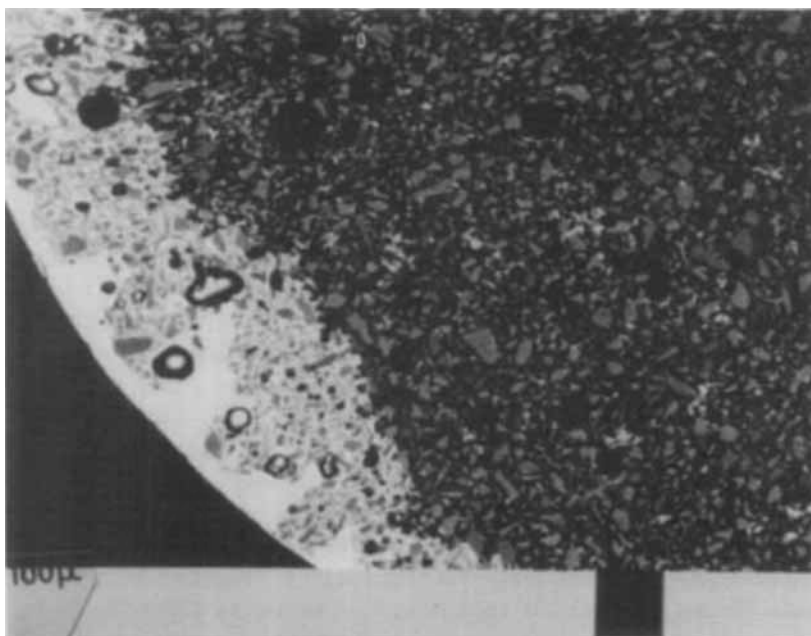


Figure 1 *Bead (fine-grained quartz:ground flint) produced by Qom technique.*

flint respectively), using the Qom technique are characterised by a comparatively sharp division between the continuous glass-plus-quartz layer and the fragmented core which itself contains only minimal amounts of interstitial glass (figures 1 and 2). A pronounced surface layer of quartz-free glaze is present only on the bead made from fine-grained quartz (i.e. ground flint) (figure 1). In contrast, the core of the bead made from fine-grained quartz (i.e. ground flint) using the efflorescence technique contains significant amounts of interstitial glass and the division between the fragmented core and the continuous glass-plus-quartz layer is much less clear cut (figure 3). The bead made from coarse-grained quartz sand using the efflorescence technique differs from all the other objects examined in that there has been no significant concentration of the glass phase towards the surface and the entire section through the bead consists of quartz embedded in an essentially continuous glass matrix (figure 4). The presence of significant amounts of glass in the cores of the beads produced by the efflorescence technique must be due to the fact that, because of the limited quantity of water in the beads, complete efflorescence of all of the glaze components to the surface cannot occur. Some of the glaze components will therefore always be left in the core of the beads and this will form glass. The incomplete efflorescence is particularly pronounced in the case of the bead made from coarse-grained quartz sand due to the greatly reduced capillary movement of the water through the associated coarser pore system. The fact that the glaze has penetrated the outer layer of the coarse-grained quartzite bead made using the Qom technique is probably because initial transport occurs in the vapour phase and the silicate melt formed has a higher surface tension, and hence greater facility for capillary movement, than water.

The two rings (Nos. 16319 and 16321) are characterised by a fine-grained quartz core

