

CHAPTER 10

ARTISTS' PIGMENTS FROM AMARNA

by

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10.1 Introduction

Nearly seventy specimens of pigments were found at the Workmen's Village during the 1979–1986 excavations. It has proved possible to have samples from a selection of these analysed at the Department of Earth Sciences of the University of Cambridge in order to determine the chemical constituents present within the various colour groups and so to provide a basis of comparison with pigment analyses from other sites and different periods. This has coincided with a series of museum visits in connection with preparatory work on the publication of the Society's North City excavations, in the course of which many pigment specimens from earlier excavations at various parts of Amarna have been located and noted (Table 10.2). A welcome discovery was of the results of experimental pigment making done late in the nineteenth century by F.C.J. Spurrell, who had been with Petrie at Amarna. This material is now in the Liverpool Museum. Some of the pigment specimens in the museums visited bear, in their actual shapes, information as to the way they were made, and, since this a neglected aspect of the subject, a special section in this chapter has been devoted to it.

A full list of all of the pigments excavated at the Workmen's Village is given in Table 10.1. However, in order to avoid unnecessary destruction of source material not all of them were sampled for analysis. Instead samples were selected which were representative of the various colours present. A list of pigments from the Main City from the work of earlier excavators and now in museums is also given (Table 10.2). Only a few of these have been analysed by previous investigators, but Pantone colour identifications, if taken together with readings from the Workmen's Village, give an indication of the range of colours used at Amarna.² Following the analytical sections, a series of observations is made on the technology of pigment production, which pay particular attention to excavated finds.

The pigments themselves fall into five main categories: blues, turquoises, greens, yellows and reds.³ Of particular interest are the blue and turquoise frits.⁴ A number of studies have already been made of the colouring agent "Egyptian blue" in blue frit, but there has been no corresponding attention paid to the study of turquoise frits. It is hoped that this report will go some way towards establishing the chemical composition of this substance.

It was noticeable that the colours of the pigments from the Workmen's Village showed little variation of tint, and this was generally the case of the colours found on the excavated wall-plaster from the site. The main source of painted plaster for comparison is the fallen fragments from the Main Chapel (at present being studied and reconstructed by one of the authors). Here the colour scheme was bold but limited, showing a possible reversion to the less naturalistic style

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² A "Pantone" colour selector, made by "Letraset", was used primarily to identify colours of pigments from the Workmen's Village and museum specimens of pigments from the Main City. Conversions into Munsell readings were later made using a Minolta CR221 Chromameter, kindly demonstrated and loaned by Dr Nigel Strudwick.

³ Although black and white are present on excavated wall plaster from Amarna (Workmen's Village and Main City) these have not been identified as discrete lumps of pigment from the excavations. The white, calcium carbonate or sulphate, could easily be overlooked as natural material, while carbon black, obtained from burning organic materials, would have existed only in powder form, and unless it was mixed with a binding material in a container would be hard to detect. The possible exception is the white powder from Petrie's excavations now in the Ashmolean Museum (1893.1–41 (402)).

⁴ Frits are materials produced from silica, lime and an alkali, with or without a pigment. Most Egyptian frits are highly coloured, usually blue or turquoise. The raw materials are heated to a sufficiently high temperature to fuse but not to flow as a glass. Both Lucas and Harris (1962: 191) and Turner (1956) have suggested a fritting temperature of at or below 750°C, that is, where a specific colour such as Egyptian blue was not to be developed.

of the pre-Amarna Period. No doubt distinct shades were also chosen to fit in with traditionally held ideas of colour symbolism. Colour tests have been taken on parts of the reconstructed paintings (Table 10.3).

Green was not present as a colour on the wall-plaster, and in fact the green samples on analysis turned out to be a raw material, similar to that used to make blue and turquoise frits, or even faience. The presence of this at the Workmen's Village, however, is a little difficult to explain, as one would normally expect it to be found close to a site of industrial production. From a range of possible colours found as frits,⁵ the pigments and wall-plaster from the Workmen's Village show that only distinct turquoises and blues were chosen for use. Other shades found by Petrie in 1891–1892 in the Main City were presumably formed by accident.⁶

We have only six excavated yellow pigment samples. Of these five are of a similar shade to the yellow present on the wall-plaster from the Workmen's Village. The sixth, visually identified as orpiment, does not appear on the surviving wall-plaster from the Workmen's Village.

The range of reds on the wall-plaster of the Main Chapel in the Workmen's Village is also very restricted, but in contrast to the other pigments, the two red samples show a very different colour from that on fragments of wall-plaster. These are of a maroon shade and are very distinct from the usual red colour found, for instance, on the feathers of the vulture, the lotus frieze background, the poppy flowers, etc. They may have provided, instead, the colour for the outline of the male face or part of a colour mix (with yellow and white) for the flesh colour of this face,⁷ or for other areas of paintwork not yet studied.

10.2 Previous studies of Egyptian blue

Egyptian blue was the first synthetic pigment⁸ and was used throughout the Dynastic period into the Roman era, subsequently spreading to the limits of the Roman Empire (Weatherhead 1987: 41–5; Augusti 1967: Section III:2). The chemical formula was established in 1889 by Fouqué as a copper-calcium-silicate, $\text{CaCuSi}_4\text{O}_{10}$ (or $\text{CuO}\cdot\text{CaO}\cdot 4\text{SiO}_2$), and it was later shown to be mineralogically equivalent to the naturally occurring mineral cuprorivaite (Pabst 1959; Mazzi and Pabst 1962).

The ingredients in its manufacture are believed to be sand, comprising silica and calcium carbonate, an alkali salt such as natron as a fusion mixture, and a copper ore. Sand is, of course, abundant and contains a strikingly high content of calcite at Amarna, 19% as lime. This constituent seems to have been derived by wind erosion of the limestone cliffs (Turner 1956: 281). The fusion mixture, impure natron, was added to lower the firing temperature, as Laurie showed in his experiments in making Egyptian blue. He also showed that, although Egyptian blue could form with little or no fusion mixture, the firing period had to be extended or temperatures raised. Natron, in an impure form, is available from the ancient natron lakes in Egypt, such as the Wadi Natrun and at el-Kab. Turner has shown that for several samples from the Wadi Natrun sodium carbonate and bicarbonate were the main constituents (with smaller amounts of sulphate

⁵ Spurrell (1895) mentions a full range of frits from blue and turquoise to grey and purple found in workshops (where grinding and mixing were presumed to have been done) and at the remains of furnaces from Petrie's excavations in the Main City. Russell notes a similar variety at the New Kingdom site of Gurob (Russell, in Petrie 1892: 45–6). Petrie's pigments and those of later excavators at the Main City, together with yellows and reds, are now mainly in the Ashmolean Museum, Liverpool Museum, Bolton Museum, the Petrie Museum (University College London), and the Cairo Museum. Synthetic pigments in various colours made by Spurrell are now in Liverpool Museum (56.21.286, 56.21.285B).

⁶ Petrie himself speaks of a "fine violet" as a half-formed frit. Russell (1893–5), who studied Petrie's coloured frits and experimented in making them, mentioned that purplish frits were produced by accident. Two pieces now in Liverpool Museum (56.21.282) and in the Petrie Museum (UC 36457) are certainly unlike the other colours; they are speckled with white inclusions and have a very coarse spongy appearance. However, one cannot perhaps entirely rule out the possibility of use of the more unusual coloured frits in the Main City (particularly on the more naturalistic scenes from Maru-Aten, the North Palace, Great Palace, etc.), or at least the greys and greens, but no analyses have yet been done. Kaczmarczyk and Hedges (1983: 30) suggest a significant manganese content could give a purplish tinge to faience.

⁷ Full details of the scenes found in the Main Chapel will be included in the final report on the excavations of the Workmen's Village.

⁸ The earliest recorded use is in the Fourth Dynasty, Lucas and Harris 1962: 341.

and chloride), but that the proportions of all the constituents can be highly variable. No potassium was present (Turner 1956: 284; also Lucas and Harris 1962: 493). He has also pointed out two other less likely sources of alkali. One is soda and potash obtained from burning plants; the other was the salt-rich deposits obtained from the evaporation of Nile water after the annual inundation. These salts were the carbonates, chlorides and sulphates of sodium and potassium, and also calcium and magnesium carbonates.⁹

The last main ingredient for making Egyptian blue is copper ore,¹⁰ presumably from the Eastern Desert or Sinai Peninsula, where there is evidence that both malachite and chrysocolla were mined in antiquity (Lucas and Harris 1962: 203–205; Hume 1937: 828, 833, 867). From experimental work both Chase (1971) and Tite, Bimson and Meeks (1981) have established that temperatures up to 1000°C were possible for the manufacture of Egyptian blue, while Bayer and Wiedemann (1976) have established the decomposition temperature to be 1080°C. This contradicts the results of earlier investigators (Laurie, McClintock and Miles 1914: 423), who maintained that the upper limit before green glass was formed was only 850°C.

Although made from the same materials and heated to a similarly high temperature, the composition of Egyptian blue is clearly distinct from faience (Lucas and Harris 1962: 173; Kaczmarczyk and Hedges 1983). Kühne (1969) and others (Kiefer and Allibert 1971) have suggested that Egyptian blue was used in the manufacture of faience, but the work carried out by Kaczmarczyk and Hedges (1983: 215) eliminates this possibility. Similarly Turner (1954), who has studied the products of the glassworks at Amarna, suggests that sand and ash (or soda) were first fritted and then heated to a higher temperature to make glass (c. 1050°C). However, Lucas notes that, at Amarna, at least, this could not have occurred as the composition of glass and frit from here are incompatible (Lucas and Harris 1962: 186). This has been corroborated for all periods by Kaczmarczyk and Hedges (1983: 217–8), with the possible exception of the Late Period.

Not only was Egyptian blue a ubiquitous pigment in the ancient world, it was also used as a modelling and ceramic material, and quite large objects could be made from it, possibly with a glass admixture (Chase 1971: 80–81, 88). It was also used to decorate pottery, although research has shown that sometimes cobalt occurs as a colouring agent on Eighteenth Dynasty pottery (Reiderer 1974: 104–6). A summary of the physico-chemical properties of Egyptian blue is given by Chase (1971: 80–81).

Many early investigators have suggested that Egyptian blue frit was fired twice, being ground up before the second firing (Laurie, McClintock and Miles 1914: 423; Spurrell 1895: 234). This was in order to remove uneven patches of colour from accidental variations in the mixture. More recently, however, Tite, Bimson and Meeks (1981) have found that repeated grinding and firing increases hardness, and that this was probably undertaken to make the moulded figurines and other objects.

10.3 Analytical methods

The pigment specimens taken from the excavated pieces were examined by powder X-ray diffraction (XRD) (with the assistance of Mr Tony Abraham of the Department of Earth Sciences, University of Cambridge) and chemically analysed by energy dispersive electron probe microanalysis (EPMA), in conjunction with a back scattered electron imaging facility, in the same department. XRD techniques are now widely used in the study of both ancient pigments (Jope and Huse 1940) and those synthesised by modern investigators (Pabst 1959; Mazzi and Pabst 1962) (particularly Egyptian blue). The XRD technique is described by Zussman (1977), and is able to provide information about the crystal structure of materials, so assisting in their identification. EPMA (described by Scott and Love 1983) can be applied either qualitatively (British Museum Research Laboratory, see Tite, Bimson and Meeks 1981; Tite, Bimson and

⁹ Turner was concerned with seeking the sources of the ingredients for glass making, but it can be assumed that these sources would be the same as for frit.

¹⁰ Kaczmarczyk and Hedges (1983: 90) conclude that bronze scrap was used regularly as a source of copper in the faience industry during the New Kingdom, and that this might have been the case with some Eighteenth Dynasty glasses (*ibid.*: 93). Use of bronze scrap should not be ruled out as a source of copper for frit making.

Cowell 1984), or can be used to provide a quantitative chemical analysis, as in this work. Traditionally, wet-chemical analysis (Laurie, McClintock and Miles 1914: 427; Russell 1893–5: 69; Lucas and Harris 1962: 495) has fulfilled this role, but because of the requirement for several grams of sample for analysis, it is not possible to obtain uncontaminated analyses of an inhomogeneous aggregate of grains. As it has been shown by several previous workers (British Museum, etc.) that many samples of Egyptian blue are indeed inhomogeneous, the bulk analyses obtained from wet chemical work have included contributions from both Egyptian blue and other constituents. However, by using EPMA it is possible to analyse an area having a diameter of only a few microns, so that individual grains can be identified and analysed. Indeed, other work has shown that the use of this method has contributed to the identification of the constituents of paint layers (Giavanoli 1969).

The samples for EPMA were prepared using standard techniques; the material was mounted on a microscope slide using epoxy resin, and then polished to a surface finish of c. 1 micron. The samples were then carbon coated.

10.4 Results of analyses

Blue.

From our study of the blue pigments, XRDs of all samples (except R10.1385) showed the presence of Egyptian blue together with the other main constituent, quartz. Scanning electron microscopy (SEM) further revealed that unreacted silica particles are surrounded by Egyptian blue crystals, and that these are embedded in a copper-rich glassy matrix (confirming Laurie's assertion as long ago as 1914). It appears that the original ingredients partially fused into a melt from which Egyptian blue crystallized out and that the remaining melt cooled to a glass. Tite, Bimson and Meeks (1981) have already noted that the reaction takes place at the surface of the silica particles which occur in excess as unfused quartz, and that these are progressively attacked to form Egyptian blue crystals. The EPMA of three out of four analysed samples confirms the presence of Egyptian blue, including R10.1385 for which the XRD data were inconclusive. (Three sherds bearing pigments were not analysed owing to difficulties in obtaining uncontaminated samples). It was also noted that the blue pigments are not always chemically homogeneous at micron level; this was found by repeated analysis of the same samples in three cases (see Table 10.4).

Almost perfect stoichiometric results were obtained for two samples (N15(1)4075, 4 readings; R10.1385, first reading) indicating that the grains analysed were almost pure Egyptian blue. The second reading of heterogeneous M10(2), which falls below the stoichiometric estimation of Egyptian blue, can be attributed to the inclusion of unreacted material or to the presence of by-products from the formation of Egyptian blue.

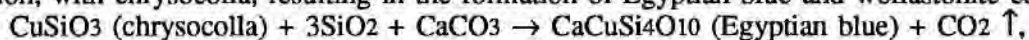
The compositions of blue frits shown by previous investigators have been notably variable when compared with stoichiometric Egyptian blue. While some bulk analyses have revealed almost perfect correlations, for instance the wet-chemical analyses of Laurie, McClintock and Miles (1914: 427) and Fouqué (1889b: 325), others summarised in Lucas and Harris (1962: 495) and Kaczmarczyk and Hedges (1983: 217, Table 35)¹¹ indicate that if stoichiometric Egyptian blue is present it must be associated with other materials. In the recent studies by the British Museum Research Laboratory (Tite, Bimson and Meeks 1981; Tite, Bimson and Cowell 1984), one of which includes the bulk analysis of blue pigments from Petrie's excavations at Amarna now in the Petrie Museum (UC 25153a–c, UC 8987, UC 24686), excesses of silica, and to a lesser extent calcium oxide, are repeatedly shown. In the Amarna pigments the constituent Egyptian blue comprises c. 60–80% of the grains analysed (Tite, Bimson and Cowell 1984: App. B).

