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# The Late Bronze Egyptian Garrison at Beth Shan: Glass and Faience Production and Importation in the Late New Kingdom\*

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*Beth Shan, strategically located at the juncture of the Jordan and Jezreel Valleys where major trade routes intersected, was architecturally restructured in the 13th century B.C.E. as one of the most important late New Kingdom Egyptian bases in Palestine. The archaeological and technological evidence from the site provides a unique perspective on how a deliberate imperialistic policy can affect local ceramic traditions, including the pottery and silicate industries. The Egyptians appear to have controlled the silicate industry at its most basic level, including the preparation and supply of raw materials. The Palestinian ceramic specialists, whether voluntarily or as a forced response, then adapted their techniques and were most likely responsible for technological and stylistic innovations. The silicate manufacture at the site, however, was limited to small artifacts, such as beads and pendants. Larger artifacts, in particular glass and faience vessels, were imported from Egypt. Chemical analyses support this interpretation, although a specific site where the vessels were manufactured in the late New Kingdom is yet to be determined.*

## INTRODUCTION

The glass and faience industries of late New Kingdom Egypt, not only in the homeland but beyond the frontier in Egypt's Asiatic "empire", are best understood within a broader historical context. Experimentation in glass and frit had begun by at least 1600 B.C.E., near the end of the Middle Bronze Age.<sup>1</sup> Several hundred years prior to the late New Kingdom, sites in northern Mesopotamia and Palestine—e.g., at Dinkha Tepe (McGovern, Fleming, and Swann 1991), Nuzi (Vandiver 1982), and in the Baq'ah Valley of Transjordan (McGovern 1986: 202–42)—have yielded relatively large groups of glass and frit artifacts

that were consistently and, presumably, intentionally made.

Particularly noteworthy about the experimentation in those vitreous materials was the use of a variety of metal colorants and opacifiers, primarily transition metals (including manganese, cobalt, iron, copper, antimony, and lead), which were prepared as calcined frits.<sup>2</sup> The opacifiers were either added to glass batch mixtures or used alone, with subsequent refiring. Palestine, although often viewed as a cultural backwater, could have contributed to those innovations in silicate technology, because its city-states had undergone an unprecedented expansion during the Middle Bronze Age and because the necessary metal ores (copper, manganese, and iron) and other raw materials (sand and sandstone, alkali salts, and lime) needed for silicate production were found there.

The experimentation in new silicate materials eventually had an impact on the traditional Egyptian faience industry (Kacyzmarczyk and Hedges 1983) whose origins lay in the Chalcolithic period

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\* There are numerous archeological perspectives on technology. This double issue is a result of an effort to present several articles that exemplify the various aspects of past or present technology. We are grateful to the authors for their cooperation.

—J.W.F.

and had remained highly conservative over the next two millennia. During the early New Kingdom, particularly during the reign of Tuthmosis III (1479–1425 B.C.E., following Kitchen 1987) of the 18th Dynasty, this industry underwent a remarkable technological and stylistic transformation, with the introduction of glass-making techniques and an enormous variety of frit and glaze colorants. Most of those colorants had originated in the Syro-Palestinian glass industry.

Egypt had reinitiated significant contact with the Levant, following a hiatus of several centuries, around 1750 B.C.E. with the rise of Semitic “Hyksos” dynasties in the Nile Delta (Bietak 1981; 1987). The material culture of the Hyksos was co-extensive with that of southern Palestine. Under those circumstances, Palestine was a natural trade partner with Egypt for raw materials and finished products.

Once native Egyptian dynasts returned to power about 1550 B.C.E., at the beginning of the New Kingdom—the Late Bronze Age in Palestinian terms—the Hyksos were defeated and driven out of Egypt—first from their capital city of Avaris (Tell ed-Dab<sup>c</sup>a) in the Delta and later from their southern Palestinian base of Sharuhēn (probably Tell el-<sup>c</sup>Ajjul). Although later Egyptian writers denigrated that period of foreign domination, the best of Asiatic material culture—including brilliantly colored and wonderfully fashioned glasses and glazes—came to be highly valued and was emulated in Egyptian workshops throughout the country. The repeated Egyptian military incursions during the 18th Dynasty, in which Palestine assumed a more subservient role to Egypt as a forward defensive position and erstwhile client state, also further intensified Egyptian-Palestinian contacts (Weinstein 1981).

The highpoint of Egyptian influence in Palestinian affairs came in the 13th century B.C.E., at the beginning of 19th Dynasty. Under the leadership of two powerful pharaohs, Sety I and Ramesses II, Egyptian policy was directed once more toward the creation of a true colony in western Asia, with a large Egyptian bureaucracy and military to control the local population and economy (Kemp 1978). Perhaps significantly, Ramesses’ family came from the northeastern Delta and had reinstated worship of the god Seth, the main deity of the Hyksos. Unlike Nubia, south of the first cataract of the Nile, or the Sinai, however, where a small local population offered little resistance, the Egyptian way of life could not be imposed easily on the relatively advanced, populous Palestinian city-states.

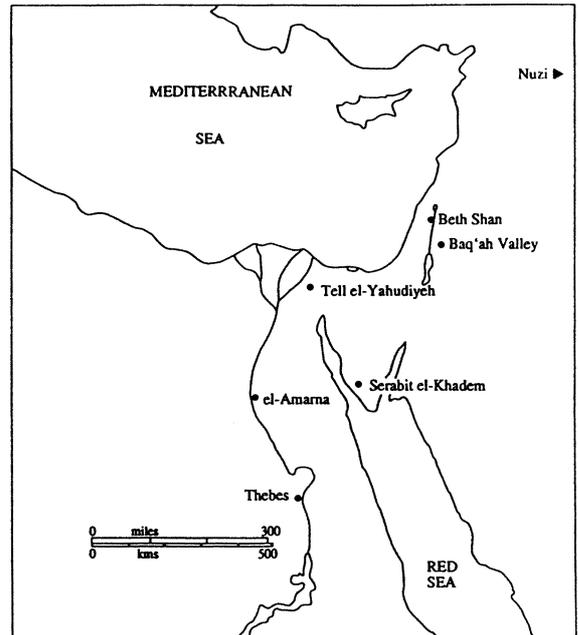


Fig. 1. Egypt and the Eastern Mediterranean.

#### BETH SHAN: AN EGYPTIAN MILITARY GARRISON IN CANAAN

Of the many communities in Palestine impacted by Egyptian imperialistic policy, Beth Shan (fig. 1) underwent the most profound changes (James and McGovern 1993). The 13th century B.C.E. levels (Levels VIII and VII) at the site were transformed into an Egyptian military base by dismantling and leveling the earlier Late Bronze Level IX and then constructing typical Egyptian New Kingdom buildings. The construction included a residential sector of courtyard houses laid out along a grid pattern of streets, a temple, and the so-called *migdol* (“fortress”) and “commandant’s house.” Matching the architectural changes, the ratio of Egyptian pottery and object types to Palestinian types is the highest that has ever been recorded at a Palestinian site. At least two monumental stelae of Sety I and one of Ramesses II (Rowe 1930: 24–30, 33–36) from Beth Shan are particularly important. They detail Egyptian military activity in the area, including the defense of the garrison against the belligerent city-states of Pella and Hamath, located several kilometers to the south, and against peoples such as the *ʿapiru*.