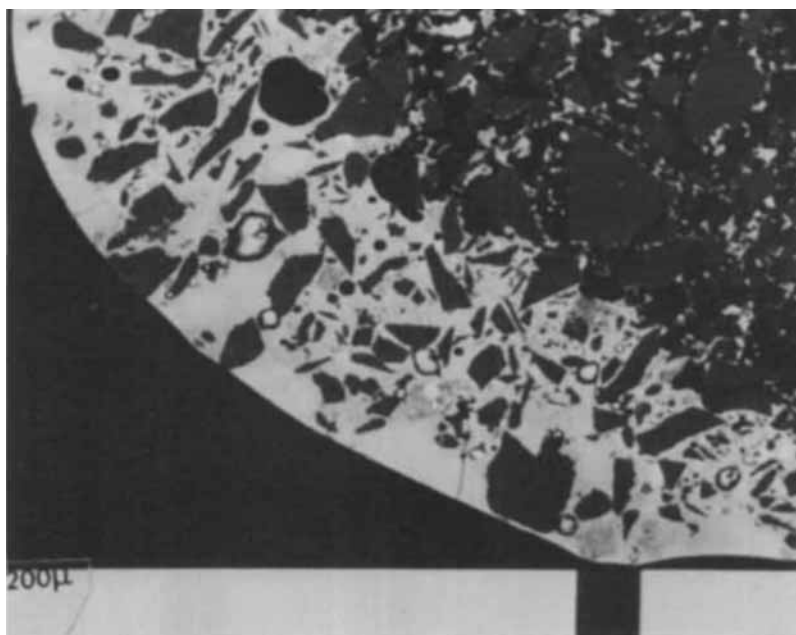


Figure 2 Bead (coarse-grained quartz: ground quartzite) produced by Qom technique.

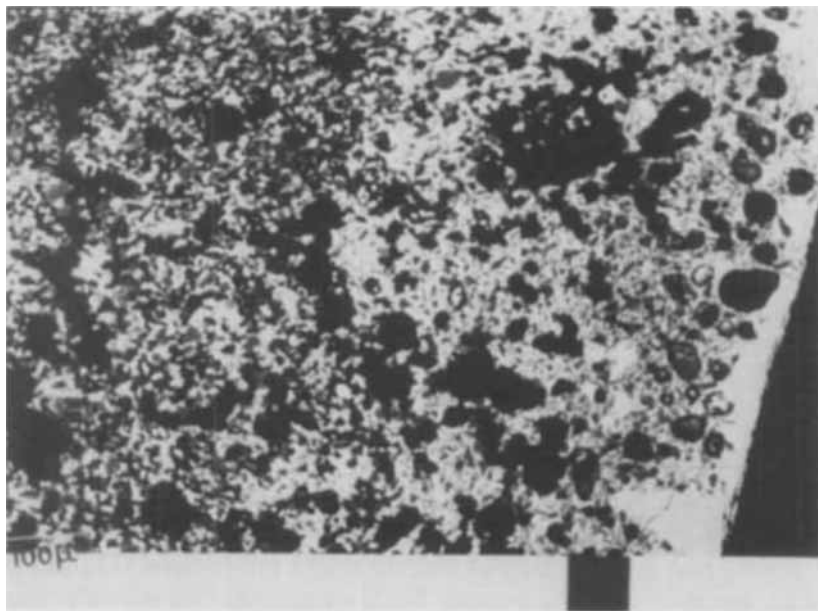


Figure 3 *Bead (fine-grained quartz: ground flint) produced by efflorescence technique.*