A point to be considered with the heterogeneous blue samples is the presence of wollastonite, CaSiO₃. EPMA of R10[1385], second reading, and sherd WS3[2094]/66354, first reading, indicate this clearly. The readings of silica and calcium oxide compare well with stoichiometric

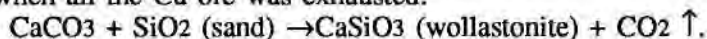
¹¹ Including the very low Ca and Cu results shown by Russell (1893–5: 69) on blue frit (? from Eighteenth Dynasty Gurob). Presumably enough Egyptian blue must have been present to give the characteristic blue colour.

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wollastonite. The textural relation of this mineral as observed by SEM indicates that this is a reaction product of quartz and calcite (both present in sand) in the furnace. This would occur where excess sand was added, or locally if the mixture was not well mixed. A possible two-stage reaction, with chrysocolla, resulting in the formation of Egyptian blue and wollastonite could be:



and when all the Cu ore was exhausted:



In the end only Egyptian blue and wollastonite and either quartz and/or calcite would be left.

It is an interesting coincidence that the amount of lime determined in sand from Amarna (18.9%, Turner 1956: 281) indicates that the sand comprises a 3:1 mix of quartz : calcite, almost the proportions in the reaction described above (an exact 3:1 mix would have 14.2% lime).

A further point to be considered is the notable absence of sodium in the EPMA's, with the obvious exception of sherd WS3[2094]/66354 (which is similar to some of the turquoises). This suggests either that the relatively small amounts of sodium previously reported from Amarna and elsewhere by the British Museum Research Laboratory (Tite, Bimson and Meeks 1981: Table 2; Tite, Bimson and Cowell 1984: App. B) and others (Lucas and Harris 1962: 495; Kaczmarczyk and Hedges 1983: Table 35 ; Dayton 1978: 31–2) were due to contamination by other materials in the sample, possibly glass or unreacted natron, or that the samples we have examined were prepared in a different way, or that they represent a different stage in the preparation of those examined by others.¹²

EPMA did not reveal the presence of tin in any of the samples; this implies that scrap bronze was not used in the original mixture. (Traces of lead and arsenic occurring in some copper alloys would not have been detectable by EPMA). However, occasional blebs of copper were observed in some of the samples by SEM, implying that, instead, scrap copper, relatively pure, could have contributed to the mixture. Through the use of different methods small amounts of tin and traces of arsenic and lead have previously been reported in blue pigments from Amarna (Tite, Bimson and Cowell 1984: 218).

Turquoise.

Examination of these samples by SEM reveals the presence of quartz grains with corroded margins, set in a matrix of calcium-copper silicate with a low sodium content; within this phase are needles, less than 10 μm in length, of calcium silicate (see Figure 10.10). Because of the size and shape of the needles it was difficult to obtain a reliable analysis of either these or the host material. As a consequence, the analyses are variable, and those quoted do not represent an individual phase. The low analytical totals (Table 10.5) suggest that the material is hydrated (elements higher than sodium cannot be determined by EPMA). The abundance of silica present is less than for Egyptian blue, and the copper : calcium ratio is often much less than 1; in the case of Egyptian blue it is typically about 1.5.

The most noticeable difference between the blue and the turquoise is the relatively high sodium content of the latter. This is indicated by the EPMA's of six of the turquoise specimens. The compositional variation of these analyses is shown in Figure 10.1. The almost uniform Cu : Na ratio of the analyses and the fact that all the more calcium-rich points have a slightly lower silica content suggest that the compositions determined are dependent on the proportion of calcium silicate at the point analysed. Despite the wide variation in bulk composition of the eight samples there is virtually no variation in colour.

Examination of the material by XRD indicates the presence of quartz in all the samples, and the presence of wollastonite (CaSiO_3) clearly in four out of eight specimens, but does not indicate the nature of the (Na)-Ca-Cu-silicate. (Such a mineral is not known to exist in nature). As wollastonite is a white-to-colourless mineral it is obviously the other phase which produces the turquoise colour of the material.

¹² Synthetic Egyptian blue, too, has shown, on analysis, the presence of alkali oxides when fusion mixture is added to the mix. Laurie, McClintock and Miles (1914: 426) used Egyptian natron (possibly from the Wadi Natrun) and obtained appreciable quantities of alkali oxide in their analysis — $\text{Na}_2\text{O} = 0.93\%$. They also successfully substituted potassium sulphate; result $\text{K}_2\text{O} = 1.19\%$.

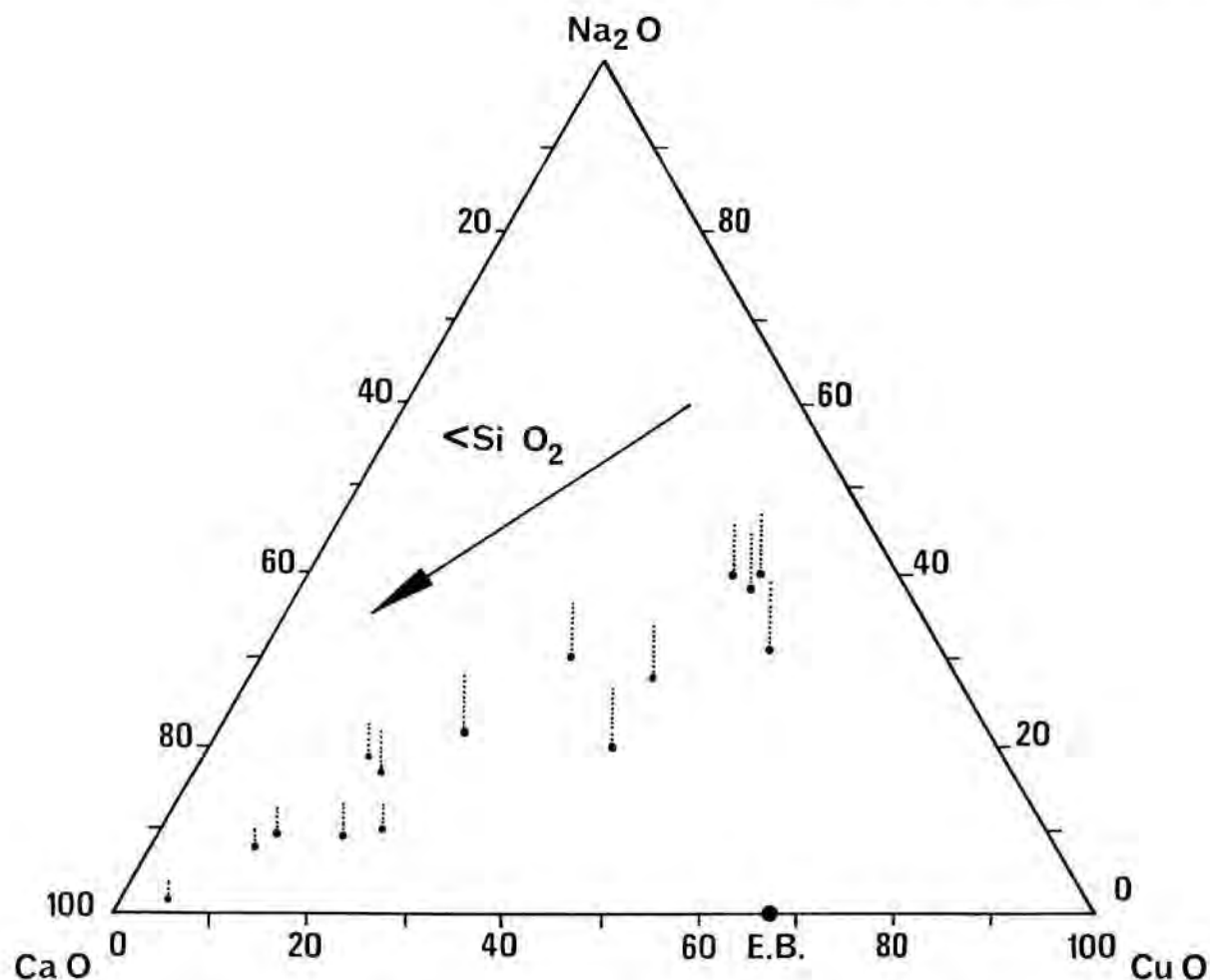


Figure 10.1. Compositional variation of analyses of turquoise material from this study. Length of vertical bars proportional to SiO_2 content. Full analyses are given in Table 10.5. Composition of Egyptian blue indicated by E.B.

The conclusion is that a significant amount of Na was added during the manufacture of turquoise frit over and above that added for blue frit. The presence of much smaller amounts of Na has already been noted in blue pigments from Amarna (Tite, Bimson and Cowell 1984: 239, 241), and elsewhere (Lucas and Harris 1962: 495; Kaczmarczyk and Hedges 1983: Table 35).¹³ This Na addition, probably as impure natron, may have been intended to assist the fusion of the material, and, as Laurie infers, to decrease the firing temperature for frit formation.¹⁴ Laurie, furthermore, showed by his experiments in synthesizing Egyptian blue that extra amounts of alkali actually inhibit the formation of Egyptian blue, although he does not give a description of the resulting colour (turquoise?). Excess amounts, on the other hand, produced only green glass. If our conjecture is correct, therefore, the addition of extra natron to form turquoise must have been carefully controlled.

The presence of chlorine as a trace element, more evident in the turquoises than blues, probably results from this increased addition of impure natron, which contains chlorides.

¹³ Occasionally larger amounts of Na occur, as in our own analysis of sherd WS3[2094]/66354; this implies that, although predominantly made up of Egyptian blue (and quartz), blue pigments can contain mineral(s) found in turquoise.

¹⁴ Evidence corroborated by later investigators (Tite, Bimson and Cowell 1984).

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Moreover, potassium, also more noticeable in the turquoises, indicates that potash might also have been added to the fusion mixture. Russell (1893–5: 69; in Petrie 1892: 46) and Petrie (1894: 25) suggest that variation in colour of the frit can be obtained by varying the amounts of copper ore (malachite) used in the mixture. Although they do not comment on the addition of fusion mixture, it is reasonable to assume that this was effectively increased as copper ore was decreased. It is stated that 3% copper ore would produce a “delicate greenish blue”, while 10% “a deeper blue colour”, and up to 20% for (unspecified) “blues” and “rich purple blues”. (Russell, too, notes that “a greenish tinge” could be obtained by arresting the heating process at an early stage).

Another feature of the turquoise results is the significant presence of iron. This does not occur in most of our blue samples, but similar quantities are reported elsewhere for Amarna blue pigments (Dayton 1978: 31; Tite, Bimson and Cowell 1984: App. B). It would appear, therefore, that iron-bearing sand could have been as easily used to make blue as turquoise. This would contradict the claims of Petrie¹⁵ and Russell that “green tinges” could usually be produced when appreciable iron was present. The same question was raised for blue versus turquoise faience, but again the evidence does not point to the exclusive use of iron-bearing sand to produce the turquoise colour (Kaczmarczyk and Hedges 1983: 39). Turner, who found that sand from Amarna contained 1.73% iron oxide (Lucas and Harris 1962: 481; Turner 1956: 281), asserted that this accounted for the high iron content of Amarna glasses, although he does not distinguish between particular colours.

Green.

Two of the green samples were shown to be, as had been expected, the copper ore chrysocolla, $\text{Cu}_{8-x}(\text{Si}_2\text{O}_5)_4\text{OH}_{12}\cdot n\text{H}_2\text{O}$. This was shown clearly by both EPMA and XRD. Because neither the copper nor the water content is fixed in the molecule, it is not possible to calculate stoichiometric quantities with which to compare the analyses. The material's non-stoichiometry may account for the variable copper content of the five analyses and the slightly low copper to silicon ratios when compared with the theoretical maximum of 2.26 (Table 10.6).

Although sample O15(4) visually appears fairly similar to the other two greens in that it is smooth and non-granular, its EPMA reading indicates a chemical composition close to some of the turquoises. A marked feature of the turquoises is the variability of the proportions of copper to calcium, the differences occurring between samples and also between separate readings of some of the same samples, indicating their heterogeneity. This heterogeneity is noted in green sample O15(4). We also note traces of iron, and quite a large proportion of sodium, together with the presence of potassium (although no chlorine was registered). It should thus be regarded as a slightly greener version of a turquoise frit, and perhaps slightly more vitrified.¹⁶ The greenness, however, could not directly be accounted for by additional amounts of these elements compared with the turquoises.

Green frits have already been identified in the Amarna Period (Spurrell 1895: 234), but green paint on wall-plaster is not so far known to exist at the Workmen's Village. For this reason the chrysocolla is difficult to explain; its use, however, is known in some of the Theban tombs (Reiderer 1974: 106). We do not know of any other analyses of green pigments from Amarna, except the samples from Tombs 28 and 29 in the Royal Valley, which were identified by XRD as arsenic sulphide (Iskander 1987).

Red.

Our single red specimen (WS3[2128]/12516) was clearly identified as haematite, Fe_2O_3 , by XRD and EPMA (see Table 10.6). Haematite is found in the Bahria Oasis and in various parts of the Eastern Desert, for instance at el-Atawi, the Elba region and the area south of Quseir (Said 1962: 265–266, 270–271). This is the anhydrous form of iron oxide, the other main type of Egyptian red pigment being red ochre which is the hydrated form.

¹⁵ Petrie found intact quartz pebbles at the remains of the industrial area at Amarna and concluded that they not only formed the base of furnaces, but that as they were iron-free they were used, crushed and calcined, in the manufacture of blue frit (Petrie 1894: 26). Remains of a similar furnace containing quartz pebbles were also found at Lisht (Vandiver, in Kaczmarczyk and Hedges 1983: A30).

¹⁶ This feature probably contradicts Russell's suggestion that greenness could be obtained by shorter firing times.

The only other red specimen found at the Workmen's Village is exactly the same in colour and texture, and one must suppose, albeit on a visual basis alone, that this is probably also haematite.¹⁷ The slightly low reading of iron oxide, compared with the stoichiometric quantity, and the low analytical total probably reflects a small quantity of water present together with traces of other elements not revealed by EPMA. Silicon or aluminium compounds are commonly found as impurities in haematite, and our sample shows the presence of these elements. The analysis compares well with two specimens analysed by Russell (1893–5: 67) from Eighteenth Dynasty Gurob, which showed 79.11% and 81.34% of ferric oxide (haematite). Russell also noted the remarkable adhesive properties of haematite, allowing it to be painted on a surface without a medium. Although our sample was not put to this test, it was noted that modern samples of impure red ochre, obtained from the nearby cliffs at Amarna, could be applied, thinly at least, with just water. The haematite which was applied with egg-white or yolk as medium did not change colour on drying. The supply of brighter red pigment which was used to obtain the predominant red colour on the wall-plaster in the Main Chapel is therefore yet to be found.

The other type of red used by ancient Egyptian artists, red ochre, occurs naturally in many areas, notably the oases of the Western Desert and near Aswan (Lucas and Harris 1962: 348). It could also be prepared by calcining or burning yellow ochres.¹⁸ Spurrell (1895: 231) mentions that several dozen of these were found by Petrie at the site of "the factory and paint shops", although these could perhaps have been the natural material instead. Also according to Spurrell burnt and raw yellow ochre were ground together to produce "fine tints" of red, whilst pink shades were made by adding gypsum. These pigments from Petrie's excavations, and possibly others from later excavations in the Main City by the Egypt Exploration Society are now in Liverpool, Oxford and Bolton museums. One of the reds from Bolton, of which there were three different shades, was analysed qualitatively by K.W. Stephens from the London Institute of Archaeology in 1976.¹⁹ It was found to consist of mostly iron with a small percentage of silicon and traces of tin, arsenic, potassium, chlorine, sulphur and magnesium. Most of the museum specimens are warm brownish reds, but deeper reds which may be haematite occur in Liverpool (56.21.287, one specimen) and Bolton (30.24.55, two specimens) (see Table 10.2).