Before Beth Shan was excavated, its importance as an Egyptian military base could hardly have been anticipated. It is far inland along the northeastern frontier of Palestine, more than 400 km from the Egyptian border. Yet, the site is strategi-

cally located at the eastern terminus of the main east-west trade route through the Palestinian Hill Country; here, where the Jezreel and Jordan Valley intersect, routes to southern Syria and Jordan branched off after crossing the Jordan River by a shallow ford. A less tangible reason for the Egyptian choice of Beth Shan as a base of operations might be that the site most nearly duplicated the conditions of an Egyptian town, with its hot climate and proximity to a major river, into which a network of waterways flowed and were periodically flooded.

After the wholesale restructuring of Levels VIII and VII by the Egyptians, the local population was not uprooted and moved elsewhere. There is ample artifactual evidence that the bulk of the population on the tell were Canaanites, perhaps about 1500 individuals out of a total population of 2000, based on areal calculations of domestic dwellings containing Palestinian-style artifacts. The Canaanites who lived alongside the 500 or so Egyptians most likely provided the basic manual and specialized labor needs of the garrison. Some of the Canaanites might even have held higher posts in the hierarchy, as earlier reported in the Amarna Letters (Helck 1971: 248–49, 251, 446–73). In general, however, Egyptians must have occupied most of the important military and administrative posts. Egyptian architects were also present, since they describe themselves as such in inscriptions from the site, and only a very exact knowledge of Egyptian building techniques can explain the similarity of the garrison layout and individual building types to New Kingdom Egyptian architecture.

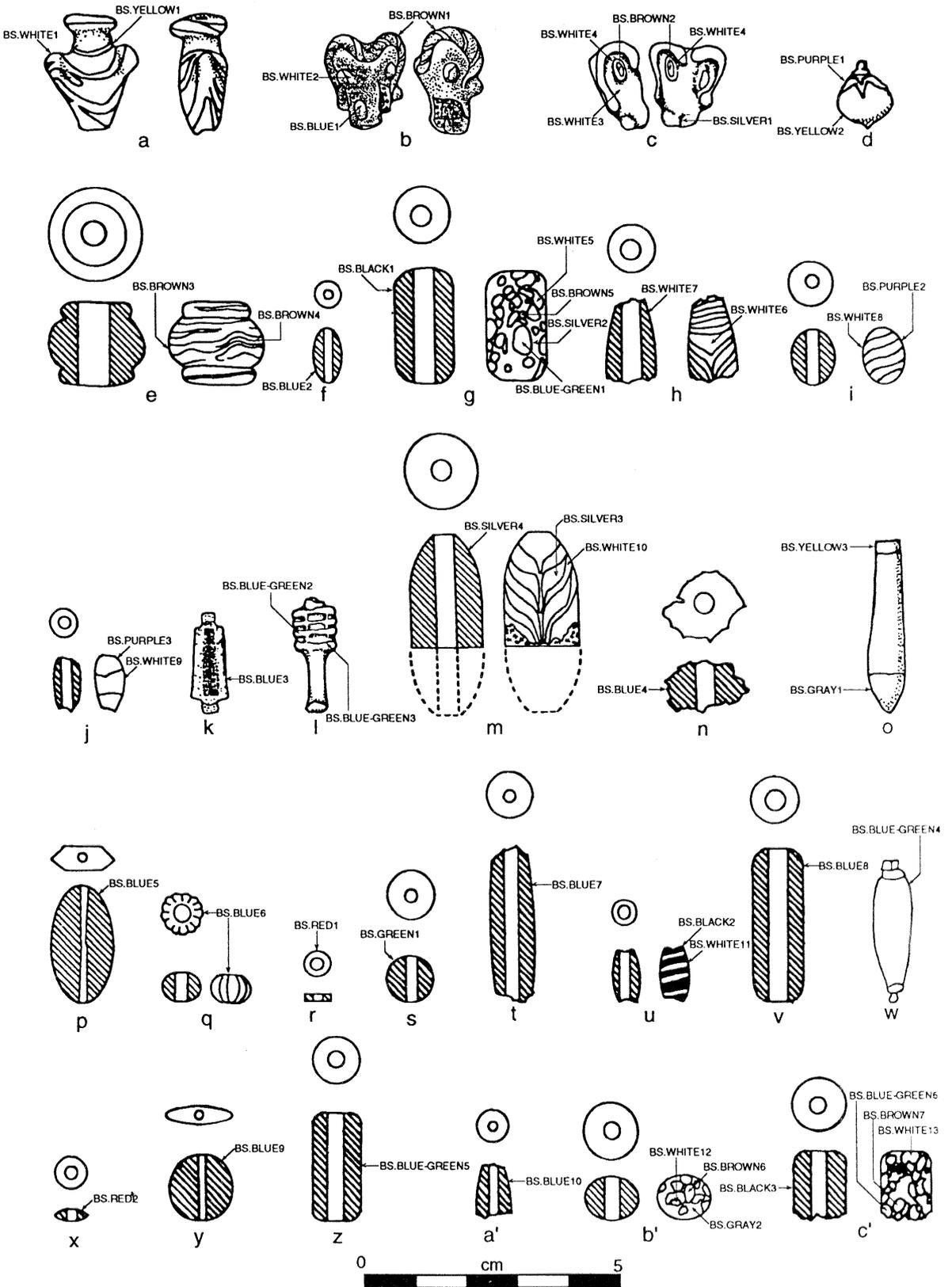
Although inscriptions at the site specifically refer only to Egyptian architects, a variety of Egyptian craftsmen probably also took up residence. Černý (1973: 116) has argued that Egyptian building projects, such as the Theban royals tombs, could not have absorbed all the young men trained in their fathers' trades, so that some always went abroad. Clearly, it was more expeditious to reproduce Egyptian material culture on-site than to import it. At the same time, the output of local Palestinian craftsmen, especially ceramic specialists, does not appear to have diminished. Some crafts (e.g., metalworking, manufacture of bone and ivory inlay, and the alabaster industry), on the other hand, appear to be almost exclusively the domain of Palestinian craftsmen and to have no Egyptian counterpart at the site.

Since the thousands of beads, hundreds of pendants, and numerous vessels from Levels VIII and VII constitute the largest corpus of silicate artifacts

ever recovered from a Late Bronze Palestinian site, Beth Shan represents a rare opportunity in the ancient world to examine the extent and direction of craft interaction (McGovern 1989a; 1989b). How did Egyptian imperialistic policy affect local silicate style and technology; and how is Palestinian practice reflected in the Egyptian industry? The crucial importance of the Egyptian presence on the Beth Shan industry is highlighted by contrasting it with that of Palestinian regions outside the Egyptian sphere; for example, the native silicate industry of the Baq<sup>ā</sup>h Valley of the central Transjordanian plateau showed very little change throughout the Late Bronze Age (McGovern 1986: 202–42).

The Level VIII/VII temple precinct and its deposits best illustrate how Egyptian and Palestinian concepts, whether stylistic or technological, might be combined (McGovern 1989b; 1990). First constructed in Level VIII (assigned to the reign of Sety I) and successively rebuilt in Levels VII (Ramesses II) and VI (Ramesses III), the temple was comprised of a lotus-columned inner courtyard, with a stairway leading up to a back altar room. Its layout was almost identical to mortuary chapels and sanctuaries at Akhenaten's mid-14th century B.C.E., capital of el-Amarna (Peet and Woolley 1923: 92–108, 125–34, pls. 24–27, 41–42), and at the contemporaneous workmen's village of Deir el-Medineh, near the southern capital of Thebes (Bruyère 1930: 9–10, 17–50; 1948: 12–24, 99–106).