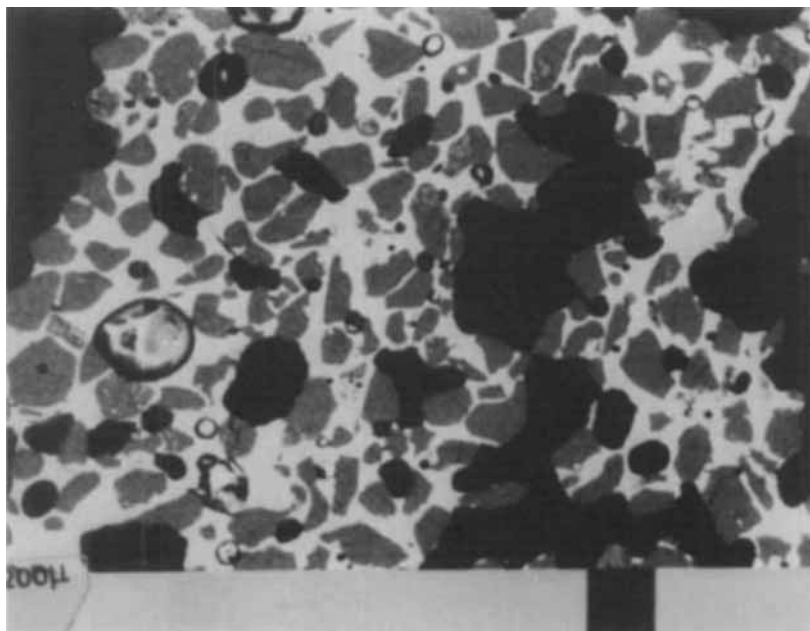


Figure 4 *Bead (coarse-grained quartz sand) produced by efflorescence technique.*