Yellow.

Examination of the yellow samples by SEM revealed that they consist of quartz grains with a thin iron-rich coating (see Figure 10.11). Within the groundmass are small inclusions of an Fe–Ti phase. XRD determinations provided little further information due to the dominance of quartz (see Table 10.6).

The commonest yellow pigment in ancient Egypt is yellow ochre, or goethite (FeO.OH) (Lucas and Harris 1962: 349–350),²⁰ and the yellow coloration of our sample is doubtless attributable to their iron-rich coatings. Significant deposits of goethite occur in the oases of the Western Desert and in the North-eastern Desert, near Wadi Abu Marwat (Hume 1937: 849), but it is likely that minor occurrences are common.²¹ However, the presence of an Fe–Ti phase may provide a means of more closely identifying the source for this particular material.

We have found only one other published analysis of a yellow specimen from Amarna. The XRD compared well with wollastonite and possibly orthoclase, KAlSi_3O_8 (Iskander 1987: 36).

¹⁷ As only two red pigment specimens were found, it was decided to leave one piece intact.

¹⁸ When Spurrell prepared red ochre by burning yellow ochre it came out very brown (i.e. Pantone 173–174U) compared with many of the ancient pigments. Cards painted with colours made in his painting experiments are now in the Liverpool Museum.

¹⁹ Our thanks to Dr Colin Hope for allowing us to refer to these unpublished results.

²⁰ Orpiment, introduced in the Eighteenth Dynasty and found in some of the early excavations at Amarna, was much rarer and is easily recognised by its crystalline structure. As already noted, one specimen has been identified amongst the Workmen's Village material.

²¹ It is possible that the sources of the yellow as well as of the red ochres may be local, although the deposits reported in the standard literature are further afield. Small lumps of yellow ochre were found by the author close to the South Tombs, whilst a colleague found a seam of bright orangy-red impure iron oxide at the mouth of the Great Wadi at Amarna.

10.5 Conclusions

Analyses have shown that the red, yellow and blue pigments were those commonly used by the Egyptians in the period, these being haematite, (impure) goethite, and Egyptian blue. Two of the green specimens, chrysocolla, were probably raw materials usually associated with industrial use. The turquoise consisted principally of a sodium-calcium-copper silicate, which was probably the colouring agent, together with wollastonite. Both blue, and especially, the turquoise samples were shown to be frequently chemically heterogeneous at micron level; and it was indicated that minerals could be common to both colours, excluding Egyptian blue which was found only in the blue.

From the analyses it has been possible to conclude that the same ingredients were probably used in the manufacture of both blue and turquoise pigments, the latter with more sodium compound. However, further investigation would be necessary to elucidate firing procedures and precise quantities of each ingredient, such as has been done for Egyptian blue. The quantities calculated by Russell (in Petrie 1892: 45–46) and Laurie, McClintock and Miles (1914: 421–422) which imply a mixture of 10 parts of sand (which includes calcite), 2 parts of copper ore and 1 part natron, have been used by later workers to manufacture Egyptian blue; one would expect a similarly convenient formula for turquoise frit.

Since there is no evidence of fritting kilns in the Workmen's Village, it appears, not surprisingly, that the industrial areas in the Main City supplied this nearby habitation with manufactured pigments. These include the glass- and frit-making areas found by Petrie in 1892–3, more fragmentary remains (glazing works suggested) in M50.14 found in 1921 (COA I: 19), and remains of an extensive and probably multi-purpose industrial area, Q48.4, discovered through the 1987 excavations (Chapter 2).

10.6 Shapes of pigments and vessels associated with them by Fran Weatherhead

Blue and turquoise frits

Although the blue and turquoise fragments are all small irregularly shaped pieces (except perhaps R10[1385] which is a small rectangular block), they all represent broken-up pieces from larger moulded shapes. Following our study of more complete specimens in museums, five types can be distinguished to date. The larger forms are always more coarsely granular than the smaller ones. The five types are:

Large round flat cakes. Many of these round cakes have been found at various sites in varying states of completeness, for instance, an almost perfect turquoise cake, c. 19 cm in diameter, which is now in the display of painters' materials in the Cairo Museum (no. 2110). A half-cake of blue frit, 22–25 cm wide, occurs in the same case (no. 2112). Sections of blue cakes from Amarna displaying this shape are now in Liverpool Museum (1973.4.351), the Petrie Museum (UC 24684), and Bolton Museum (1966.A22/1–2, from the excavations of the Egypt Exploration Society. Another sizeable blue piece from Tell el-Yahudiya is now in the British Museum (71.9–16.485). See Figure 10.2, nos. 1–4.

Large flat rectangular cakes. One very large blue piece from Amarna now in the Petrie Museum (UC 24686) shows one angled end where a slice has been cut away (Figure 10.3). This piece has a slight rim along two edges where they had met the sides of the fritting pan. The numerous circular depressions and parallel grooves would indicate that the surface had been scored prior to firing in order to assist the release of gases.

Bowl-shaped cakes. With these the top is flat and the base rounded. A large blue piece of an approximate one-quarter section with chunks taken from it is a good example. It is now in the British Museum (55.12–5.345, unprovenanced). Other examples in turquoise are no. 5561 (which has a very jagged surface) from Thebes, also in the British Museum, and 56.21.786 from Amarna in Liverpool Museum (Figure 10.2). It is a matter of opinion whether UC 36459 in the Petrie Museum, with a flatter section, was made in a bowl-shaped vessel or a more flat-bottomed vessel. Its importance lies in the impressions found on its base, rarely seen on other frits. These show

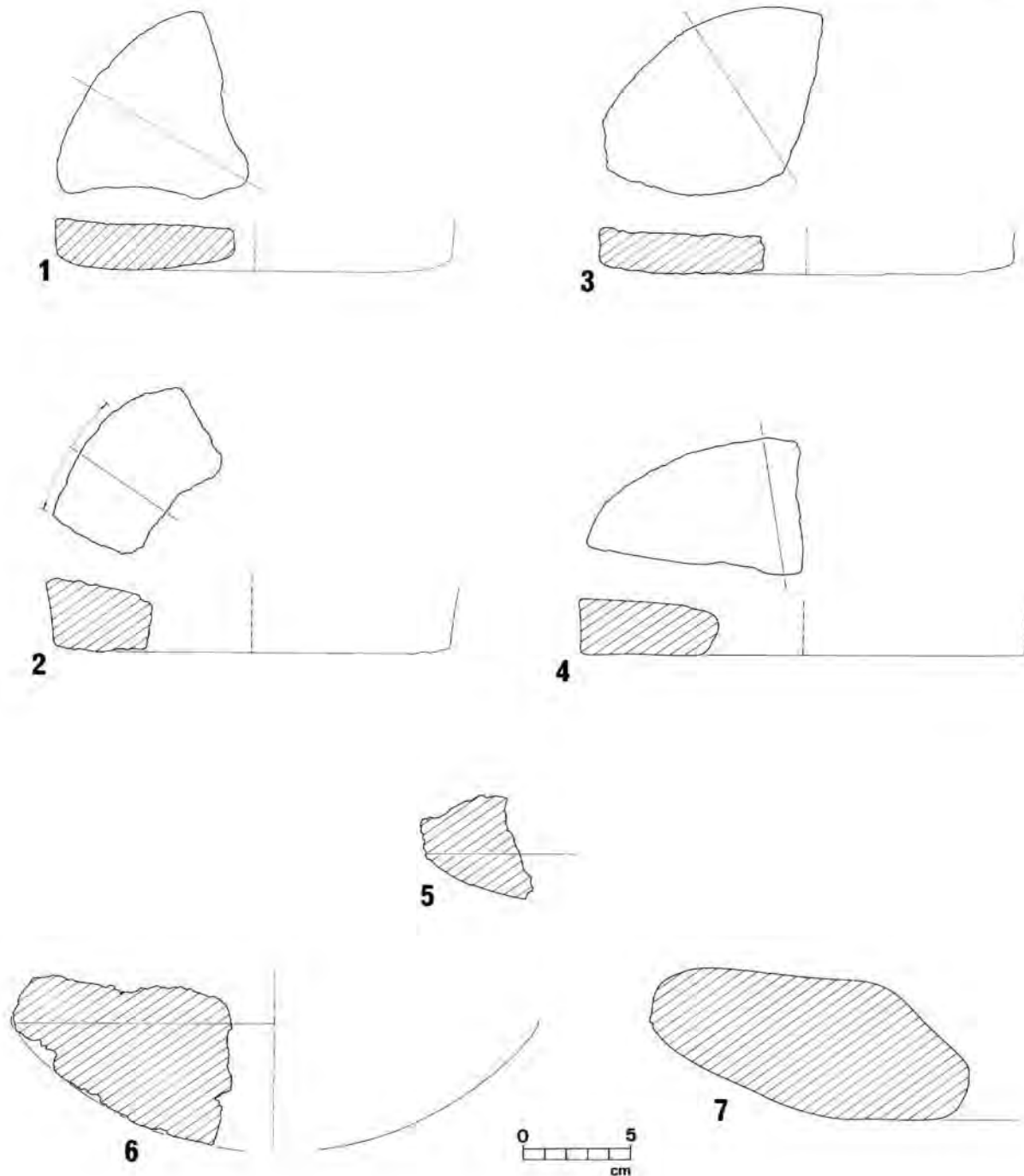


Figure 10.2. Nos. 1-4 are portions of round flat cakes of pigment. The outline of the surviving fragment is shown above the section, with line showing where the section was taken. The sections show the reconstructed diameter: 1. blue frit from Amarna, Liverpool Museum 1973.4.351; 2. blue frit from Amarna, Bolton Museum 1966.A22, no. 2 (arrows indicate surviving outer edge of cake); 3. blue frit from Amarna, Bolton Museum 1966.A22, no. 1; 4. blue frit from Tell el-Yahudiya, British Museum 71.6.19.485. Nos. 5-7 are portions of bowl-shaped cakes: 5. turquoise frit from Thebes, British Museum 5561 (it was not possible to estimate the original diameter, possible stance is shown); 6. turquoise frit from Amarna, Liverpool Museum 56.21.786 (possible change of angle in vessel wall shown); 7. blue frit, unprovenanced, British Museum 55.12.5.345 (original diameter unknown, possible stance shown).

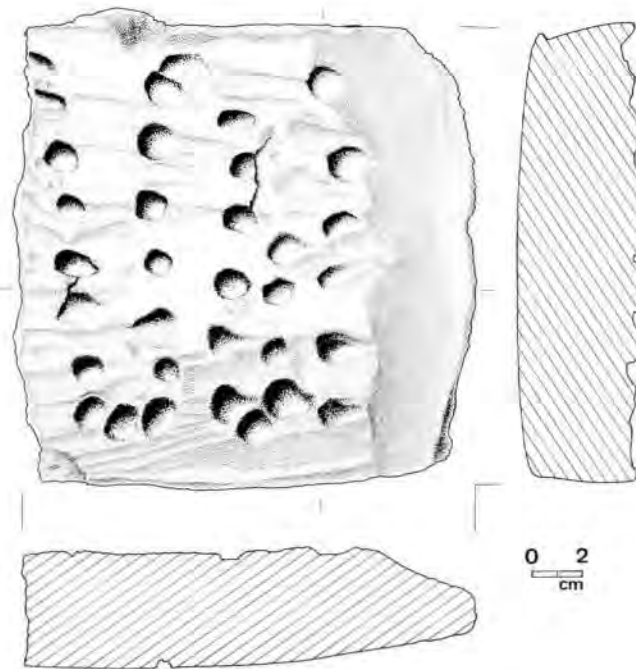


Figure 10.3. Flat rectangular cake showing scored surface and two cut ends. Petrie Museum, UC 24686.

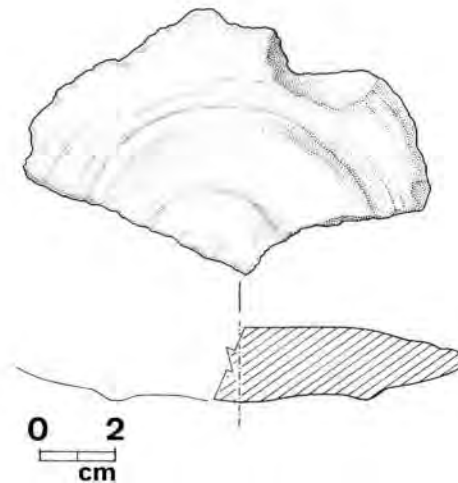


Figure 10.4. Blue-frit portion showing wheelmark impressions from vessel on underside. Petrie Museum, UC 36459.

clearly that it was formed in a wheel-made vessel (Figure 10.4).

The round-bottomed type of moulded frit is probably what Russell (1893–5: 67) erroneously referred to as having been ground against a concave surface under water, when observing the smooth curved sides of frits from Petrie's excavations at Gurob and Kahun.

Small sack-shaped pieces. Several of these, about 5–7 cm long and 5–6 cm wide, are now in the Cairo Museum: JdE 96788 (Figure 10.5), JdE 96789a, and no. 2106; also one flattened example from Amarna, length 10.5 cm, width 8.5 cm, JdE 53025, excavator's no. 1928-29/174, from the North Suburb house V35.4, COA II: 32 (Figure 10.5). These show that either the ingredients for frit making had been placed in a small linen bag before firing and then fired, or that ground-up frit had been placed in a bag for a second firing.

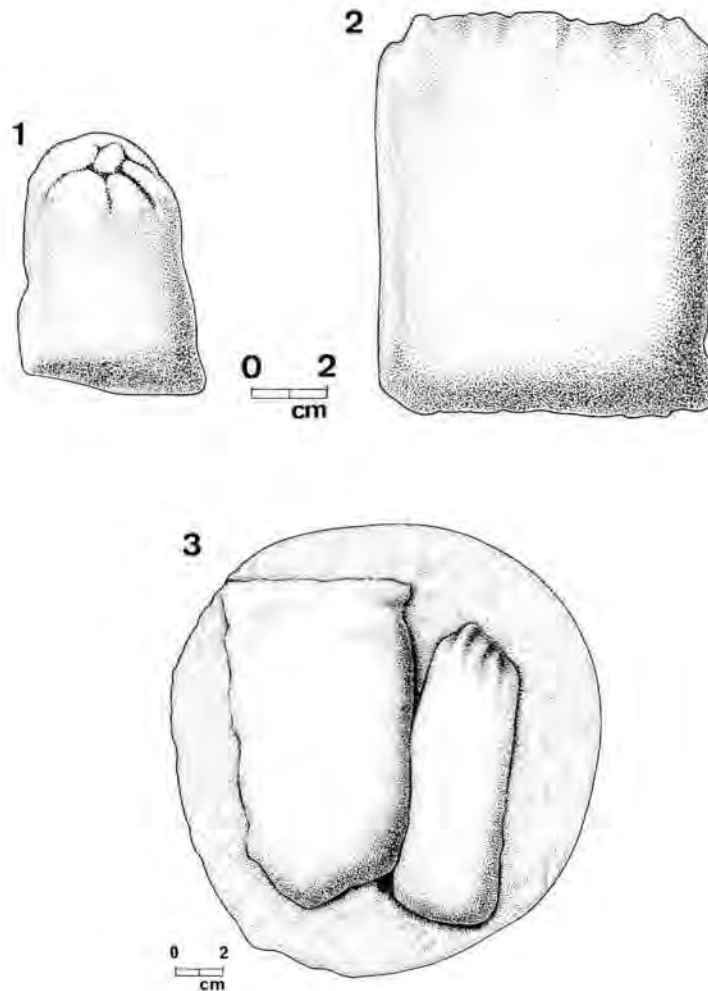


Figure 10.5. Sack-shaped frits: 1. piece showing impression from sack tied at one end, uncertain provenance, Cairo Museum JdE 96788; 2. flattened sack from Amarna, originally showing impressions of cloth and a seam along two sides (excavation no. 1928–9/174), Cairo Museum JdE 53025; 3. cake of coarse frit containing sack shapes of finer grained frit, Thebes, Tomb of Kheruef, after Saleh 1974: Fig. 3.