Although the temple type evidently was derived from an Egyptian model (which, in turn, quite possibly has an earlier Syro-Palestinian prototype), the artifacts attest to a combined Egyptian/Canaanite cult. Finds included dedicatory stelae showing principal Canaanite female and male deities attired in standard Egyptian fashion, and artifacts associated with the worship of Hathor, the Egyptian goddess of foreign countries and "Lady of Turquoise." There also was a very large hoard of glass and faience jewelry and vessels—more than 1500 beads, 300 pendants, and 40 vessels—found buried below or in the vicinity of the stairway. Some of those objects probably played a direct role in the syncretistic cult. For example, the faience lotus bowls, very common in the Beth Shan group, were used to present food offerings to theriomorphic deities in New Kingdom Egypt. The masses of beads and pendants had most likely been strung together originally to form pectorals or collars that adorned temple personnel or a cult statue. Many of the pendant types were of Egyptian style, representing Egyptian deities (e.g., Bes and the baboon of



Thoth) or hypostasized concepts (life [*ankh*], stability [*dd*], etc.). Those pendants apparently had been mixed together indiscriminately on the same jewelry pieces with Palestinian types (the star disc, crescent with horns, etc.), which were symbolic of Canaanite deities and religious ideas (McGovern 1985: 48–49). The practice of burying special objects as *ex voto* or foundation deposits under walls, floors, and, in the case of the Level VIII/VII temple, under the steps leading up to the sanctuary, is characteristically Canaanite. Even most of the Egyptian-style artifacts were treated in the same fashion.

If the local Palestinians and immigrant Egyptians had no inherent difficulty in combining religious iconography and practice (although it is uncertain to what extent a borrowed concept or motif would have been recast so as to be more compatible with native belief and practice), then a similar sharing of technological expertise might have occurred at the site.

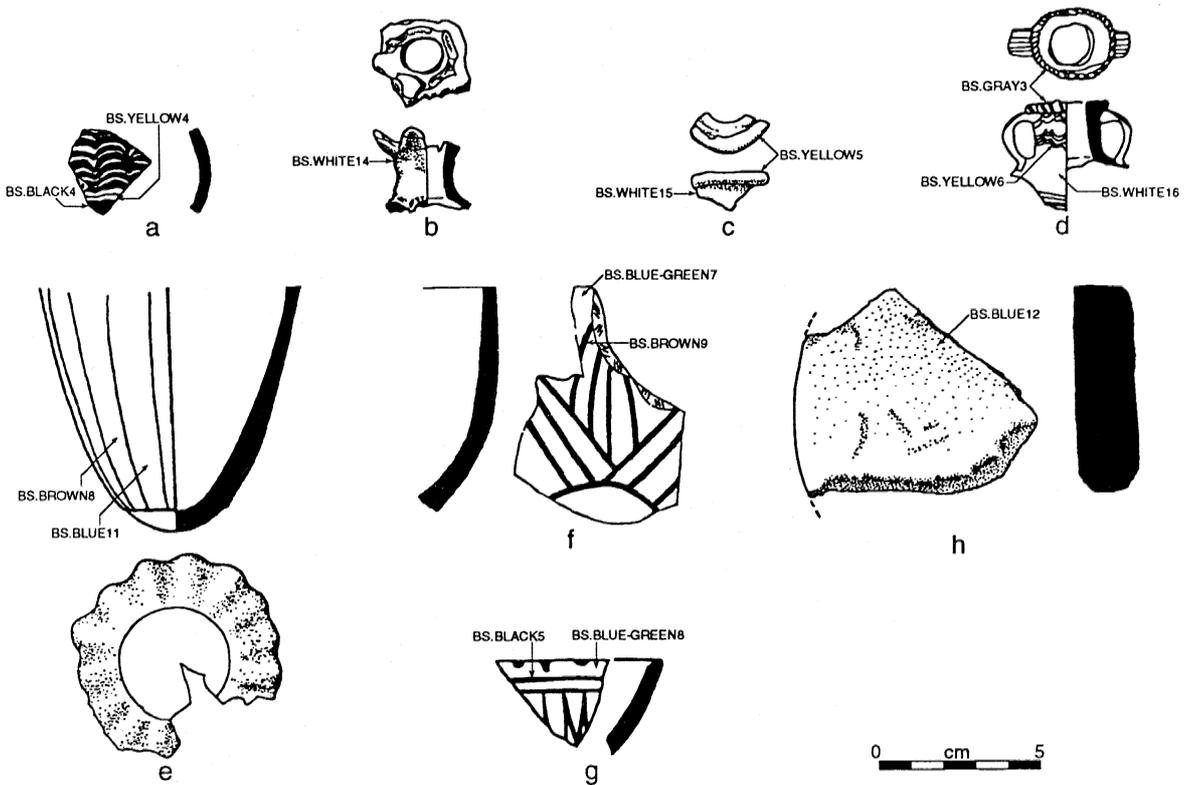
### *Beth Shan Silicate Analysis*

The initial investigation of the Beth Shan silicate collection involved analyzing 54 small objects, including nine Level IX artifacts broadly dated to the Late Bronze Age, and seven vessels (figs. 2, 3), which were chosen as being sufficiently intact and representative of the range of variation for detailed scientific analysis.<sup>3</sup> Most of the small objects and vessels were found in the temple complex at the center of the tell (marked with an asterisk in the captions to figs. 2, 3), which underwent a major architectural change between Levels IX and VIII. The remainder of the artifacts came from residences in surrounding areas.

Based on the analyses (detailed in McGovern 1986: 202–42; 1987; 1989b), it is likely that a local variant of the Syro-Palestinian silicate industry existed at Beth Shan prior to Level VIII. The glasses and frits were of the standard Middle Bronze-Late Bronze types (see note 1). Specimens are well-fused;