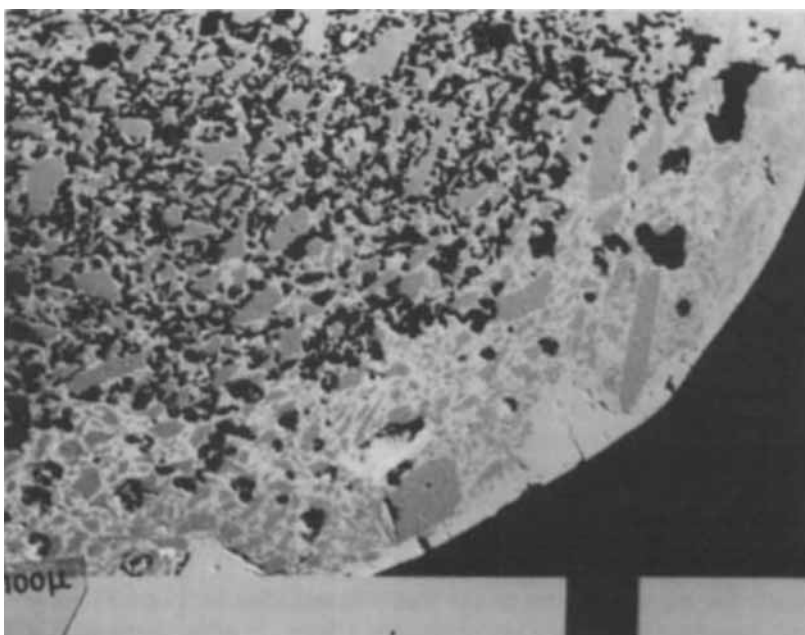


Figure 5 *Ring No. 16319 (New Kingdom)*

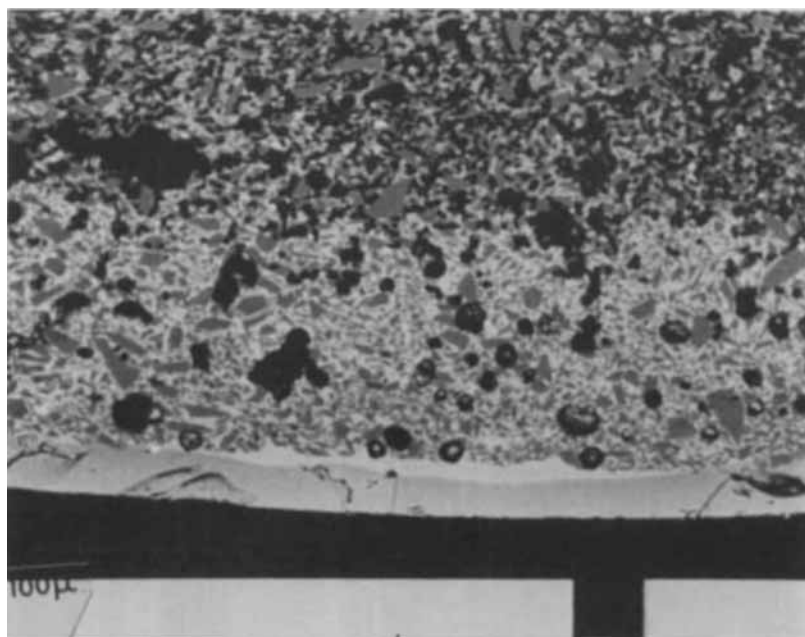


Figure 6 *Ring No. 16321 (18th Dynasty – Amarna period)*

containing some interstitial glass and a fairly sharp division between the fragmented core and the continuous glass-plus-quartz layer (figures 5 and 6). A clearly-defined surface layer of quartz-free glaze is only present on ring No. 16321 (figure 6). In contrast, the two shabti-figures are characterised by a coarse-grained quartz core containing only minimal amounts of interstitial glass (figures 7 and 8). In shabti-figure No. 16323 there is a sharp division between the fragmented core and the continuous glass-plus-quartz layer (figure 7). Shabti-figure No. 16322 differs in having a very thick surface layer of essentially quartz-free glaze but the underlying continuous glass-plus-quartz layer is poorly defined (figure 8). Calcium carbonate and feldspars are present, interspersing the quartz in the core of this latter shabti-figure.

The microstructures of the two rings (figures 5 and 6) are therefore essentially intermediate between those of the beads reproduced by the Qom and efflorescence techniques (figures 1 and 3 respectively) using fine-grained quartz (i.e. ground flint) of comparable grain size to that of the quartz cores of the rings. Furthermore, the absence of support marks on the rings does not help in distinguishing between the two techniques, since even if produced by the efflorescence technique support marks could have been avoided by laying the rings on a layer of hydrated lime during firing (Noble 1969). However, the presence of some interstitial glass in the cores of the rings does tend to favour the hypothesis that the efflorescence technique was used in their production.

In contrast, the microstructures of the shabti-figures (figures 7 and 8) are similar to that of the bead reproduced by the Qom technique (figure 2) using coarse-grained quartz (i.e. ground quartzite) and in no way compares with the bead reproduced by the efflorescence technique (figure 4) using coarse-grained quartz sand of comparable grain-size to that of the

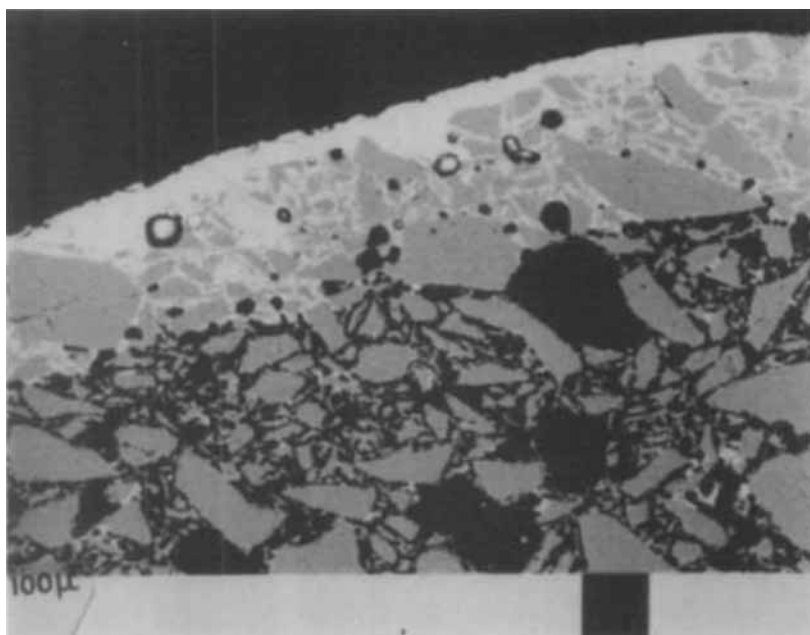


Figure 7 *Shabti-figure No. 16323 (21st Dynasty)*

quartz cores of the shabti-figure. The similarity between the shabti-figure No. 16323 (figure 7) and the Qom bead (figure 2) is particularly close, strongly suggesting that the Qom technique was used in the production of this object. The use of the Qom technique for the production of the shabti-figure No. 16322 (figure 8) is, however, less certain, since the surface layer of continuous glaze is much thicker on this object and there is no well-defined continuous glass-plus-quartz layer. It therefore seems possible that, in this case, the glazing mixture was applied to the surface prior to firing.