In an extraordinary cache of painter's equipment contained within a wooden chest found at the tomb of Kheruef at Thebes (Saleh, Iskander, El Masry and Helmi 1974) were included several large round cakes (mean diameter 18 cm, width 3 cm), each with two sack-shaped pieces set within them. It appears that while the discs consisting of the original ingredients received their first firing, bags of already fired and ground-up material were for convenience placed within them for their second firing. Thus, when the bags subsequently disintegrated under the intense heat their contents still retained their shape (Figure 10.5).

Spherical shapes. Five of these are displayed in the Cairo Museum (JdE 96787, JdE 57017), c. 3–4 cm in diameter. Spurrell (1895: 235) mentions twelve more “fine violet” specimens found by Belzoni. However, these may all be from the Ptolemaic and Roman Periods.

Spherically shaped frits have been found in the shops of Pompeii and Herculaneum. Small spherical shapes c. 1 cm in diameter of possible pigments were also found at first century B.C. kilns at Memphis (Vandiver, in Kaczmarczyk and Hedges 1983: A31, in 1a). It is worth quoting in full the account of Vitruvius of how balls of frit were made before firing:²²

Sand²³ and flowers of natron are brayed together so finely that the product is like meal, and copper is grated by means of coarse files over the mixture like sawdust, to form a conglomerate. Then it is made into balls by rolling it in the hands and thus bound together for drying. The dry balls are put in an earthen jar, and the jars in an oven. As soon as the copper and the sand grow hot and unite under the intensity of the fire, they mutually receive each other's sweat, relinquishing their peculiar qualities and having lost their properties through the intensity of the fire, they are reduced to a blue colour (Vitruvius 7,11,1 = Morgan 1926: 218).

To account for the large moulded pigments one has to look at the items found associated with the industrial area in the Main City at Amarna from Petrie's excavations of 1891–92. This industrial area consisted of three or four glass factories and two large glazing works which included the remains of a workroom, together with waste heaps (Petrie 1894: 25ff.; Turner 1954: 437ff.). No specific location is mentioned by Petrie, but it is assumed, on the basis of a note on his general plan of Amarna, to have been close to the cultivation, south of the Central City, near to the site of the modern water-tower. Nothing now remains of it.

Two types of vessel were found by Petrie, and shown in his diagram to illustrate the process of frit-making, which he believed to be the first stage of glass-making (Petrie 1894: 62, Pl. XII):

- 1) bowl-shaped pans, the “fritting pans”, c. 25 cm in diameter, c. 7.5 cm deep;
- 2) cylindrical vessels, or saggars, c. 18 cm in diameter, 13 cm deep. These are now in the Petrie Museum and the Ashmolean Museum (Figure 10.6). These show flat and concave bases inside.

Unfortunately no certain fritting pans for the making of pigment now exist, and this is surprising considering how much pigment has been found. Petrie mentions a half pan of uncombined frit from which he deduced the original size, but this is in neither the Petrie Museum nor the Ashmolean. However, a smaller section of light purple spongy frit to which is attached a displaced sherd may be the only remains of a fritting pan (UC 36457, see Figures 10.7 and 10.12). The reconstructed diameter could be in the region of c. 20 cms or a little wider.²⁴ Two large round-shaped sherds associated with Petrie's industrial items can be dismissed as possible fritting pans. One (UC 36460, Figure 10.7) fine-bodied ware only has the slightest trace of pigment, and the other was clearly used as a convenient container for pigment. Although possibly more complete when in use, numerous sherds have been found at Amarna containing blue or turquoise frits (Figure 10.13). Traces of pigment along their edge sometimes indicate that artists reused discarded pieces of broken pottery. It is also unlikely that the pigment was actually ground in such concave makeshift containers, as Petrie suggests in an insertion in Russell's report on the pigments from Kahun and Gurob (Petrie 1892: 47). One would expect that the hard glassy frit would abrade the pot fabric. Spurrell (1895: 234) instead suggests that the grinding of frits was done under water on a hard flat stone. If this is correct, it would explain the lack of extant grinding equipment, for such objects would be hard to recognise during excavation.

The cylindrical pots which Turner (1954: 436–440) studied in the Petrie Museum led him to believe that they acted not only as supports (inverted) for the fritting pans, as in Petrie's diagram, but that they were also used as crucibles for the melting of glass. Glass was found on the inside of one piece (not illustrated), as well as splashed on the outside, as more commonly found, from being used upside down as supports. Although Turner thought that these pots were used as

²² Pellets of Egyptian blue were made by Tite, Bimson and Meeks (1981: 299) simply by dampening the finely ground ingredients of the mixture with water and forming pellets by hand. Once-fired frit could also be ground and formed in this way before subsequent firing.

²³ It is to be noted that Vitruvius apparently did not recognise the importance of calcite as an ingredient in the mix. This is because the sand added already included this substance.

²⁴ This is possibly the same fragment mentioned by Petrie (1892: 46) as part of a dish of frit, although the blackened edges mentioned by Petrie are not visible on this piece.

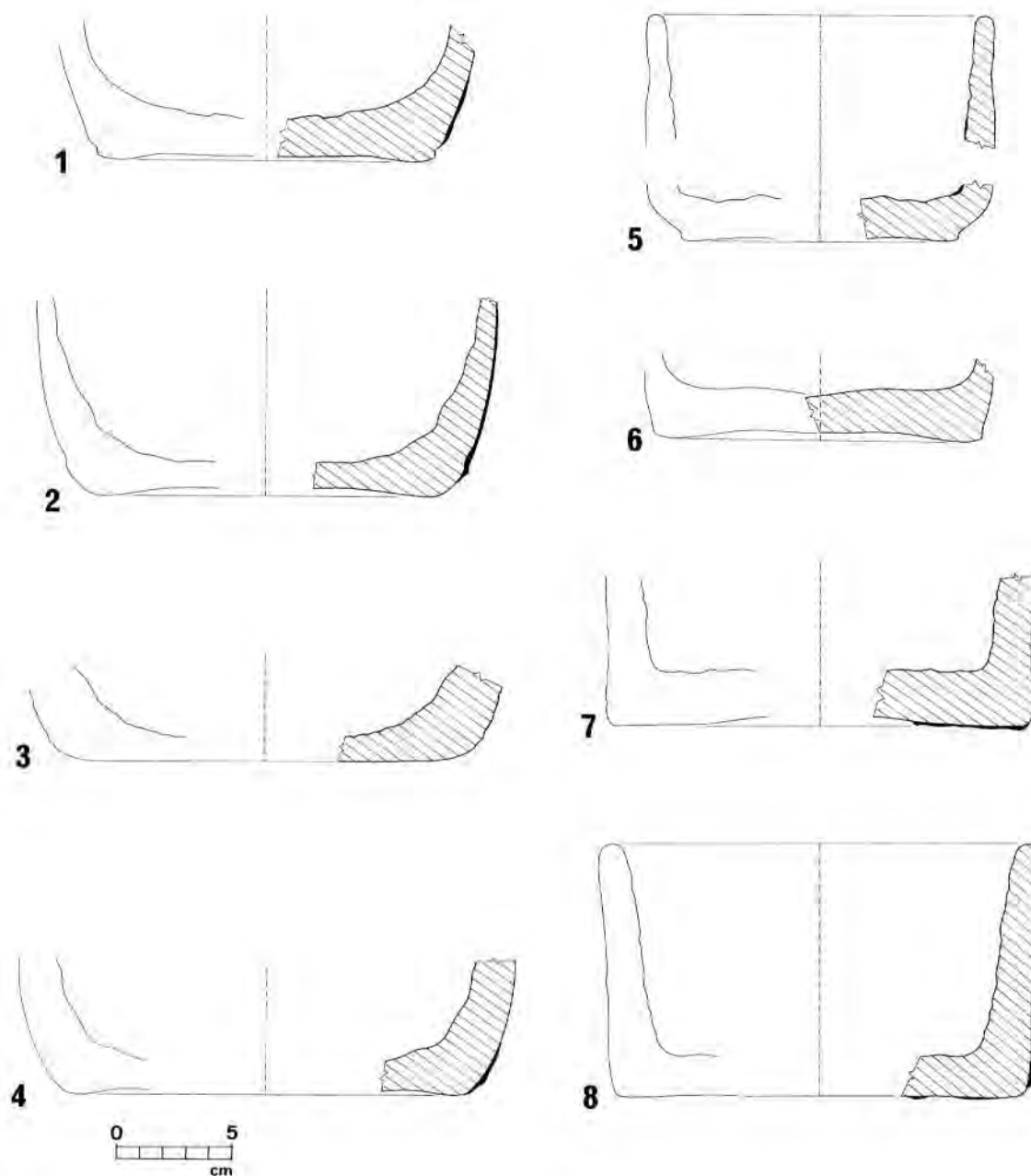


Figure 10.6. Sections of cylindrical vessels or “saggers” from Amarna showing inner profile and reconstructed diameter. Glassy deposits are shown as black: 1. Main City surface survey 1987 (diameter may be smaller); 2. Petrie Museum UC 8989; 3. Main City surface survey 1987 (original by Pamela Rose); 4. Ashmolean Museum 1.41.1893 (396); 5. Main City surface survey 1987 (original by Pamela Rose; the two pieces may be from different vessels; note glassy slag on interior); 6. Ashmolean Museum 1.41.1893 (396); 7. Petrie Museum UC 8986; 8. Main City surface survey 1988.

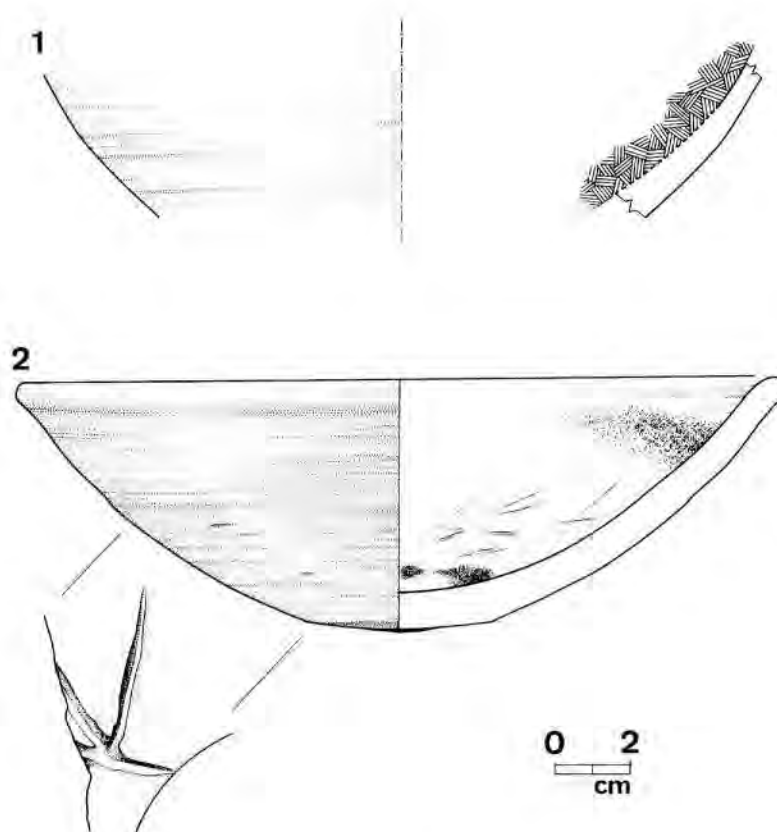


Figure 10.7. 1. Possible reconstruction taken from sherd adhering to purplish frit, from Amarna, Petrie Museum UC 36457.
 2. Red slipped bowl from glassworking area, with traces of frit and soot marks on interior, and a small area of frit on the base; the owner's mark (scratched into the surface after firing) on outer body now partly lost, Petrie Museum UC 36460.

crucibles, he pointed out that their composition was not of a refractory nature. He also suggested that the thin "slip" inside the vessel helped to prevent corrosion by the molten mixture placed inside the vessels, although it seems more likely that this is the corrosion itself. The possibility might also be considered that cylindrical pots, such as these, could have produced the flat disc-shaped frits. Indeed, Spurrell (1895: 233), reviewing Petrie's excavated material, implies that this is so. However, generally the dimensions of the pigment cakes tend to be rather larger than the reconstructed dimensions of the cylindrical pots (Figures 10.2 and 10.6). Although not very frit-like, as it is very compacted and laminated, there is one section of a sagger containing what might be a malformed frit (UC 36458) (Figure 10.14). For the present the lack of fritting pans must remain a mystery.

Red and yellow pigments

Our two red specimens are roughly triangular in shape with one flat surface. This is also noticeable on many of the specimens in the museums, some of which have more than one flat side, as if the block was repeatedly turned over in the process of being ground down. A rough surface was obviously used to grind down the blocks, whether in order to produce powder ready for use as paint, or to purify first by means of levigation. Petrie (1892: 47), as with the frits, had first suggested grinding in a concave potsherd, but, as Spurrell (1895: 232) points out, pigments do not show traces of earthenware in their composition. Instead, Spurrell suggested grinding of

red and yellow pigments occurred on a flat stone contained within a large vessel, remains of which he recognised, although it is unclear whether he refers to examples found at Amarna. In our own use of the red pigment WS3[2122]12516 (as with blue and turquoise frits, and yellow) a modern porcelain pestle and mortar or the rough metal surface of a sculptor's riffler was used to grind to a powder. Ancient equivalents of these objects have been hard to find, or to recognise, at Amarna, or, indeed, at other sites.²⁵ However, in the report of the excavation of house U35.2 (COA II: 32), a painter's house (?) in the North Suburb at Amarna, there is an intriguing reference to a rubstone and a black stone pounder. Unfortunately there are no further records of these objects, or of other pieces of the artist's equipment from this house in the E.E.S. archives, and one must assume that the objects were left in place. Two large grinding stones, which appear as larger versions of rectangular cosmetic palettes, were found in house V36.5, also in the North Suburb. One (excavation no. 1928-9/52), measuring 29 x 16.5 cm, is now in the Horniman Museum; the other (1928-9/53), 35 x 19 cm, was allocated to the Wellcome collection (Figure 10.8).

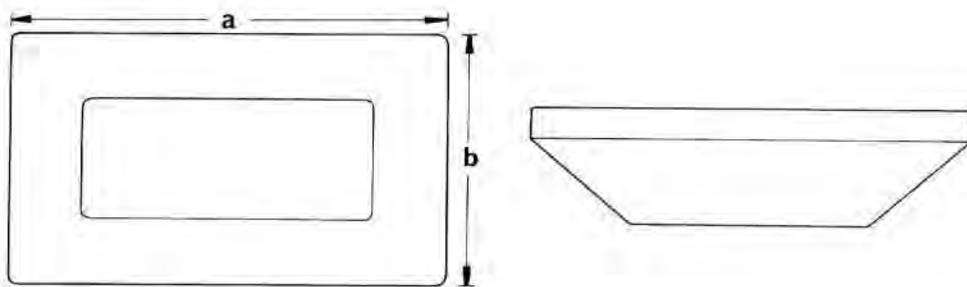


Figure 10.8. Composite drawing of two stone palettes/grinding stones from North Suburb house V36.5, taken from the excavation records. Dimensions of 28-9/52: a = 29 cm, b = 16.5 cm; dimensions of 28-9/53: a = 35 cm, b = 19 cm.