**Fig. 2.** Analytical corpus of Beth Shan silicate small objects.

- \*a. *jb* ("heart") pendant, white glass with yellow (BS.YELLOW1) and white (BS.WHITE1) impressed bands, P.29-105-744;
- \*b. ram's head pendant, white glass with brown (BS.BROWN1) and white applied canes for horns, brown and white (BS.WHITE2) overglazes on eyes, and blue (BS.BLUE1) overglaze on nostrils, P.29-104-190;
- \*c. ram's head pendant, white (BS.WHITE3, BS.WHITE4) glass with brown and white applied canes for horns, silvery and brown (BS.BROWN2) overglazes on eyes, silvery overglaze on nostrils (BS.SILVER1), and piece of malachite inserted into left eye, P.29-104-192;
- \*d. mandrake fruit pendant, yellow (BS.YELLOW2) frit with purple (BS.PURPLE1) overglaze, P.29-104-311;
- \*e. collared spheroid bead, brown (BS.BROWN3, BS.BROWN4) and white swirled glass, P.29-104-482;
- \*f. barrel bead, blue (BS.BLUE2) glass, P.29-104-470;
- \*g. barrel bead, silvery (BS.SILVER2) glass with brown (BS.BROWN5), blue-green (BS.BLUE-GREEN1), and white (BS.WHITE5) impressed crumbs, black (BLACK1) interior matrix, P.29-104-384;
- \*h. barrel bead, white (BS.WHITE6, BS.WHITE7) glass with purple impressed band, P.29-104-383;
- \*i. barrel bead, white (BS.WHITE8) glass with purple (BS.PURPLE2) impressed bands, P.29-104-383;
- \*j. barrel bead, white (BS.WHITE9) glass with purple (BS.PURPLE3) impressed bands, P.29-104-383;
- \*k. reeds(?) pendant, blue (BS.BLUE3) glazed faience, with attached blue-green glazed faience suspension rings, P.29-104-311;
- \*l. *dd* pendant, blue-green (BS.BLUE-GREEN2) glazed faience, with blue-green (BS.BLUE-GREEN3) suspension ring on each end, P.29-104-194;
- \*m. barrel bead, silvery (BS.SILVER3, BS.SILVER4) glass with white (BS.WHITE10) impressed bands, P.29-104-433;
- \*n. spheroid bead, transparent blue (BS.BLUE4) glass, P.29-104-449;
- \*o. petal or leaf pendant, white glazed faience with yellow (BS.YELLOW3) and gray (BS.GRAY1) overglazes, P.29-10-334;
- \*p. hexagonal ellipsoid bead, Egyptian Blue (BS.BLUE5) frit, P.29-104-648;
- q. luted spheroid bead, Egyptian Blue (BS.BLUE6) frit, P.29-104-653;
- r. disc bead, red (BS.RED1) glazed frit, P.29-104-653;
- \*s. spheroid bead, transparent green (BS.GREEN1) glass, P.29-104-638;
- \*t. cylindrical bead, blue (BS.BLUE7) glass, P.29-104-580;
- \*u. barrel bead, black (BS.BLACK2) glass with white (BS.WHITE11) impressed band, P.29-104-676;
- \*v. cylindrical bead, blue (BS.BLUE8) glass, P.29-104-374;
- w. petal or leaf pendant, blue-green (BS.BLUE-GREEN4) glazed faience, P.29-104-249;
- x. disc bead, red (BS.RED2) glazed frit, P.29-104-566;
- \*y. lenticular cylinder bead, Egyptian Blue (BS.BLUE9) frit, P.29-104-545;
- z. cylindrical bead, blue-green (BS.BLUE-GREEN5) glazed faience, P.29-104-531;
- \*a'. barrel bead, blue (BS.BLUE10) glass, P.29-104-493;
- b'. spheroid bead, gray (BS.GRAY2) glass with brown (BS.BROWN6) and white (BS.WHITE12) impressed crumbs, P.29-104-157;
- c'. cylindrical bead, black (BS.BLACK3) glass with white (BS.WHITE13), blue great (BS.BLUE-GREEN6), and brown (BS.BROWN7) impressed crumbs, P.29-104-543.



**Fig. 3.** Analytical corpus of Beth Shan silicate vessels and pigment cake.

- \*a. vessel body fragment, mottled white glass with yellow (BS.YELLOW4), white, and black (BS.BLACK4) impressed bands, P.29-105-786;
- \*b. rim and neck of pomegranate vessel with six sepals, yellow overglaze on white (BS.WHITE14) glass for sepals, P.29-105-785;
- \*c. rim fragment, white (BS.WHYTE15) glass with yellow (BS.YELLOW5) cane along edge, P.29-105-787;
- \*d. flask, white glass with yellow impressed bands, yellow (BS.YELLOW6), white (BS.WHITE16), and gray vertical impressed bands on handles, and gray (BS.GRAY3) and white toroid rim, P.29-105-785;
- \*e. jar or chalice/goblet, blue-green glazed faience with brown (BS.BROWN8) and blue (BS.BLUE11) overglazes, P.29-105-504;
- \*f. bowl, blue-green (BS.BLUE-GREEN7) glazed faience with brown (BS.BROWN9) overglaze, P.29-105-550;
- \*g. bowl, blue-green (BS.BLUE-GREEN8) glazed faience with black (BS.BLACK5) overglaze, P.29-105-534;
- \*h. pigment cake, Egyptian Blue (BS.BLUE12) frit, P.29-105-862.

and in the case of frits, individual crystals are embedded in an extensively vitrified matrix. The surface particles of the refired frit sometimes had fused to form a glaze. The particle sizes for the various colored frits (50–100 microns in diameter) and the relative fraction of glass were comparable to examples from Nuzi (Vandiver 1982) and in New Kingdom Egyptian Blue specimens (Tite, Freestone, and Bimson, 1983). Despite their physical similarities, frits and glasses, however, were less common in Levels VIII and VII at Beth Shan than other Late Bronze Syro-Palestinian sites.

After the site was converted into an Egyptian military garrison, faience of standard New Kingdom type, which was lower fired than Syro-Palestinian

faiences, became very prevalent; concurrently, the relative percentage of frit and glass declined. Of those specimens studied, the faience had been made by the efflorescence technique (Tite, Bimson, and Cowell 1984) in which salts and other ions migrated to the surface during the drying process and were then fired to a glaze (Vandiver 1983). The diffuse glaze boundaries and minimal sintering of interior silica particles of the Beth Shan examples suggest that the drying process was not very intensive and/or that the firing temperature range was relatively low. Only cupric blue-green and a transparent glaze over a frit body of intermixed hematite and silica were effloresced. Other colors (yellow, white, gray, etc.), which were developed first within

the Syro-Palestinian glass/frit industry, were overlaid as glazes (up to 300 microns thick) onto the effloresced surfaces, probably as liquid slurries, and fired.

A more detailed chemical analysis of the silicate glazes and glasses by proton-induced X-ray emission (PIXE) spectrometry<sup>4</sup> revealed other significant details about their composition and place of manufacture. Those results are only summarized here, since they are published in detail elsewhere, with tables of data (McGovern 1986: 202–42; 1987; 1989b).

Soda appears to have been the primary flux in the small object specimens, since five specimens contain between seven and ten percent of the oxide. The majority of specimens, however, have much lower soda values, most likely the result of leaching. Low potassium oxide values for most of the specimens probably also reflect leaching effects; the Beth Shan small objects overall averaged about 2.8% potassium oxide. Several Beth Shan objects (BS.PURPLE1; BS.BLACK2 [Level IX]; BS.GRAY2), however, retained as much as 6 to 7% of potassium oxide, suggesting that a plant material was used in conjunction with a sodium salt as a flux.

The mean contents of soda (approximately 0.2%) and potassium oxide in the vessel glasses and glazes were less than a quarter of the values for the small objects. The amounts of alkaline earths and alumina of the vessels were also half those of the small objects, which contained about 4% alumina and 4% lime, and 1.5% magnesia, in accord with other published results (Brill 1970; Sayre 1965). The vessels would then appear to have been more subject to weathering, even though they were found in the same archaeological contexts as the beads and pendants.