3.2 Glaze/glass composition

The results of the electron microprobe analysis of the faience glazes and interstitial glasses are presented in table 2. The reasons for the low analytical totals and low Na_2O concentrations, as discussed in section 2.2, are given in the footnotes to this table.

The analytical data for those regions of the glaze/glass from which no obvious depletion of alkalis has occurred indicates that the glazing mixtures used on the ancient faience are all of the soda-lime-silica type and glazes of comparable compositions have been achieved in the beads produced in the laboratory using the Qom and efflorescence techniques. However, the compositions of the glazes on the ancient faience vary quite considerably and differ in a number of respects from those of contemporary glass. Although the concentration of Na_2O (16 – 19 per cent) in the glazes are similar to those in contemporary glass, in the case of the two rings the concentrations of K_2O (i.e. 3 – 6 per cent) are significantly higher and the concentrations of CaO (0.2 – 3 per cent) are significantly lower. Further, the concentrations of the copper oxide colorant in all the glazes (2 – 8 per cent) are again higher than those in contemporary

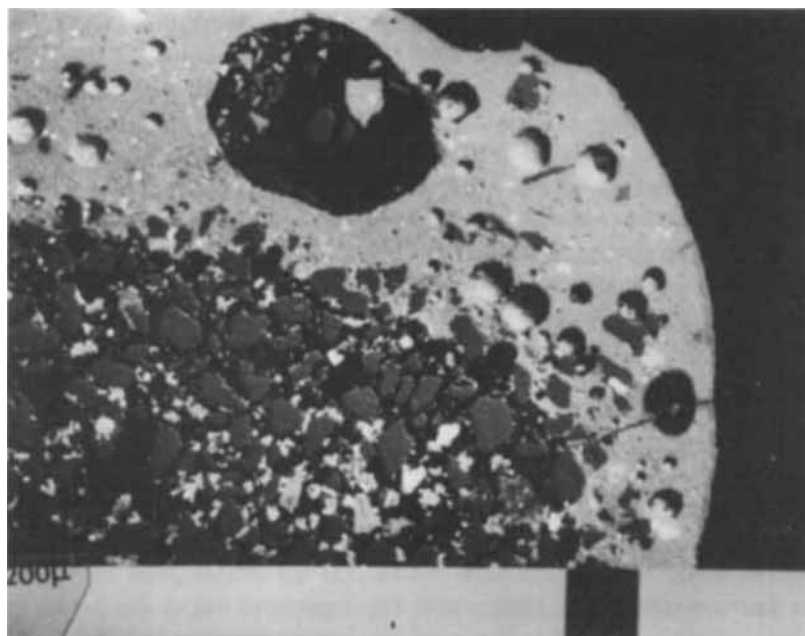


Figure 8 *Shabti-figure No. 16322 (Late Period).*

blue glass (normally <1 per cent). In spite of the variation in composition of the glazes in terms of K_2O , CaO and CuO , when their compositions are expressed in standardised terms $R_2O-RO-SiO_2$, after Iliffe and Newton (1976), they are remarkably consistent with R_2O from 16 – 20 mole per cent, RO from 6.5 – 9 mole per cent and SiO_2 from 71 – 76 mole per cent. It appears that CuO and CaO may be regarded as approximately equivalent in terms of the melting behaviour of the glazes, and the presence of CuO has depressed their CaO content, although the combined $CuO + CaO$ content is relatively constant and is typical of the CaO content of many soda-lime and silica glasses. The glaze compositions, as reformulated, are relatively durable, whereas glasses with lower RO contents would be rapidly weathered (Iliffe and Newton 1976).