Various vessels have been found which contained powdered red pigment from Amarna and elsewhere. We have found from the early excavations at Amarna a small hemispherical vessel with out-turned rim, broken in six places to give a hexagonal rim shape (excavation no. 1935-6/332; Cairo Museum JdE 66110). This contained a deposit of bright red pigment, slightly orangy in shade (Figure 10.9). Several small vessels of about the same diameter or slightly smaller, but with flat sloping sides, containing pigments (all colours), are in the display of painters' materials in the Cairo Museum. It is not certain whether all these were found with the pigments they now contain. Of those that did, one showed a thick deposit of red pigment in the bottom (no. 2101) and another traces of blue and a block of blue pigment (JdE 96786). Another of these small vessels which is now in the Petrie Museum also contains a blue deposit (UC 8986). It does not appear that these splayed vessels formed part of the specialised equipment of the ancient Egyptian artist; they had a variety of other uses and occur commonly in the Amarna Period and later (Rose, personal communication).

As in the case of the other colours, various types of vessel were used to contain yellow pigment powder, implying that the ancient artists used whatever convenient shape lay close to hand. Although no pigment containers were found at the Workmen's Village, we have these from other recently excavated parts of the site. In the 1987 season a broken amphora was found in house P46.33, which had been used to store yellow pigment as a liquid.²⁶ During the 1988 excavations at Kom el-Nana the base of a beer-jar (sherd no. 81975) which had been used to store pigment, probably also in liquid form (Figure 10.9), was found in a workshop (unit [4006]).

²⁵ It is suggested that some reported pestles and mortars may perhaps have been used to prepare cosmetics (Forbes 1955: 237, Fig. 43).

²⁶ To be published in a future volume of *AR*.

Pigments from Amarna

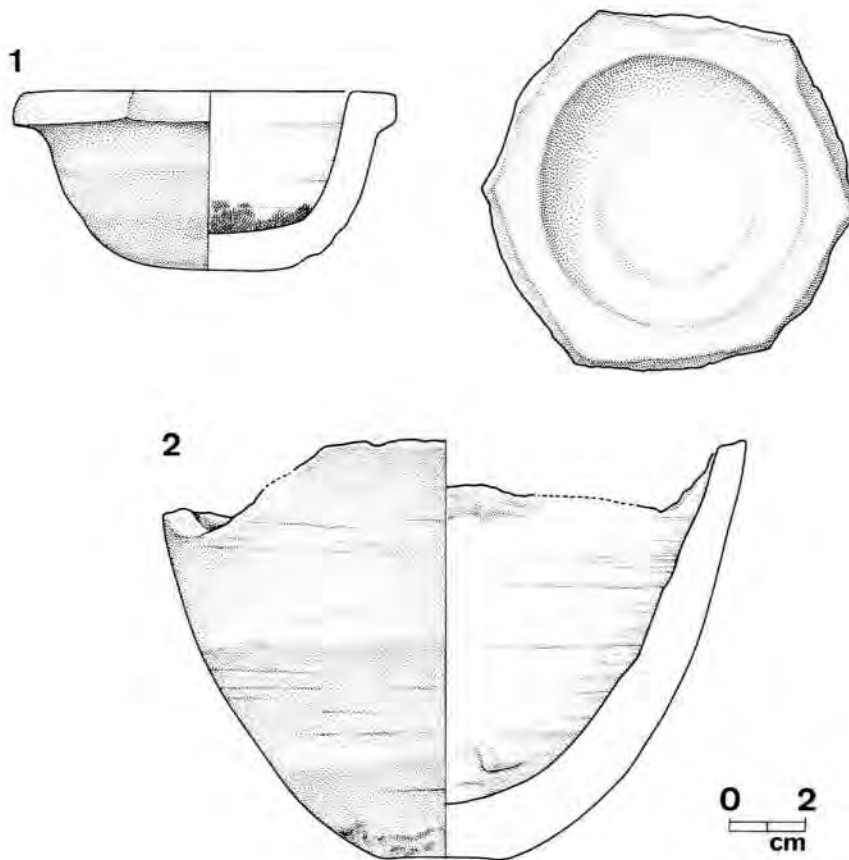


Figure 10.9. 1. Small pottery vessel with rim chipped to hexagonal shape. The interior contains bright orange-red pigment (Pantone ref. "Warm Red U"), the exterior is coated with ? gypsum up to 0.5 mm thick. Amarna excavation no. 35-6/332, Cairo Museum JdE 6610. E.E.S. record card gives diameter as 9.6 cm.
2. Pot base from the 1988 excavations at Kom el-Nana containing the remains of yellow pigment. Modern damage shown by dotted lines. Sherd no. 81975.

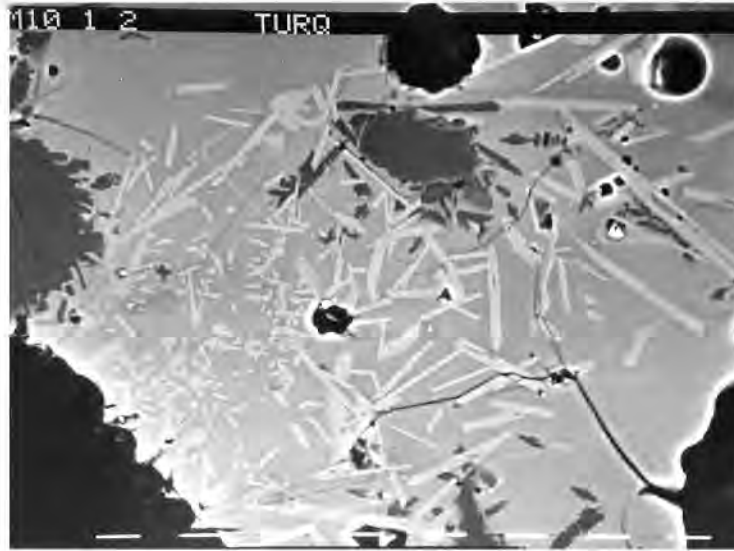


Figure 10.10. Scanning electron micrograph of turquoise sample M10(1)/(2). Scale bar of 10 microns is shown at base of photograph. Needle-shaped grains are calcium silicate (wollastonite); dark grey areas with irregular (corroded) outlines are quartz. Medium-grey groundmass is Na-Ca-Cu silicate.

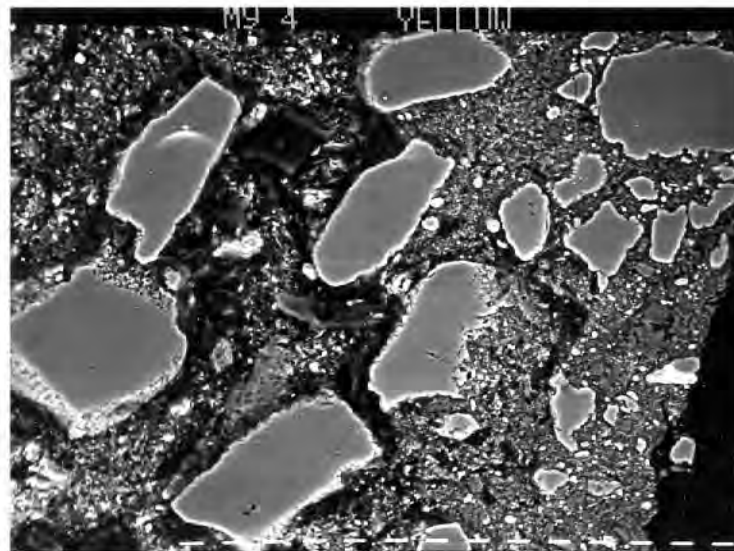


Figure 10.11. Scanning electron micrograph of yellow pigment, sample M9. Scale bar of 10 microns is shown at base of photograph. Quartz grains rimmed by iron-rich material. Groundmass is mainly composed of small quartz fragments and clay minerals; the occasional small bright patches are Fe-Ti oxides.

Pigments from Amarna



Figure 10.12. Pigments from the Petrie Museum. On the left (Acc. no. UC 36457) is spongy light-purple frit with attached sherd (possibly the remains of a fritting pan). Photograph by courtesy of the Petrie Museum, University College London.



Figure 10.13. Potsherds as containers of blue frit, from Amarna, in the Liverpool Museum. Left: 56.21.280.1; right: 56.21.281. Scale bar is marked in centimetres. Photograph by courtesy of Liverpool Museum.



Figure 10.14. Top and underside of sagger containing laminated substance (? malformed frit). The underside shows splash-mark of glass. The scale bar is 2 cm. Petrie Museum, UC 36858. Photograph by courtesy of the Petrie Museum, University College London.

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Tables 10.1 to 10.6

| Date excavtd | Provenance | Find spot/ ident. no. | Description | Colour identifications | | Weight | Sampled for anal. |
|---------------------------|--|-----------------------|---|--|---|----------------------------|-------------------|
| | | | | Pantone | Munsell | | |
| Blue pigments | | | | | | | |
| 1979 | Site X1, West Building | X1.D5 (3A)[3] | 1 lump, flat surface | 292U | 3.9 PB 6.1/9.0 | 0.75g | |
| 1980 | Dump from 1922 excavation inside WV | S19-18 | 1 lump, bright blue | 285U | 5.9 PB 4.8/10.9 | 0.5g | |
| 1981 | Rubbish fill of Main Quarry | M9(4) | 1 tiny lump, granular, bright blue | Reflex blue U | 7.6 PB 3.4/10.7 | 0.2g | |
| 1981 | Surface above Main Quarry | M10(1) | 1 tiny lump, smooth, blue | 284-5U | 4.3 PB 6.4/8.0 to 5.9 PB 4.8/10.9 | 0.2g | |
| 1981 | Surface above Main Quarry | M10(1) | 1 small lump, granular | 280U | 6.6 PB 3.5/7.7 | 0.1g | |
| 1981 | Rubbish fill of Main Quarry | M10(2) | 1 lump, granular, bright blue | 286U ext. 285U int. | 6.9 PB 3.7/11.3 ext. 5.9 PB 4.8/10.9 int. | 1.5g | |
| 1981 | Surface south of WV | N15(1)/ 4075 | 1 small lump, bright blue granular | 286- 293U | 6.9 PB 3.7/11.3 to 5.9 PB 4.1/11.0 | 0.2g | |
| 1982 | Rubbish fill of Main Quarry | M12[127] | 1 small crumb | 299U | 2.1 PB 5.7/9.9 | 0.1g | |
| 1982 | Sand deposit over Zir-Area | H6[146] | 1 lump, smooth, two flat parallel surfaces | 291U | 2.9 PB 7.0/6.9 | 2.25g | |
| 1983 | Rubbish fill of Main Quarry | M11[264] | 2 tiny crumbs | 300U | 3.6 PB 4.7/10.7 | 0.15g | |
| 1983 | Peet's 1921 chapel excavation dump | R18[247]/ 10260 | 1 lump, granular | 299U | 2.1 PB 5.7/9.9 | 2.0g | |
| 1985 | Building 300, surface sand | R10[1385] | 1 lump, rectangular, granular; bright blue, lightish shade | 285-292U ext. 291-284U int. | 5.9 PB 4.8/10.9 to 3.9 PB 6.1/9.0 ext. 2.9 PB 7.0/6.9 to 4.3 PB 6.4/8.0 int. | 1.0g | |
| 1986 | West St. 3, Front Room, undisturbed fill | WS3[2123]/ 12374 | 4 tiny crumbs, granular; dull blue | 292U | 3.9 PB 6.1/9.0 | < 0.1g | |
| 1986 | West St. 3, Front Room, undisturbed fill | WS3[2128]/ 12455 | 1 tiny crumbly lump + 2 bits, all granular | 292-298U + 297-291U ext. 292-285U int. | 3.9 PB 6.1/9.0 to 1.1 PB 6.2/8.8 + 9.7 B 7.2/6.7 to 2.9 PB 7.0/6.9 ext. 3.9 PB 6.1/9.0 to 5.9 PB 4.8/10.9 int. | 0.05g + Tog. 0.5g | |
| Turquoise pigments | | | | | | | |
| 1979 | Site X1, West Building | X1.D5 (3a)[3] | 2 lumps, granular | 311U | 4.3 B 6.7/8.1 | 2.0g | |
| 1979 | Surface south of Main Chapel | P17(1) | 1 lump, very granular | 318-324U | 0.9 B 7.8/5.8 to 6.4 BG 8.0/3.9 | 1.0g | |

| | | | | | | |
|------|---|------------------|---|--------------------------------|--|--------|
| 1979 | Surface south of Main Chapel | O17(1) 73 | 1 lump, very granular | 318-324U | 0.9 B 7.8/5.8 to 6.4 BG 8.0/3.9 | 1.0g |
| 1979 | Long Wall St. 6, Rear Room North | LW6 [3a](2) 129 | 1 lump, very granular | 312U | 5.0 B 6.0/9.0 | 3.5g |
| 1980 | Immediately south of WV | M18 surface | 2 lumps & 6 crumbs, granular mixed with some dirt/sand; light turquoise | 324-331U | 6.4 BG 8.0/3.9 to 2.1 BG 8.4/3.9 | 2.0g |
| 1981 | Rubbish fill of Main Quarry | M9(8) feature 8 | 1 lump, granular. Dirty exterior | 318-324U ext. 319U int. | 0.9 B 7.8/5.8 to 6.4 BG 8.0/3.9 ext. 0.7 B 7.0/7.4 int. | 3.0g |
| 1981 | Rubbish fill of Main Quarry | M9(4) | 2 tiny lumps, granular | 310U | 3.7 B 7.3/6.9 | 0.2g |
| 1981 | Rubble from collapsed enclosure wall around WV | L18(4) | 1 small lump, granular | 325U | 6.2 BG 6.9/6.6 | 0.1g |
| 1981 | Rubbish fill of Main Quarry | M10(2) | 1 lump, very granular | 305-310U ext. 311-325U int. | 5.6 B 7.1/7.6 to 3.7 B 7.3/6.9 ext. 4.3 B 6.7/8.1 to 6.2 BG 6.9/6.6 | 2.5g |
| 1981 | Rubbish fill of Main Quarry | M10(2) | Small lump, granular | 304U | 2.7 B 8.0/4.2 | 0.2g |
| 1981 | Rubbish fill of Main Quarry | M10(3) | 2 small lumps, granular | 310U | 3.7 B 7.3/6.9 | 0.25g |
| 1981 | Dump from 1922 excavations inside WV | N18(1) | 3 small lumps, granular | 310U | 3.7 B 7.3/6.9 | 1.0g |
| 1981 | Rubbish fill of Main Quarry | M10(1)/(2) | 1 lump, very granular | 311U ext. 311-306U int. | 4.3 B 6.7/8.1 ext. 4.3 B 6.7/8.1 to 7.1 B 6.5/9.0 int. | 2.0g |
| 1981 | Ancient floor surface in front of Main Chapel Annexe (450) | O17(3) | 1 "toggle"-shaped lump, groove round middle, granular. Bright turquoise | 319-325U | 0.7 B 7.0/7.4 to 6.2 BG 6.9/6.6 | 1.0g |
| 1981 | Fill of robbers' pit, rubbish south of WV | P15(5) feature 3 | | 319U | | 0.1g |
| 1982 | Rubbish covering Animal Pens 350, Areas xiv-xvi | M15[4] | 1 lump, granular | 319U | 0.7 B 7.0/7.4 | 1.5g |
| 1982 | Rubbish south of WV | L11[25] | 1 lump, very granular | - | 9.8 BG 7.1/5.2 | 2.25g |
| 1982 | Rubbish south of WV | L14[11] | 1 small lump, very granular | - | 0.5 B 6.2/5.4 | 0.25g |
| 1982 | Main Quarry, drift sand | M10 | 1 small lump, very granular | - | 2.4 B 7.0/5.6 | 0.3g |
| 1982 | Surface above Animal Pens 350, Areas xiv-xvi | M15[1] | Very large block of irregular shape, very granular. Dirty exterior | 319U | 0.7 B 7.0/7.4 | 150.0g |
| 1982 | Surface rubbish south of WV | L15[135] | 1 lump, very granular | 325U | 6.2 BG 6.9/6.6 | 3.0g |
| 1982 | Dump from 1922 excavations inside WV | L16[14] | Several small lumps, very granular | 319U | 0.7 B 7.0/7.4 | 2.0g |