Heavy metal colorants were even more distinctive of the two Beth Shan corpora (viz., small objects and vessels). Computer clustering of the PIXE data for the oxides of titanium and elements of higher atomic number,<sup>5</sup> which include the colorants and associated minor and trace elements, revealed very distinct groupings of similar-looking colors of vessels and small objects, as follows.

a. Three *blue* colorants could be defined in the small object collection: cobalt aluminate (small objects BS.BLUE1, BS.BLUE2, BS.BLUE8 [Level IX], BS.BLUE10 [Level IX]; vessel BS.BLUE11); cupric ion blue-green/blue (small objects BS.BLUE3, BS.BLUE4, BS.BLUE-GREEN1, BS.BLUE-GREEN2, BS.BLUE-GREEN3, BS.BLUE-

GREEN4, BS.BLUE-GREEN5 [Level IX], BS.BLUE-GREEN6; vessels BS.BLUE-GREEN7, BS.BLUE-GREEN8, BS.BLUE-GREEN9, BS.BLUE-GREEN8); and Egyptian Blue frit (small objects BS.BLUE5, BS.BLUE6, BS.BLUE7 [Level IX], BS.BLUE9 [Level IX]; cake fragment BS.BLUE12), which was composed of crystalline copper calcium silicate.

The cake fragment of Egyptian Blue frit (BS.BLUE12), as might be anticipated for a highly concentrated colorant, contained greater amounts of the oxides of calcium (14.6%), copper (11.0%), and tin (1.9%) than did the Egyptian Blue small objects (averaging 13.4%, 4.3%, and 0.3%, respectively); although only a single sample was analyzed, the cake specimen also appeared to be depleted in trace elements apart from lead (0.025%). Calcium oxide generally exceeded its stoichiometric equivalency (ratio of 0.71:1) with cupric oxide in Egyptian Blue specimens from Late Bronze Palestine (McGovern 1987), indicating that additional lime was added to the frit batch mixture. Possibly, it was also added to the final batch, since the cake fragment was only moderately enriched in lime as compared with that in the small objects.

The small object and vessel blues were chemically more similar to one another than were any other colorants in the corpus. For example, the single example of a vessel cobalt blue (BS.BLUE11) was comparable to two of the small object cobalt blues (BS.BLUE1 and BS.BLUE2). Each of those specimens contained minor amounts of cupric oxide.

Similarly, the cupric blues and blue-greens, whether of small objects or vessels, all contained minor amounts of tin. Additionally, the faience vessel glazes had relatively higher levels of lead oxide. Although a bronze additive as the cupric colorant probably accounts for the tin (and lead), the relative stannic oxide content of some samples suggests that tin was deliberately added to the batch mixture (Kaczmarczyk and Hedges 1983: 88–93; Sayre 1963). Since tin is known to have been transported in ingot form during the Late Bronze Age and added separately to copper (Maddin, Wheeler, and Muhly 1977) the same possibility cannot be excluded for silicates.

b. The color *brown* of Beth Shan small objects and vessels was achieved by manganese in the +3 oxidation state or lead antimonate in the presence of iron. Two manganic browns (BS.BROWN9 and BS.BLACK5) were represented on faience vessels, and they were chemically different from the small

object manganic browns (BS.BROWN2, BS.BROWN3, BS.BROWN4, BS.SILVER1), which were differentiated by their relative amounts of iron. Minor amounts of lead (mean of 0.06%) and tin (0.14%) in the vessel manganic browns were absent from the small object browns.

c. The basic composition of lead antimonate opaque *yellow* or *brown* (the latter when the iron content was elevated) was the same for both collections. On average, the ratio of lead oxide to antimony pentoxide in the small objects was 1.51:1, which was very close to the 1.4:1 stoichiometric ratio. The lead/antimony oxide ratio of the vessels (3.45:1), on the other hand, was 2.5 times that of the stoichiometric ratio, indicating a large excess of lead. Three small objects (BS.YELLOW1, BS.YELLOW3, and BS.BROWN7 [Level IX]) contained excess antimony; minor amounts of manganese, which accentuated the coloration, occurred in one small object (BS.BROWN6) and one vessel (BS.YELLOW4).

Primarily because of differing lead/antimony ratio, the vessel glasses and glazes could be clearly distinguished from those of the small objects.

d. *White* opaque coloration of the small objects was exclusively the result of calcium antimonate (Sayre 1963). Four specimens (BS.WHITE3, BS.WHITE4, BS.WHITE5, BS.WHITE12), had anomalously high amounts of antimony and contained no calcium (perhaps as a result of leaching). The antimony pentoxide to calcium oxide ratio for the remaining nine specimens (BS.WHITE1-2, BS.WHITE6-11, BS.WHYTE13 [Level IX]) was exactly the 1.1:1 stoichiometric ratio. Only one such white (BS.WHITE16) was observed on a vessel, but it had a distinctly lower antimony content (0.43%), somewhat elevated tin and lead content (0.061% and 0.010%, respectively), and no correlation between antimony and trace levels of titanium and iron.

Calcium antimonate also was used as an opacifying agent for other small object colorants, viz., cupric blue-green, manganese brown, and cobalt blue. Antimony pentoxide amounts ranged as high as 8.25% (BS.BLUE7 [Level IX]), and averaged 2.0%. Only one of the vessel colorants, a black (BS.BLACK4), had been opacified with 0.10% antimony.

e. Two of the whites on the vessels (BS.WHITE14 and BS.WHITE15) totally differed from the small object calcium antimonate whites in that the white was the result of a *depletion of all heavy metals* and devitrification of the silica matrix (the glass was probably originally transparent).

Very pure sand and other raw materials must have been exploited or prepared to prevent contaminants, such as iron, from entering batch mixtures.

A *gray* colorant on a vessel (BS.GRAY3) and three small object *blacks* (BS.BLACK1, BS.BLACK2 [Level IX], BS.BLACK3 [Level IX]) were comparable in that they all lacked any heavy metal colorant. Their coloration was possibly due to elemental carbon (not detected by PIXE), as suggested by the elevated levels of elements often associated with organic materials—potassium and/or strontium. An iron-sulfur (ferri-sulfide) complex (Sayre and Smith 1974; Brill 1988), although an extremely intense colorant, is less probable as the colorant here, since iron and sulfur were present in only trace amounts. One small object specimen (BS.BLACK2 [Level IX]) had an elevated manganese level, which would have contributed to a darker color.

f. A *black* colorant (BS.BLACK4) on one vessel was achieved by a combination of elevated levels of copper (0.130%), manganese (2.41%), and cobalt (0.118%) as ions in +2, +3, and +2 oxidation states, respectively. The purple (BS.PURPLE1) and gray (BS.GRAY1) glazes on two pendants were similar in composition, but had higher mean oxide levels of cobalt (0.21%) and reduced oxide amounts of manganese (0.18%) and copper (0.08%). Two additional small objects (BS.BROWN1 and BS.GRAY2) were high in manganese and copper, but lacked cobalt.

g. Several colorants were unique in the small object collection: a transparent glaze over a *red* hematite frit body (BS.RED1 and BS.RED2 [Level IX]), and a silver colloid producing a *silvery* color (BS.SILVER2, BS.SILVER3, and BS.SILVER4) or a *purple* when a small amount of additional cobalt (BS.PURPLE2 and BS.PURPLE3) was present. The silver content of the silver colloidal colorants, which were dispersed as particles (up to a micron in diameter) in the vitreous matrix, was as high as 0.77%. The silver correlated most closely with titanium and manganese as trace elements ( $R = 0.65$ ). No example of cuprous red was recorded.