In spite of this relatively durable composition, there has, however, been a significant depletion of alkalis from the surfaces of the glazes of the ancient faience as a result of weathering, except for the shabti-figure No. 16323. The surface layers of continuous glaze on the ring No. 16321 and the shabti-figure No. 16322 have been depleted in alkalis to depths of 60 μm and 30 μm respectively and in the latter case, the glass rimming pores which are within the glaze layer and which are connected to its surface have also been depleted. In the case of the ring No. 16319, depletion has extended into the continuous glass-plus-quartz layer to an overall depth of about 100 μm . In addition to the very obvious depletion of alkalis, a clear enrichment of copper and some depletion of iron, magnesium and calcium have also occurred. These effects are entirely characteristic of the weathering of glass (Caley 1962).

The fact that, with the Qom technique, the glazing mixture in which the beads are buried during firing does not fuse and subsequently crumbles away from the glazed beads is almost certainly due to its high CaO content as compared with the glaze itself. The phase diagram for the system $Na_2O-CaO-SiO_2$ (Morey and Bowen 1925) indicates that the glazing mixture, whose composition according to Wulff *et al.* (1968) is approximately 43 per cent SiO_2 , 20 per cent Na_2O and 20 per cent CaO , only melts totally in the 1200–1300°C range whereas the glaze is produced at approximately 1000°C. The composition of the glaze (about 65 per cent SiO_2 , 16 per cent Na_2O , 5 per cent CaO) approximates to that of the high-silica ternary eutectic, whereas the glazing mixture falls in the low-silica part of the system and will begin to melt at another eutectic point. Thus in order for the glaze to be produced, some silica from the bead itself must be incorporated. A slight rounding of the quartz particles near the surface of the bead can be observed, confirming that this process does occur. Extensive melting occurs only where the glazing mixture is in contact with the bead, equal weight proportions of glazing mixture and quartz from the bead yielding a glaze of approximately the correct silica content. Perhaps surprisingly, the high CaO content of the glazing mixture causes it to be relatively refractory and it undergoes a minimal amount of melting so that it can be easily disaggregated after firing.

4. CONCLUSIONS

The results presented above indicate that the microstructure of ancient faience as observed in cross-section in the SEM is of considerable help in identifying the method of production used in antiquity. It would appear from these results that the efflorescence technique cannot be used to produce a coarse-grained faience with the fragmented quartz core which characterises all the ancient objects examined in this work. In contrast the Qom technique can be used to produce both coarse- and fine-grained faience with the characteristic fragmented quartz core.

Further, the results for the specific ancient objects examined provide strong evidence to suggest that the Qom technique in which the quartz bodies are fired whilst buried in a glazing mixture was employed in antiquity in Egypt. However, it seems likely that both the efflorescence technique in which the glaze components are mixed with the quartz body prior to firing and the direct application of the glazing mixture to the surface of the quartz body prior to firing were also employed. A further fact to emerge from this work is that a significant depletion of alkalis and enrichment of copper can occur to depths of as much as 100 μm in glazes which from visual examination appear to be essentially unweathered. Since the extent to which these weathering effects occur depends on both the composition of the glaze/glass and on environmental factors such as temperature, pH and groundwater compositions (Barkett *et al.* 1981), no routine correction is possible when analysing glazes. Fully quantitative analysis of faience glazes is therefore difficult since analyses made on the untreated surface must obviously be interpreted with considerable caution and abrasion of the surface to remove the weathered layer is likely to penetrate beyond the continuous glaze layer into the continuous glass-plus-quartz layer. Hence, where it is possible to remove a small sample, analysis of the section through the glaze by electron microprobe is probably the most satisfactory approach to the problem.

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