| | | | | | | |
|------|--|--------------------|--|------------------------|--|--------|
| 1982 | Rubbish fill of Main Quarry | M12[127] | 2 small lumps, very granular | 312U | 5.0 B 6.0/9.0 | 0.75g. |
| 1982 | Rubbish fill of Main Quarry | M12[126] | 2 small lumps, very granular | 310-325U | 3.7 B 7.3/6.9 to 6.2 BG 6.9/6.6 | 0.5g |
| 1983 | Sand fill of Main Chapel Annexe | Q18[418] | 1 small lump, very granular | 318U | 0.9 PB 7.8/5.8 | 0.25g |
| 1983 | Surface sand south of Main Chapel | R17[273] | 1 small lump, very granular | 318U | 0.9 PB 7.8/5.8 | 0.25g |
| 1983 | Rubbish fill of Main Quarry | M11[264] | 1 small lump, granular | 319U | 0.7 B 7.0/7.4 | 0.2g |
| 1984 | Pee't's 1921 chapel excavation dump | S18[966]/ 5447 | A few crumbs, granular; light turquoise | 318-304U | 0.9 B 7.8/5.8 to 2.7 B 8.0/4.2 | 0.15g |
| 1985 | West St. 2, disturbed fill over house | WS2[1703]/ 6089 | 1 small lump, granular | 318U | 0.9 B 7.8/5.8 | - |
| 1985 | West St. 3, Middle Room, disturbed fill | WS3[2122]/ 7191 | 2 lumps, granular; light turquoise | 304-318U | 2.7 B 8.0/4.2 to 0.9 B 7.8/5.8 | - |
| 1986 | Main Chapel Annexe, Area vi, undisturbed rubble | S18[2156] | 1 flattish lump, granular | 312U ext. 311U int. | 5.0 B 6.0/9.0 ext. 4.3 B 6.7/8.1 int. | 1.0g |

Green samples

| | | | | | | |
|------|--|---------------------|--|-----------------------|-------------------------------------|--------|
| 1980 | Animal pens 350, Area iv, intact organic fill | L17(3)/ 1128 | 1 lump & crumbs, smooth; bright green | 326-7U | 5.0 BG 6.1/7.6 to 4.0 BG 5.3/7.5 | c 0.9g |
| 1981 | Rubbish fill of Main Quarry | N15(1) | 1 small lump, smooth | 326-7U | ditto | 0.2g |
| 1981 | Surface above Main Quarry | M10(1) | 1 small lump, smooth | 327U | 4.0 BG 5.3/7.5 | 0.2g |
| 1981 | Surface above Main Quarry | M10(1) | 1 small lump, granular; frit ? | 326U | 5.0 BG 6.1/7.6 | 0.25g |
| 1981 | Rubbish covering Animal Pens 350, Area xxvi | O15(4) | 3 small lumps, smooth | 327U | 4.0 BG 5.3/7.5 | 0.5g |
| 1983 | Sand deposit over Zir-Area | I8[254] | 4 small bright green lumps, smooth | 326U- Pantone Gr.U | 5.0 BG 6.1/7.6 | 0.5g |
| 1986 | West St. 3, Front Room, undisturbed fill | WS3[2123]/ 12374 | 1 small piece of bright green, smooth | 333-326U | 3.4 BG 7.4/7.8 to 5.0 BG 6.1/7.6 | < 0.1g |

Cairo
Museum

Red pigments

| | | | | | | |
|------|--|---------------------|---|------|---------------|-------|
| 1982 | Rubbish fill of Main Quarry | M12[95]/ 12549 | Large lump, compact like a stone, but surface can easily be reduced to a powder with a glass bristle brush. Flat on one side | 484U | 8.0 R 4.3/5.9 | 40.0g |
| 1986 | West St. 3, Front Room, undisturbed fill | WS3[2128]/ 12516 | Large lump, compact, etc., like above | 484U | 8.0 R 4.3/5.9 | 27.0g |

Yellow pigments

| | | | | | | |
|-------------------------------------|--|---------------------------|--|----------------------------|---|-------|
| 1979 | Site X1, Central Rooms | X1.F6 (2c)[6] | 2 slivers, finely granular | 129U | 0.1 R 7.6/9.5 | 3.5g |
| 1979 | Site X1, West Building | X1.D6 (3b)[1] | Several lumps | — | 5.4 Y 9.1/3.8 | 8.0g |
| 1979 | Long Wall St. 6 | LW6 | 1 lump, smooth, 2 flat surfaces | 135U | 0.1 Y 8.3/6.7 | 2.75g |
| 1981 | Surface south of WV | N15(1) | 1 large, irregularly shaped lump; compact, but fine powder; slightly orangy yellow | 135U ext. 135–121U int. | 0.1 Y 8.3/6.7 ext. 0.1 Y 8.3/6.7 to 1.2 Y 8.1/9.3 ext. | 8.5g |
| 1981 | Rubbish fill of Main Quarry | M9(4) | Very large block of irregular shape | 121–142U ext. 129U int. | 1.2 Y 8.1/9.3 to 8.9 YR 7.5/8.1 ext. 0.1 R 7.6/9.5 int. | 95.0g |
| 1981 | Dump from 1922 excavations inside WV | K18(1) | 1 flattish lump, crystalline texture | 114–115U | — | 1.0g |
| Sherds with pigment adhering | | | | | | |
| 1980 | Ancient floor surface in front of Main Chapel Annexe (450) | N17(3)/ 2089 | Layer of turquoise pigment, c 1 mm thick | 324U | 6.4 BG 8.0/3.9 | — |
| 1981 | Dump from 1922 excavations inside WV | L18(1)/ 3956 | Lumpy patches of turquoise | 318U | 0.9 B 7.8/5.8 | — |
| 1986 | West St. 3, disturbed fill | WS3[2094]/ sherd 66354 | Lumpy area, plus traces of blue | 285U | 5.9 PB 4.8/10.9 | — |
| 1986 | West St. 3, disturbed fill | WS3[2094]/ sherd 66393 | Traces of blue | 291U | 2.9 PB 7.0/6.9 | — |
| 1986 | Surface sand over Main Chapel Annexe (450) | T19[2265] | Traces of blue, very faint | 291U | 2.9 PB 7.0/6.9 | — |

Table 10.1. List of pigments from the Workmen's Village excavations, 1979–1986.

| Excavation number | Museum number | Description | Colour identifications | | Illus. in this report |
|-------------------------|---------------|---|------------------------|--------------------------------------|-----------------------|
| | | | Pantone | Munsell | |
| BLUE PIGMENTS | | | | | |
| Bolton Museum | | | | | |
| - | 1966-A22/1 | Fragment of circular cake of dark blue; 30.5 x 7.5 x 1.5 cm, Very coarsely granular. E.E.S. excavations. | 293U | 5.9 PB 4.1/11.0 | |
| - | 1966-A22/2 | Fragment of circular cake of dark blue, 9.5 x 5 x 3 cm, very coarsely granular. E.E.S. excavations. | 286U | 6.9 PB 3.7/11.3 | |
| - | 1966-A22/12 | Fragment of blue. Very uneven one side, flattish on other. Max. width 4 cm. Finely granular. E.E.S. excavations. | - | 3.8 PB 6.0/7.7 | |
| - | 1966-A22/13 | Fragment of blue, finely granular. Max. width 3 cm E.E.S. excavations. | 284-285U | 4.3 PB 6.4/7.7 to 5.9 PB 4.8/10.9 | |
| - | 30.24.55 | Fragment of cake of blue, coarsely granular. 1.25-1.75 cm thick; max. width 5 cm. | 285U | 5.9 PB 4.8/10.9 | |
| - | 30.24.55 | Fragment of circular cake, coarsely granular. 1.5 cm thick; max. width 4.5 cm. | 285U | 5.9 PB 4.8/10.9 | |
| Liverpool Museum | | | | | |
| - | 55.04 | Fragment of blue, in eyeglass. Ex Spurrell Coll. | 292-299U | 3.9 PB 6.1/9.0 to 2.1 PB 5.7/9.9 | |
| - | 55.04 | 3 fragments of blue, in eyeglass. Ex Spurrell Coll. | 292U | 3.9 PB 6.1/9.0 | |
| - | 55.04 | Fragment of blue, in eyeglass. Ex Spurrell Coll. | 298-291U | 1.1 PB 6.2/8.8 to 2.9 PB 7.0/6.9 | |
| - | 55.04 | Fragment of blue, in bottle. Ex Spurrell Coll. | 292U | 3.9 PB 6.1/9.0 | |
| - | 56.21.281 | Coarse sherd from base of pot, max. width 6.5 cm, containing blue pigment (now in loose pieces). Blue c. 0.4 cm thick. Fairly finely granular. Max. width 3.5 cm. Ex Spurrell Coll. | 292-299U | 3.9 PB 6.1/9.0 to 2.1 PB 5.7/9.9 | |
| - | 56.21.280(.1) | Large sherd from side of pot, max. width 11 cm, containing lumpy patch of pigment (some fallen away). Coarsely granular. Max. width 4.5 cm. From workshops, Amarna. Ex Spurrell Coll. | 292-300U | 3.9 PB 6.1/9.0 to 3.6 PB 4.7/10.7 | |
| - | 56.21.280(.2) | Sherd from base of pot, max. width 8.5 cm. One lumpy patch of pigment. From workshops, Amarna. Ex Spurrell Coll. | 292U | 3.9 PB 6.1/9.0 | |
| - | 56.21.280(.3) | Small sherd, containing small patch of pigment. Ex Spurrell Coll. | 291-292U | 2.9 PB 7.0/6.9 to 3.9 PB 6.1/9.0 | |

| | | | | |
|---|------------|--|--------------------------------------|---|
| - | 56.21.282 | 4 fragments of blue. All ex Spurrell Coll. i) small part of cake, 1.5 cm thick. ii) fragment of blue. iii) fragment of blue, with some green. Uneven firing. iv) fragment of blue, with some green. Uneven firing. | 286U 281U 285-286U 293U | 6.9 PB 3.7/11.3 6.3 PB 3.3/5.8 5.9 PB 4.8/10.9 to 6.9 PB 3.7/11.3 (with patches of 0.5 B 6.2/5.4) 5.9 PB 4.1/11.0 (with patches of 1.2 B 5.6/5.3) |
| - | 1973.4.351 | Almost quarter-segment of circular cake of blue, thickness 8.5 cm, width 10.7 cm. Amarna ? | 285-300U | 5.9 PB 4.8/10.9 to 3.6 PB 4.7/10.7 |

Petrie Museum, University College London

| | | | | |
|---|----------|---|--|---|
| - | UC 24686 | Large rectangular fragment of deep blue frit. Colour varies to greenish in patches on base. Also some brownish discoloration; some small white inclusions. Top has series of depressions and grooves and marked ridge on two sides. Two other sides cut, one of which slopes smoothly at angle. From Petrie's excavations 1891-2 (?), although this unusual piece not mentioned in Petrie 1894. Analysis in Tite, Binson and Cowell 1984. | 293-294U (with patches of 339U) | 5.9 PB 4.1/11.0 to 4.3 PB 3.7/7.2 (with patches of 7.6 G 6.1/8.0) |
| - | UC 36459 | Almost one third section of circular cake of blue frit. Buff deposit on base. Impression of wheel-made pot also on base, shallow bowl shape. Coarsely granular frit. Max. width 10.5 cm. From Petrie's 1891-2 excavations. | 285U | 5.9 PB 4.8/10.9 |
| - | UC 8986 | Small complete straight-sided pot containing compacted deposit of blue frit. Incised marks on exterior of pot. Dia. of pot 8.5 cm, width of pigment 3.5 cm. From Petrie's 1891-2 excavations, glass factory. See Dayton 1978, Fig. 317. | 278-279U | 4.3 PB 7.1/6.0 to 5.6 PB 5.8/9.2 |
| - | UC 24685 | Several small fragments of pale blue rather powdery frit. Some slightly paler on surface. Fairly fine-grained. One lump has small white inclusions. Max. width 3 cm. From Petrie's 1891-2 excavations. | 291-29-2U | 2.9 PB 7.0/6.9 to 3.9 PB 6.1/9.0 |
| - | UC 24684 | Section from (circular ?) cake of blue frit. One part of original edge preserved. Fairly coarsely granular, esp. on base. Max. width 9 cm, thickness 1.25 cm. From Petrie's 1891-2 excavations. | 293U | 5.9 PB 4.1/11.0 |
| - | UC 8987 | Large fragment of slightly pointed base of pot containing thick layer of blue frit. Height of pot 9.85 cm, width 11.85 cm. Sherd section shows grey inner layer; oxidation of fabric therefore not complete. Pigment fills concavity of sherd and is up to 1.5 cm thick. Surface fairly smooth, but not quite level. Fairly finely granular. | 285-292U | 5.9 PB 4.8/10.9 to 3.9 PB 6.1/9.0 |
| - | UC 25153 | Three irregular fragments of blue frit, originally from flat-sided cake. Partly coated with pinkish clay. Medium coarseness. a) Thickness 1.9 cm, max. width 8.7 cm. Drilled. b) Thickness 2.25 cm, max. width 7.2 cm. Slightly pale creamy green shows on edge. c) Thickness 1.9 cm, max. width 6.8 cm. Shows curved edge. Analysis in Tite, Binson and Cowell 1984. Also four smaller associated (?) pieces, one of them grooved possibly from attempt to break off piece. From Petrie's 1891-2 excavations. | All 292U 299-300U | All 3.9 PB 6.1/9.0 2.1 PB 5.7/9.1 to 3.6 PB 4.7/10.7 |
| - | UC 25040 | Fragment of blue frit from (circular ?) cake. Flat top and bottom; edge preserved. From Petrie's 1891-2 excavations. | 285-300U | 5.9 PB 4.8/10.9 to 3.6 PB 4.7/10.7 |