#### *Implications of the Beth Shan Silicate Evidence*

The minor elements associated with the colorants of the Egyptian-style and Palestinian small objects (beads and pendants) were different from those of the vessels, which were exclusively Egyptian in style. The minor elements (specifically, lead and tin associated with calcium antimonate white, cupric blue-green, and manganese-iron brown, and

copper associated with cobalt blue) that were more prevalent in the vessel colorants are also characteristic of vessel glazes and glasses on vessels definitely made in New Kingdom Egypt (Kaczmarczyk and Hedges 1983: 43, 84–88, 110–12). One “colorant,” a white resulting from the depletion of all heavy metals and probable devitrification of the matrix, occurred only for vessels. Transparent faience glazes (Kaczmarczyk and Hedges 1983: 145–46) and glasses are also documented in Egypt for the same time. Although as yet unattested in New Kingdom, the absence of a silver colloid colorant there, as well as in the Beth Shan vessel collection, may be due to limited sampling.

Since a very large, representative collection of small objects from Levels VIII and VII was analyzed, it is difficult to account for the consistent differences between the chemical profiles of most of the main colorants of the small objects and the vessels. It also is difficult to explain the absence of depleted white/transparent glasses and glazes among the small objects, unless the latter, even those of Egyptian style, had been made locally. Correspondingly, the faience and core-formed glass vessels, which would have demanded much more technical expertise to manufacture, were most likely made in Egypt and exported to Beth Shan. This chemical inference is further supported by a paucity of such vessels in Palestine, the absence of an industrial installation (such as at el-Amarna, below) or manufacturing debris in Levels VIII and VII, and their Egyptian stylistic affinities.

Local production of Egyptian-style faience small artifacts, especially beads and pendants, would have been facilitated by an already-established Palestinian glass industry. Some Egyptian craftsmen, however, also must have been present, to account for the close stylistic and technical characteristics of the Egyptian-style beads and pendants from Levels VIII and VII to those of New Kingdom Egypt. Silicate manufacture at Beth Shan also can be inferred from pieces of misshapen and overfired refuse glass and faience, a cake fragment and other pieces of Egyptian Blue frit colorant, and a mold for a fluted bead or inlay. Except for the several metal colorants (e.g., cobalt blue, below), which were probably imported, the necessary raw materials for silicate production were widely available in Palestine.

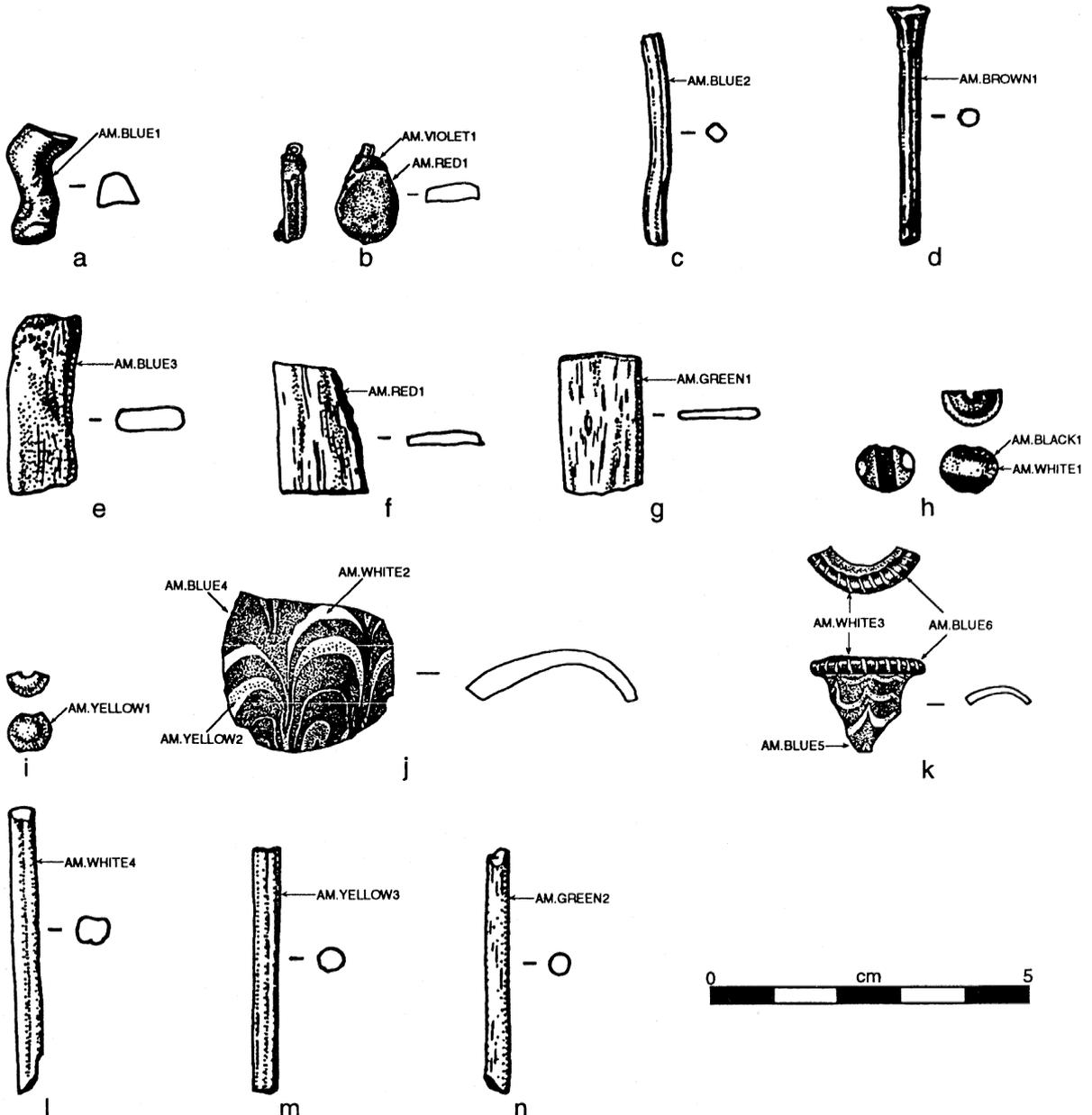
The large increase in the percentage of faience in Levels VIII and VII also points to considerable Egyptian influence in the silicate industry. Syro-Palestinian overglazes onto effloresced, low-fired faience surfaces may be an instance of technologi-

cal coalescence, although the same technique was already being practiced a century earlier in Egypt.

#### NEW KINGDOM EGYPT: ARTIFACTS AND ANALYSIS

Any assessment of the interactions between the Egyptian and Palestinian silicate industries—including the provenancing of raw materials, determination of place(s) of manufacture, etc.—demands detailed, published scientific studies for late New Kingdom Egyptian silicate artifacts. Several relevant studies have been cited (above); but to have as comparable a data set as possible, a pilot PIXE study of glass, faience, and frit artifacts from the Egyptian collection of the University Museum was carried out. Two late New Kingdom Egyptian sites, Thebes and Tell el-Yahudiyeh, were investigated. Those sites are known to have had workshops in operation during this period. A tightly held Egyptian colony in Sinai (Serabit el-Khadem), where the Egyptians had long mined turquoise and probably locally manufactured silicate materials, was also investigated (figs. 1, 8, 9). Although well-dated and well-provenanced, the University Museum collection did not include any glass artifacts from those sites. The deficiency was partly alleviated by analyzing a group of glass vessel fragments and manufacturing debris, together with two faience pendants, from el-Amarna (fig. 4). Despite not being strictly contemporaneous, architectural affiliations between el-Amarna and Beth Shan have already been noted. Approximately one-half to two-thirds of the numerous faience pendant types at Amarna, many appearing here for the first time, are later represented at Beth Shan (McGovern 1985; James and McGovern 1993). It was also possible that some of the artifacts found in the hoard under the Beth Shan stairway were heirlooms that could have been made a century earlier at el-Amarna and then imported to Palestine. Amarna, as one of the few glass workshops ever excavated in the ancient Near East, also provides an important reference point for earlier and later developments in silicate production throughout the area. Numerous craftsmen from all over Egypt and abroad appear to have taken up residence at the site.