| | | | | |
|--|---------------------|--|----------|-------------------------------------|
| - | UC 8979C | Fragment of blue frit (with two turquoises). C) fairly finely granular. Max. width 4.5 cm. From Petrie's 1891-2 excavations. | 298-299U | 1.1 PB 6.2/8.8 to 2.1 PB 5.7/9.9 |
| - | UC 25039 | Fragment of blue frit, originally from flat cake. Two flat sides, 0.75 cm thick, max. width 4.0 cm. Fairly finely granular. From Petrie's 1891-2 excavations. | 292U | 3.9 PB 6.1/9.0 |
| - | UC 25154 | Buff sherd, max. width 10.0 cm, with thin layer of blue frit. (Associated with eight unnumbered sherd-s smeared with or containing blue frit of similar colour). From Petrie's 1891-2 excavations. Analysis in Tite, Binson and Cowell 1984. | 292U | 3.9 PB 6.1/9.0 to 7.4 BG 7.8/4.4 |
| - | UC 25037 | Fragment of blue frit, with impression of vessel on buff rough base. Length 5.6 cm. From Petrie's 1891-2 excavations. | Not seen | |
| Cairo Museum | | | | |
| 1928-9 | JdE 50760/ 50762 | Fragment of blue frit (with yellow and red pigment). Max. width 6.0 cm. | Not seen | |
| 1928-9/174 House V35.4 | JdE 53025 | Flattened sack-shaped block of blue frit. Shows impression of cloth, and seam of same along edge. Medium granular. Length 10.5 cm, width 8.5 cm. COA II: 32. | - | - |
| Science Museum, South Kensington, London (according to E.E.S. records) | | | | |
| 1928-29/248 House U35.20 | | Large circular cake of blue frit (COA II: 34). | Not seen | |
| Haskell Oriental Museum, Chicago University, U.S.A. (according to E.E.S. records) | | | | |
| 1922/ ? | | Fragments of crucible and frit for glass-making | Not seen | |
| TURQUOISE PIGMENTS | | | | |
| Bolton Museum | | | | |
| - | 1966-A22/3 | Fragment of cake of turquoise, very uneven surface. Very coarsely granular. Max. width 10.0 cm. E.E.S. excavations. | 305U | 5.6 B 7.1/7.6 |
| 1928-29/26 | 1966-A22/4 | Fragment of cake of turquoise. Very coarsely granular. Max. width 7.0 cm. E.E.S. excavations. | 310-311U | 3.7 B 7.3/6.9 to 4.3 B 6.7/8.1 |
| - | 1966-A22/5 | Fragment of cake of turquoise. Coarsely granular. Max. width 5.0 cm. E.E.S. excavations. | 310-311U | 3.7 B 7.3/6.9 to 4.3 B 6.7/8.1 |
| - | 1966-A22/6 | Fragment of turquoise, brilliant. Coarsely granular. Max. width 5.7 cm. E.E.S. excavations. | 311U | 4.3 B 6.7/8.1 |
| - | 1966-A22/7 | Very uneven fragment of turquoise, coarsely granular. Colour does not show up brighter in area where specimen has been cut. Max. width 3.5 cm. E.E.S. excavations. | - | 0.5 B 6.2/5.4 |
| - | 1966-A22/8 | Uneven fragment of turquoise, coarsely granular and very dirty on surface. Drilled. Max. width 5.5 cm. E.E.S. excavations. | - | 9.8 BG 7.1/5.2 |

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|---|-------------|---|---|-------------------------------------|
| - | 1966-A22/9 | Fragment of turquoise. Very coarsely granular. Pitted and drilled. Max. width 3.0 cm. E.E.S. excavations. | - | 9.8 BG 7.1/5.2 |
| - | 1966-A22/10 | Fragment of turquoise, coarsely granular, dirty on surface. Max. width 3.0 cm. E.E.S. excavations. | - | 9.8 BG 7.1/5.2 to 9.7 BG 7.2/6.2 |
| - | 1966-A22/11 | Fragment of turquoise, coarsely granular. Max. width 3 cm. E.E.S. excavations. | - | 9.8 BG 7.1/5.2 to 2.3 B 7.8/4.9 |

Liverpool Museum

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|---|-----------|--|----------|-------------------------------------|
| - | 56.21.282 | 6 fragments of turquoise, b) and c) very coarsely granular. 4.5 cm wide or less. Ex Spurrell Coll. | | |
| | | a). | 311U | 4.3 B 6.7/8.1 |
| | | b). | 311U | 4.3 B 6.7/8.1 |
| | | c). | 312U | 5.0 B 6.0/9.0 |
| | | d). | 310U | 3.7 B 7.3/6.9 |
| | | e). | 304U | 2.7 B 8.0/4.2 |
| | | f). | 326-327U | 5.0 BG 6.1/7.6 to 4.0 BG 5.3/7.5 |
| - | 56.21.286 | Section of turquoise frit showing rounded base. Length 12.5 cm, width 8.5 cm, max. thickness 6.0 cm. Ex Spurrell Coll. | 311-312U | 4.3 B 6.7/8.1 to 5.0 B 6.0/9.0 |

Ashmolean Museum, Oxford

| | | | | |
|---|-----------------|---|------|-------------------------------------|
| - | 1893.1-41 (402) | 4 fragments of turquoise, finely granular. Max. width 2.5 cm. | - | 7.3 BG 7.8/4.4 to 5.7 BG 7.5/6.2 |
| | | 1 fragment of turquoise, coarser. Max. width 2.5 cm. | 311U | 3.2 B 6.9/6.1 to 4.3 B 6.7/8.1 |
| | | All from Petrie's 1891-2 excavations. | | |

Petrie Museum, University College London

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|---|--------------|---|---|------------------------------------|
| - | UC 24690 | Sherd from base of a pot containing turquoise frit. Finely granular, uneven surface. Sherd max. width 9 cm, pigment max. width 6 cm, less than 1 cm thick. From Petrie's 1891-2 excavations. | - | 2.3 B 7.8/4.9 |
| - | UC 8979A + B | 2 fragments of turquoise (with one blue, see above). Both fairly coarsely granular. A: probably part of a flat cake, 2.5 cm thick, max. width 4 cm. Recently cut for analysis. B: Dirty buff powder on surface, colouring therefore difficult to determine. Max. width 2 cm. All from Petrie's 1891-2 excavations. | - | 3.2 B 6.9/6.1 to 9.7 BG 7.2/6.2 |
| | | | - | 7.3 BG 7.8/4.4 |
| - | UC 24689 | Sherd from lower part of pot containing small amount of turquoise frit (some of which has been removed). Max. width of sherd 8 cm. Section shows grey inner layer, from incomplete oxidation (?). Frit fairly finely granular, less than 0.3 cm thick. From Petrie's 1891-2 excavations. | - | 4.7 BG 7.1/4.7 |

| | | | | |
|---|----------|---|----------|------------------------------------|
| - | UC 25038 | Fragment of turquoise-blue frit. Rough buff underside, smooth and slightly rounded top surface. Top shows some small white inclusions. Medium granular. Max. width 5.1 cm. From Petrie's glassworks excavations 1891-2. | 297-298U | 9.7 B 7.2/6.7 to 1.1 PB 6.2/8.8 |
| - | UC 25041 | Fragment of turquoise frit. From Petrie's 1891-2 excavations. | Not seen | |
| - | UC 25044 | Fragment of turquoise frit, medium granular. Max. width 7.2 cm. Slightly rounded edge. From Petrie's 1891-2 excavations. (Associated with 4 unnumbered paler turquoise pieces ?). | - | 4.7 BG 7.1/4.7 |
| - | UC 36458 | Portion of cylindrical pot (sagger) containing turquoise substance - malformed frit ? Top of vertical side of pot lost, but shows fairly even colouration of fabric. Turquoise substance rather laminated, showing some coppery reddish-grey. Texture compact, not granular. Impressions of textile on surface. Max. width turquoise substance 6.5 cm, less than 0.75 cm thick. | - | 4.7 BG 7.1/4.7 |

RED PIGMENTS

Bolton Museum

| | | | | |
|---|-------------|--|----------|---|
| - | 1966-A22/14 | Fragment of red pigment (?). 3 smooth sides, shiny, almost waxy feel. Squared corners. (Realgar ?). Max. width 7 cm. E.E.S. excavations. | 166-173U | 9.9 R 5.6/10.1 to 8.4 R 5.0/9.0 |
| - | 30.24.55 | Uneven fragment of red. Fine texture. Broken-off end. Max. width 3.5 cm. | 484U | 1.7 YR 5.9/6.8 8.0 R 4.3/5.9 to 8.3 R 4.0/7.3 |
| - | 30.24.55 | Fragment of dark red. Broken-off end. Fine texture. Max. width 4.5 cm. | 484-490U | 8.0 R 4.3/5.9 to 5.4 R 3.9/3.1 |

Liverpool Museum

| | | | | |
|---|-----------|---|----------|-------------------------------------|
| - | no no. | Red powder, in eyeglass. Ex Spurrell Coll. | 180U | 7.4 R 4.4/7.2 |
| - | no no. | 4 fragments of red. Fine texture. Ex Spurrell Coll. | 159-173U | 0.7 YR 5.5/8.1 to 8.4 R 5.0/9.0 |
| - | 55.04 | Fragment of red, in eyeglass. Fine texture. Ex Spurrell Coll. | 173-179U | 8.4 R 5.0/9.0 to 6.9 R 5.2/10.7 |
| - | 55.04 | 5 fragments of pinkish-red, in eyeglass. Fine texture. Ex Spurrell Coll. | - | 2.6 YR 8.0/4.0 to 2.6 YR 7.6/3.9 |
| - | 55.04 | Fragment of red, in eyeglass. Fine texture. Ex Spurrell Coll. | 490-491U | 5.4 R 3.9/3.1 to 4.4 R 4.0/4.4 |
| - | 56.21.283 | 5 fragments of pinkish-red with white specks. Flat on one side (from grinding). Two of these show a whitish substance on the other side. Fine texture. Max. width 4.25 cm. Ex Spurrell Coll. | - | 2.6 YR 7.6/3.9 |
| - | 56.21.287 | 3 fragments of red, one of which blackish-red and stone-like (probably haematite). One piece shows 3 flat surfaces, another shows 1 flat surface (from grinding). Max. width 4.75 cm. Ex Spurrell Coll. | 491-484U | 4.4 R 4.0/4.4 to 8.0 R 4.3/5.9 |

Ashmolean Museum, Oxford

| | | | | |
|---|--------------------|--|--------------------------|--|
| - | 1893.1-41 (402) | Box containing 2 large pale red fragments. Both max. width 7 cm. | - | 6.1 R 5.1/7.2 int. 8.9 R 5.8/6.8 ext. |
| | | Box containing reddish-brown powder. | 180U | 7.4 R 4.4/7.2 to 8.3 R 4.0/7.3 |
| | | Box containing red powder. | 179U | 6.9 R 5.2/10.7 |
| | | Box containing 3 red fragments: a) 1 flattish side. Finely granular. Max. width 3 cm. b) 2 flat surfaces. Top and base incised by (cutting ?) lines. Max. width 2.5 cm. c) Sliver. Slightly more granular than a) and b). Max. width 3 cm. All from Petrie's 1891-2 excavations. | 158U 159U 180-187U | 0.1 YR 6.1/10.6 0.7 YR 5.5/8.1 7.4 R 4.4/7.2 to 3.4 R 4.3/8.0 |

Petrie Museum, University College London

| | | | | |
|---|----------|---|------------------|---|
| - | UC 24691 | Two fragments of red pigment. a) Smooth texture, almost waxy feel. Irregular shape. Realgar ? Max. width 4 cm. Petrie 1891-2 excavations; see Petrie 1894: Ch. IV. b) Finely granular texture, irregular shape. Labelled "TA21", so presumably excavations of E.E.S. Surface partly coated with buff layer. Max. width 4 cm. | 166U 180-174U | 9.9 R 5.6/10.1 7.4 R 4.4/7.2 to 9.5 R 4.4/5.4 |
|---|----------|---|------------------|---|

Cairo Museum

| | | | | |
|------------|---------------------------|--|-----------|------------------------------------|
| 1926-7/? | JdE 50760/ 50762 | Fragment of red pigment (with yellow and blue pigments). Max. width 7.3 cm. | Not seen | |
| 1935-6/332 | JdE 66110 Great Palace | Small bowl with chipped octagonal rim, containing red pigment. width 9.6 cm. See COA III: 74. | 173U-179U | 8.4 R 5.0/9.0 to 6.9 R 5.2/10.7 |

YELLOW PIGMENTS**Bolton Museum**

| | | | | |
|---|-------------|---|----------|-----------------------------------|
| - | 1966-A22/15 | Fragment of yellow, fine texture. Max. width 3 cm. E.E.S. excavations. | 127U | 5.0 Y 8.9/7.0 to 5.2 Y 8.4/6.8 |
| - | 1966-A22/16 | Fragment of yellow. E.E.S. excavations. | Not seen | |
| - | 1966-A22/17 | Fragment of yellow, fine texture. Max. width 3 cm. E.E.S. excavations. | 127U | 5.0 Y 8.9/7.0 to 5.2 Y 8.4/6.8 |
| - | 1966-A22/18 | 2 fragments of yellow, fine texture. Max. widths both 2.5 cm. E.E.S. excavations. | 127U | 5.0 Y 8.9/7.0 to 5.2 Y 8.4/6.8 |
| - | 30.24.55 | Irregular fragment of yellow, fine texture, "chalky". Max. width 6 cm. | - | 4.7 Y 8.8/6.3 |
| - | 30.24.55 | Fragment of yellow, fine texture, "chalky". Max. width 3 cm. | - | 5.4 Y 9.1/3.8 |
| - | 30.24.55 | Fragment of yellow, fine texture. Max. width 7 cm. | - | 1.9 Y 8.4/7.1 |
| - | 30.24.70 | Fragment of orpiment, crystalline, yellow, with some traces of red. Max. width 3.5 cm. | - | 7.4 Y 8.9/9.5 |

Liverpool Museum

| | | | | |
|---|-------------|---|---------------------------|--|
| - | 55.04 | 6 fragments of yellow, in eyeglass. Fine texture. Ex Spurrell Coll. | 124U | 8.6 YR 6.4/9.0 |
| - | 55.04 | 4 fragments of yellow, in eyeglass. Fine texture. Ex Spurrell Coll. | - | 6.8 YR 7.3/6.5 to 8.0 YR 7.9/7.6 |
| - | 56.20.195-6 | b) bottle containing 2 fragments of orpiment, max. width 2.75 cm. (plus 4 smaller fragments of mud partly coloured with yellow). b) bottle containing yellow powder. All ex Spurrell Coll. | orpiment: 128U 129U | orpiment: 3.8 Y 8.2/8.0 0.1 R 7.6/9.5 to 8.0 YR 7.9/7.6 |
| - | 56.21.288 | 5 fragments of yellow. One has 2 flat sides, 1 corner broken off. Fine texture. Max. width 4 cm. Ex Spurrell Coll. | 121-135U | 1.2 Y 8.1/9.3 to 0.1 Y 8.3/6.7 |
| - | 56.21.748 | Fragments of yellow, fine texture, only small crumbs remaining. Also gold leaf. | 128U | 3.8 Y 8.2/8.0 |

Ashmolean Museum, Oxford

| | | | | |
|---|--------------------|--|------------------|--|
| - | 1893.1-41 (402) | Box containing several fragments of yellow. All finely textured; one piece has small white inclusions. Largest piece max. width 7.5 cm. Fine yellow powder with smaller fragments. | 134U 124U | 2.2 Y 8.5/5.8 to 1.2 Y 8.4/6.4 8.6 YR 6.4/9.0 to 6.6 YR 8.1/2.5 |
| | | Box containing 4 fragments of darker yellow (with 3 red fragments), with powder. Texture varies. All 2.5-2.75 cm max. width. | 129-135U | 0.1 R 7.6/9.5 to 0.1 Y 8.3/6.7 |
| | | Box containing yellow pigment (with 2 red fragments), flatish on one side. Max. width 3.25 cm. All from Petrie's 1891-2 excavations. | 129U | 8.0 YR 7.9/7.6 to 0.1 R 7.6/9.5 |

Calro Museum

| | | | |
|-----------|---------------------|---|----------|
| 1926-7/ ? | JdE 50760/ 50762 | Golden yellow block (with red pigment and blue frit). Max. width 6.8 cm. | Not seen |
|-----------|---------------------|---|----------|

Boston Museum of Fine Arts, U.S.A. (according to E.E.S. records)

| | | | |
|-----------|--|-------------------|----------|
| 1924-5/ ? | | Piece of orpiment | Not seen |
|-----------|--|-------------------|----------|

U.S.A. unspecified museum (according to E.E.S. records)

| | | | |
|--------|--|-------------------|----------|
| 23/359 | | Piece of orpiment | Not seen |
|--------|--|-------------------|----------|

GREY, PURPLE, GREEN AND UNSPECIFIED COLOURS**Liverpool Museum**

| | | | | |
|---|-----------|--|----------|------------------------------------|
| - | 56.21.282 | Fragment of purplish-grey frit. Spongy, coarse texture, speckled with white particles. Max. width 6.5 cm. Ex Spurrell Coll. | 279-271U | 5.6 PB 5.8/9.2 to 1.8 P 4.9/4.0 |
| - | 56.21.282 | Smaller fragment of purplish-grey frit. Coarse texture, some white particles. Max. width 2.25 cm. Ex Spurrell Coll. | - | 6.0 PB 6.6/6.7 |

Ashmolean Museum, Oxford

- 1893.1-41 (402) Box of white powder with some coarser lumps. Sand present. Probably calcite or gypsum. From Petrie's 1891-2 excavations.