A conservative tendency in the use of Syro-Palestinian materials and colorants has been noted in the New Kingdom industry of Egypt itself (Peltenberg 1974: 107–43; Vandiver 1983). Yet, our investigation of a limited range of artifact types and materials implies that considerable expertise, often involving improvisation, existed there.



**Fig. 4.** Analytical corpus of el-Amarna silicate small objects, vessels, and manufacturing debris.

- a. cattle leg pendant, light blue (AM.BLUE1) glazed faience, P.E791;
- b. poppy petal pendant, red (AM.RED1) and violet (AM.VIOLET1) glazed faience with attached blue-green glazed faience suspension ring, P.E793;
- c. rod, dark blue (AM.BLUE2) glass, P.E843a;
- d. rod, brown (AM.BROWN1) glass, P.E843b;
- e. strip, light blue (AM.BLUE3) glass, P.E844b;
- f. strip, red (AM.RED2) glass, P.E844d;
- g. strip, green (AM.GREEN1) glass, P.E844i;
- h. bead, black (AM.BLACK1) and white (AM.WHITE1) glass, P.E845a;
- i. bead, yellow (AM.YELLOW1) glass;
- j. vessel body fragment, dark blue glass (AM.BLUE4) with light blue, yellow (AM.YELLOW2), and white (AM.WHITE2) impressed bands, P.E860a;
- k. vessel rim, light blue (AM.BLUE5) glass with dark blue (AM.BLUE6) and white (AM.WHITE3) toroid rim and yellow and white impressed bands, P.E860b;
- l. rod, white (AM.WHITE4) glass, P.E1008c;
- m. rod, yellow (AM.YELLOW3) glass, P.E1008e;
- n. rod, green (AM.GREEN2) transparent glass, P.E1008g.

### 18th Dynasty Egypt: *el-Amarna*

The middle-Nile site of el-Amarna, which was constructed *de novo* by the pharaoh Akhenaten (1352–1336 B.C.E.) as his capital city, yielded one of the few glassmaking installations yet excavated in the ancient Near East (Petrie 1894). In his monotheistic adherence to the sun disk (Aten), Akhenaten was considered heretical by the kings who followed him. That proved to be a boon for the archaeologist, since the site was soon abandoned (during the reign of Tutankhamun), and the several glass factories can therefore be very precisely dated to the mid-14th century B.C.E.

The glass workshops, located east and south of the great temple to Aten, had been destroyed, but the layout of the industry could be reconstructed from the debris. Fritting pans, shallow bowls for melting glasses and preparing colorants, had evidently been placed on upside-down cylindrical jars in the furnace. In some cases, the molten glass had flowed over the rim of the pans onto the jars. No furnace was found in the vicinity of the debris, but Petrie reported a well-preserved furnace closeby, with doors on its northern and southern sides. Such a double-door arrangement would have been well-suited to a glass/frit furnace, since the prevailing northerly winds would have helped to fire the furnace and to blow noxious fumes southward, away from the main part of the city. A layer of white quartz pebbles in the area of the factories evidenced the stockpiling of the most important raw material in glassmaking, silica.

The stages in the production process could be reconstructed from a variety of rolled glass rods, flattened glass strips, and ingot fragments of single colored glass, together with clay molds. Intriguingly, flat, circular ingots of a single color could not have been made in any of the fritting pans that were found, since they were of a different diameter and thicker than the maximum depth of the pans. They may represent imported colorant cakes, like those recorded at contemporaneous sites throughout the Eastern Mediterranean (Saleh et al. 1974; McGovern 1989b: n. 17). Once a proper glass or frit had been prepared in the pan, it was broken up, remelted, and flattened into strips or rods that were rolled out in a diagonal fashion, as shown by surface marks. The rods could then be drawn out to form a “cane”; the drawing-out process is substantiated by the direction and elongation of interior bubbles or striae.

The glass was formed into inlays, beads, and pendants using clay molds. The mold types were easily replicated by pressing finished artifacts into

wads of clay and baking them in the sun. Consequently, a remarkable range of motifs—Egyptian hieroglyphs, animals, floral elements, fruits, deities, etc.—were mass-produced and incorporated into tilework, jewelry, and other decorative items. Beads of simple geometric shapes (spheroids, discs, cylinders, etc.) were also made by winding threads of glass onto metal wires, which were extracted upon cooling, and variously flattening and cutting up the coiled products. The coiling process almost always left a “tail” at one end of the bead. Imperfectly formed and discarded beads were also found, some with copper wires still in place.

Truly *tour de force* glassmaking is exhibited by the many variegated colored glass vessels from the city proper, fragments of which were found in the workshops. As determined from analyses and replication experiments, the body of the vessel was probably formed over a clay-dung core (Wosinski and Brill 1968). The details of rim and base were worked by hand. Multicolored designs were achieved by the manipulation of rods, canes, and smaller elements, e.g., by dragging viscous threads of glass up and down across the surface (to produce wavy, ogee, and spiral designs), probably with a metal tool, or by winding rods or canes spirally around one another. Handles were separately attached. The friable clay-dung core could be removed easily after cooling.

The samples selected for analysis from the University Museum collection represented a range of manufacturing debris and artifacts (fig. 4) according to color (*viz.*, light and dark blue, green, yellow, brown, violet, black, white, and red) and material (glass and faience glaze). Altogether, 14 objects were analyzed. Except for black and possibly purple (note, however, that a violet is included in this study), the full range of colorants from the workshops, as described by Petrie, is represented.

A distinction must first be made between the glass and faience industries at el-Amarna. As shown in fig. 5, the faience glaze colorants (AM.BLUE1, AM.RED1, and AM.VIOLET1), although few in number, are chemically more similar to one another than they are to any of the glass colorants. This is so even though the principal colorant (*viz.*, cuprous/cupric ion) in two of the glazes (AM.RED1 and AM.BLUE1) is the same as in three of the glasses (AM.RED2, AM.BLUE3, and AM.BLUE5) and this colorant differs from the violet faience glaze in not being combined with manganese and cobalt (Table 1). Moreover, none of the cuprous/cupric faience glazes are opacified with calcium antimonate, whereas two of the glass examples are. Even though