Petrie Museum, University College London

- UC 36457 Fragment of purplish-grey frit, to which are attached 2 sherds from a broken round-bottomed vessel. Sherds are of coarse brownish-grey ware. Section is dark grey (fired under reducing conditions?). Frit is spongy and contains many small white inclusions. Coarse texture. Max. width 12.5 cm. 2 small pieces of frit (?), same colour, but blackened on one side (labelled f) associated with this object. Ref "Pan of unfinished frit which had broken in the furnace" (Petrie in Russell 1892 is the same object?). From Petrie's 1891-2 excavations. 4.0 PB 5.7/5.7 to 3.9 PB 5.0/6.4

- UC 24687 Several fragments of malachite (possibly raw-material for frit-making). From Petrie's 1891-2 excavations.

British Museum (according to E.E.S. records)

1921/469 House N49.20 Fragment of malachite (possibly raw-material for frit-making). 4.8 x 3.0 cm. COA I: 24. Not seen

Colorado Museum of Natural History, Denver, Colorado U.S.A. (according to E.E.S. records)

1922/? Paint brush and samples of paint. Not seen

Brooklyn Museum, New York, U.S.A. (according to E.E.S. records)

1922/? Samples of paint (and small brush). Not seen

1933-4/? 4 lumps of raw paint. Not seen

San Diego Museum, California, U.S.A. (according to E.E.S. records)

1930-1/? Two fragments of paint from an el-Amarna house. Not seen

Toledo Museum of Art, U.S.A. (according to E.E.S. records)

1922/? Samples of paint (and paint brush). Broken crucible, frit and fragments of glass. Not seen

Ny Carlsberg Glyptotek, Copenhagen (according to E.E.S. records)

1922/? Selection of paints. Not seen

Table 10.2. Catalogue of pigment and colour specimens from Amarna in museum collections.

Pigments from Amarna

| Blue | | Turquoise | | Red | | Yellow | |
|----------|---|-----------|--|----------|---|----------|--|
| Pantone | Munsell | Pantone | Munsell | Pantone | Munsell | Pantone | Munsell |
| 285–300V | 5.9 PB 4.8/ 10.9 to 3.6 PB 4.7/ 10.7 | 319–325U | 0.7 B 7.0/ 7.4 to 6.2 BG 6.9/ 6.6 | 186–179U | 3.9 R 4.8/ 11.4 to 6.9 R 5.2/ 10.7 | 121–122U | 1.2 Y 8.1/ 9.3 to 9.5 Y 7.8/ 10.5 |

Table 10.3. Colour identification of wall-plaster from the Main Chapel (Sanctuary).

| | Na ₂ O | MgO | Al ₂ O ₃ | SiO ₂ | SO ₂ | Cl | K ₂ O | CaO | Cr ₂ O ₃ | FeO | CuO | Total | Comments | XRD (all samples contain quartz) |
|--|-------------------|------|--------------------------------|------------------|-----------------|------|------------------|-------|--------------------------------|------|-------|--------|--|--|
| M10(2) | - | - | 0.21 | 57.37 | 0.48 | 0.48 | 0.72 | 28.02 | 0.12 | 0.63 | 6.54 | 94.58 | Wide deviation from stoichiometric EB (& other Ca-Cu-silicates). Grain comprises EB (68%) & unreacted Si & Cu. Pleochrism revealed under x60 magnification indicates EB. | Strong correlation with EB; ASTM no. 12-512. |
| | - | 0.28 | 0.32 | 61.73 | - | 0.25 | 0.78 | 10.10 | - | 0.75 | 17.67 | 91.87 | | |
| N15(1)/4075 | - | - | - | 63.89 | - | - | - | 15.03 | - | - | 21.10 | 100.03 | Almost perfect results for EB. Two other grains gave similar results; homogeneous sampled implied. | Good correlation with EB; ASTM no. 12-512. |
| R10 [1385] | - | - | - | 61.83 | - | - | - | 14.80 | - | - | 21.49 | 98.11 | Very good result for EB. | Bands too few & too diffuse to be interpreted. |
| | - | - | - | 51.54 | - | - | - | 47.97 | - | - | 0.84 | 100.33 | CaSiO ₃ , wollastonite. Heterogeneous sample implied. | |
| Sherd WS3[2094]/66354 | - | - | - | 52.15 | - | - | - | 46.51 | - | - | 0.76 | 99.42 | CaSiO ₃ , wollastonite. | Strong correlation with EB; ASTM no. 12-512. |
| | 7.12 | 0.37 | 1.29 | 53.55 | - | 0.43 | 1.07 | 17.79 | - | 1.41 | 8.70 | 91.72 | A (Na)-Ca-Cu-silicate. Heterogeneous sampled implied. | |
| Sherd WS3[2094]/66393 | | | | | | | | | | | | | Sample unsuitable for preparation for EPMA. | ditto |
| Sherd T19[2265] | | | | | | | | | | | | | ditto | ditto |
| Stoichiometric EB | - | - | - | 63.9 | - | - | - | 14.9 | - | - | 21.2 | - | | |
| Stoichiometric CaSiO ₃ , wollastonite | - | - | - | 51.7 | - | - | - | 48.3 | - | - | - | - | | |

Table 10.4. Results of electron micro-probe analyses of blue pigments. Blank spaces indicate oxides of elements below the limits of detection. Detection limits typically 1000 ppm (=0.1%) for EPMA. EB = Egyptian Blue.

| | Na ₂ O | MgO | Al ₂ O ₃ | SiO ₂ | SO ₂ | Cl | K ₂ O | CaO | Cr ₂ O ₃ | TiO ₂ | FeO | CuO | Total | CuO/CaO | Comments | XRD (all samples contain quartz) |
|--|-------------------|-----|--------------------------------|------------------|-----------------|------|------------------|-------|--------------------------------|------------------|------|-------|--------|---------|---|--|
| S18[2156] | - | - | - | 57.96 | 0.26 | 0.73 | 1.03 | 28.45 | - | 0.12 | 0.31 | 8.57 | 97.44 | <0.1 | Ca-Cu-silicate as a mixture with CaSiO ₃ , wollastonite implied. | Good correlation with wollastonite; ASTM no. 10-489. |
| | - | - | - | 62.75 | - | 0.85 | 1.47 | 23.50 | 0.16 | - | 0.29 | 9.23 | 98.23 | 0.4 | | |
| M18 surface | - | - | 0.30 | 60.24 | - | 1.15 | 0.13 | 18.43 | - | - | 0.35 | 11.11 | 91.70 | 0.6 | ditto | Slight correlation with wollastonite; ASTM no. 10-489. |
| | - | - | 0.22 | 59.73 | - | 0.97 | 0.18 | 22.44 | 0.11 | - | 0.38 | 10.67 | 94.71 | 0.5 | | |
| M10(1)/(2) | 7.20 | - | - | 61.22 | - | - | 0.37 | 24.90 | - | - | 0.26 | 6.63 | 100.40 | 0.3 | (Na)-Ca-Cu-silicate implied. | Moderate correlation with wollastonite; ASTM nos. 10-489, 27-1064. |
| | 3.25 | - | - | 57.16 | - | - | 0.19 | 32.57 | - | - | 0.21 | 4.26 | 97.63 | 0.1 | | |
| | 3.59 | - | - | 58.24 | - | - | 0.26 | 30.25 | - | - | 0.21 | 4.74 | 97.29 | 0.2 | | |
| | 8.72 | - | - | 59.45 | - | - | 0.52 | 10.97 | - | - | 0.37 | 9.44 | 89.45 | 0.9 | | |
| WS3[2122]/7191 | 9.90 | - | - | 60.26 | 0.22 | 1.29 | 0.14 | 5.77 | - | - | 0.22 | 16.58 | 94.38 | 2.9 | ditto | Slight correlation with wollastonite; ASTM no. 10-489 |
| | 9.78 | - | - | 63.61 | - | 1.33 | 0.60 | 4.15 | - | - | 0.47 | 11.33 | 91.27 | 2.7 | | |
| M9(8) feature 8 | 3.54 | - | - | 54.37 | 0.41 | 0.50 | 0.19 | 24.35 | - | - | 0.41 | 8.10 | 91.87 | 0.3 | ditto | Slight correlation with wollastonite; ASTM no. 10-489. |
| | 3.33 | - | - | 54.90 | - | 0.47 | 0.26 | 27.57 | - | - | 0.19 | 7.19 | 93.92 | 0.3 | | |
| M10(2) | 6.87 | - | 0.46 | 59.26 | - | - | 1.11 | 13.73 | - | - | 0.64 | 14.59 | 96.66 | 1.1 | ditto | Good correlation with wollastonite; ASTM nos. 10-489, 27-1064. |
| Sherd N17(3) 2089 | 5.98 | - | - | 59.74 | - | 0.73 | 0.98 | 22.25 | - | - | 0.24 | 6.52 | 96.43 | 0.3 | ditto | No correlation found with any mineral. |
| | 10.22 | - | - | 62.33 | - | 1.25 | 0.26 | 4.33 | - | - | 0.35 | 12.26 | 90.89 | 2.8 | | |
| Sherd L18(1)/3956 | 12.07 | - | 0.32 | 61.93 | - | 1.42 | 0.21 | 4.02 | - | - | 0.41 | 14.21 | 94.58 | 3.5 | ditto very heterogeneous sample | Good correlation with wollastonite; ASTM no. 10-489. |
| | 8.43 | - | - | 58.09 | - | 1.25 | 0.17 | 9.31 | - | - | 0.45 | 12.91 | 90.60 | 1.4 | | |
| | 6.90 | - | - | 57.59 | - | 0.93 | 0.13 | 17.92 | - | - | 0.40 | 9.57 | 93.44 | 0.5 | | |
| | 1.42 | - | - | 52.94 | - | 0.31 | - | 36.97 | - | - | - | 3.33 | 95.03 | 0.1 | | |
| | - | - | - | 4.38 | 31.95 | 0.51 | - | 23.80 | - | - | - | 0.32 | 60.96 | <0.1 | CaSO ₄ , longish grains. | |
| Stoichiometric CaSiO ₃ wollastonite | - | - | - | 51.7 | - | - | - | 48.3 | - | - | - | - | - | - | | |

Table 10.5. Results of electron micro-probe analyses of turquoise pigments. Blank spaces indicate oxides of elements below the limits of detection. Detection limits typically 1000 ppm (=0.1%) for EPMA.

| | Na ₂ O | Al ₂ O ₃ | SiO ₂ | Cl | K ₂ O | CaO | TiO ₂ | Cr ₂ O ₃ | MnO ₂ | FeO | CuO | CoO | Total | Comments | XRD |
|---|-------------------|--------------------------------|------------------|------|------------------|-------|------------------|--------------------------------|------------------|-------|-------|------|--------|---|--|
| Green samples | | | | | | | | | | | | | | | |
| I8[254] | - | 2.25 | 41.27 | - | - | 1.14 | - | - | 0.23 | - | 49.12 | - | 94.01 | Chrysocolla indicated. | Good correlation with chrysocolla; ASTM no. 27-188. |
| | - | 2.69 | 40.70 | 0.09 | 0.14 | 1.30 | - | - | 0.14 | - | 47.20 | - | 92.26 | | |
| L17(3)/1228 | - | 1.94 | 37.51 | 0.98 | 0.20 | 0.69 | - | - | 0.21 | - | 45.58 | - | 87.11 | Chrysocolla indicated | ditto |
| | - | 3.00 | 37.53 | 2.27 | 0.16 | 1.48 | - | - | 0.14 | - | 41.22 | - | 85.80 | | |
| | - | 2.83 | 39.44 | 1.52 | 0.21 | 1.38 | - | - | 0.19 | - | 41.72 | - | 87.29 | | |
| O15(4) | 6.63 | - | 60.38 | - | 0.77 | 13.05 | 0.22 | - | - | 0.50 | 12.88 | - | 94.43 | Analyses of matrix, (other patches=quartz). Heterogeneous sample; probably CaSiO ₃ , wollastonite, and other materials as in turquoise frit. Not a natural ore like other green samples; more of a glass. | Bands too weak & diffuse to be interpreted (? owing to interference by glass). |
| | 3.11 | - | 55.41 | - | 0.22 | 31.98 | 0.21 | - | - | 0.23 | 5.97 | - | 97.13 | | |
| | 4.52 | 1.19 | 62.42 | - | 3.29 | 3.52 | 0.29 | - | - | 0.40 | 17.31 | - | 92.88 | | |
| Red pigment samples | | | | | | | | | | | | | | | |
| WS3 [2128]/12516 | - | 1.17 | 2.24 | 0.29 | - | 0.17 | - | - | - | 79.71 | - | 1.82 | 85.39 | Slightly low reading for Fe ₂ O ₃ compared with stoichiometric estimation | Good correlation with haematite; ASTM no. 33-664. |
| Stoichiometric haematite Fe ₂ O ₃ | - | - | - | - | - | - | - | - | - | 90.0 | - | - | | | |
| Yellow pigment samples | | | | | | | | | | | | | | | |
| N15(1) | - | 1.37 | 1.99 | - | - | - | 61.86 | 0.12 | 0.82 | 36.06 | - | 0.29 | 102.53 | Quartz crystals in matrix of fine material, predominantly aluminium silicates. Analysis is of included grains of Fe/Ti phase; these are very small and volumetrically minor. Also present is Ti-free Fe oxide coating on the quartz grains. | XRD determinations are dominated by the presence of quartz. |

| | | | | | | | | | | | | | | | |
|--|---|------|------|---|---|------|-------|---|------|-------|------|---|-------|---|-------|
| M9(4) | - | 0.46 | 0.59 | - | - | 0.17 | 60.19 | - | 1.62 | 34.41 | 0.24 | - | 97.68 | As above but larger Fe/Ti grains. | ditto |
| Stoichio- metric goethite FeO(OH) | - | - | - | - | - | - | - | - | - | 80.8 | - | - | - | | |

Table 10.6. Results of electron micro-probe analyses of green, red and yellow samples. Blank spaces indicate oxides of elements below the limits of detection. Detection limits typically 1000 ppm (=0.1%) for EPMA.