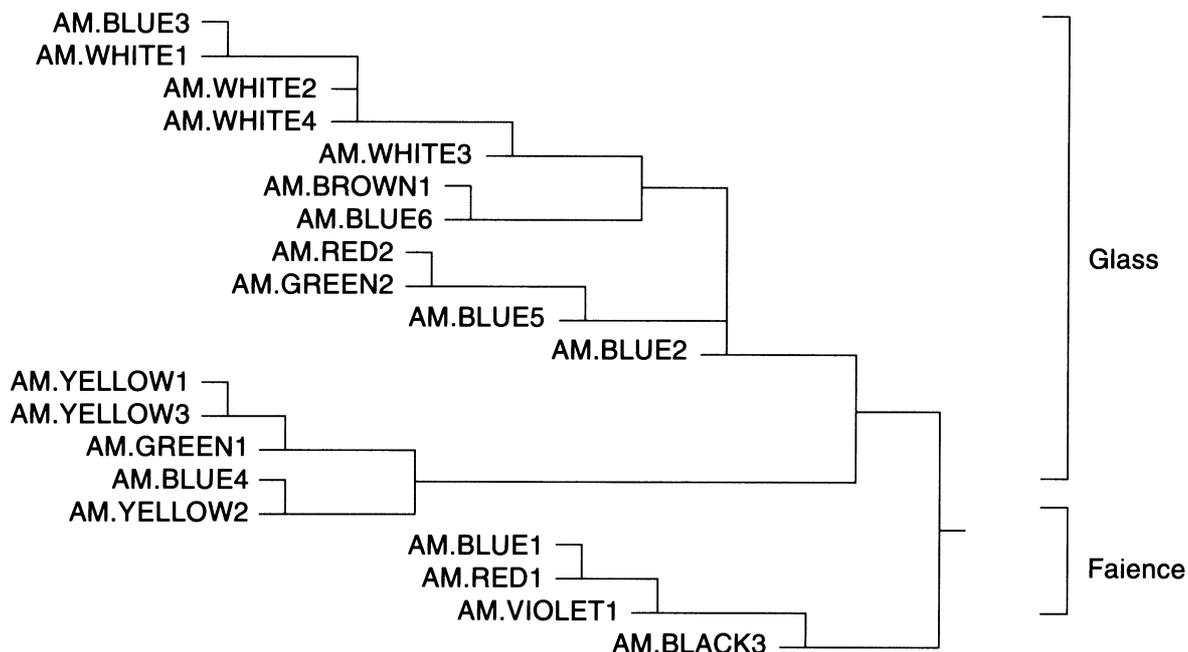


Fig. 5. El-Amarna: Dendrogram of glass and glaze colorants.

Petrie reported no faience workshops at el-Amarna, this chemical evidence and the large number of excavated clay molds and faience artifacts corresponding to the molds, imply that such installations must also have been in operation at the site.

The divergent colorant compositions of the faience glazes and glasses can be partly accounted for by different batch recipes. To eliminate the effects of colorant, opacifier, and other additives, the major and minor oxides of a vitreous material ( $\text{Na}_2\text{O}$ ,  $\text{CaO}$ ,  $\text{K}_2\text{O}$ ,  $\text{MgO}$ ,  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$ ) can be normalized to give a total of 100% for the selected oxides (Brill 1987).<sup>6</sup> When this calculation is carried out for the el-Amarna samples, the glasses are observed to have significantly higher amounts of lime (10.1% vs. 2.47%), soda (12.4% vs. 1.15%), and potassium oxide (2.51% vs. 0.65%) than the faience glazes (Table 2). Since a primary difference between faience and glass is that a faience body has a lower alkali content, lower levels of soda and potassium in a faience glaze are not unexpected.

The much higher lime content of the glasses<sup>7</sup> is more difficult to explain. It not only exceeds the lime content of the faience glazes, most likely made at el-Amarna, but it is approximately twice that of later New Kingdom and Late Bronze glasses from other Egyptian and Eastern Mediterranean sites, including Beth Shan (Sayre 1963; Brill 1970; McGovern 1987; James and McGovern 1993). The prevalence of calcium antimonate

white in the group, which also served as an opacifier in a number of samples (below), certainly would accentuate any difference. It is also possible that lime was either intentionally added to el-Amarna glass batch mixtures as a stabilizer or that one or more of the raw materials used in making glass were richer in lime.

The distinctiveness of the el-Amarna glasses vis-à-vis the glazes is further highlighted by a closer examination of the chemical compositions of the colorants. Figure 5 reveals excellent segregation of similar-looking colors of glass vessels, small objects, and manufacturing debris. Evidently, the newly established royal industry at el-Amarna set high quality controls. One exception was the presence of lead antimonate in a cobalt blue sample (AM.BLUE4); that element apparently was accidentally added to the batch mixture.

The following el-Amarna glass colorants were recorded:

- Lead antimonate opaque yellow: AM. YELLOW1-3
- Calcium antimonate opaque white: AM. WHITE1-4
- Cobalt dark blue: AM.BLUE2, 4, and 6
- Cupric transparent green: AM.GREEN2
- Cupric light blue: AM.BLUE3 and 5
- Cuprous opaque red: AM.RED2
- Combined lead antimonate yellow and cupric opaque green: AM.GREEN1
- Combined manganese-copper black: AM. BLACK1
- Transparent brown (AM.BROWN1)

TABLE 1. Constituents of el-Amarna Glasses and Faience Glazes

Color reference*	Batch Constituents							Minor Constituents							Minor and Trace Elements						
	Oxide Content (% by weight)							Oxide Content (% by weight)							Oxide Content (parts per million, by weight)						
	SiO <sub>2</sub>	Na <sub>2</sub> O	CaO	K <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	MgO	Fe <sub>2</sub> O <sub>3</sub>	Color reference	PbO	Sb <sub>2</sub> O <sub>5</sub>	CuO	SO <sub>3</sub>	Color reference	TiO <sub>2</sub>	MnO	CoO	As <sub>2</sub> O <sub>3</sub>	SrO	SnO		
<i>Faience glazes</i>								<i>Faience glazes</i>					<i>Faience glazes</i>								
AM.BLUE1	80.8	1.17	1.03	0.64	0.81	1.02	0.18	AM.BLUE1	0.040	≤0.019	10.5	1.15	AM.BLUE1	835	525	225	125	140	585		
AM.RED1	83.2	1.06	2.23	0.82	1.82	0.79	4.12	AM.RED1	0.036	0.036	3.05	0.60	AM.RED1	390	≤155	805	1550	715	≤255		
AM.VIOLET1	76.4	0.81	3.26	0.26	1.70	0.93	0.80	AM.VIOLET1	0.138	0.080	10.8	0.69	AM.VIOLET1	1130	1790	6350	33	590	2530		
<i>Glasses</i>								<i>Glasses</i>					<i>Glasses</i>								
AM.BLUE2	54.0	14.3	10.8	0.56	2.72	4.20	1.01	AM.BLUE2	0.012	3.92	2.53	0.31	AM.BLUE2	1235	2265	11570	66	4680	3980		
AM.BROWN1	61.8	15.6	10.1	2.38	0.70	4.49	0.49	AM.BROWN1	0.036	0.11	0.154	0.84	AM.BROWN1	690	265	≤360	45	7140	≤770		
AM.BLUE3	57.2	12.8	10.0	3.76	0.68	2.99	0.43	AM.BLUE3	0.043	6.95	1.91	0.63	AM.BLUE3	535	265	320	885	5800	2345		
AM.RED2	55.4	10.4	7.7	2.33	0.70	3.32	0.90	AM.RED2	0.0070	1.38	15.2	0.49	AM.RED2	455	230	955	280	4160	5240		
AM.GREEN1	56.0	9.5	12.1	2.50	1.11	3.43	0.56	AM.GREEN1	2.67	6.36	0.176	0.95	AM.GREEN1	555	570	≤245	350	3660	2130		
AM.BLACK1	56.5	13.4	11.5	1.96	0.78	4.62	0.42	AM.BLACK1	0.016	0.078	5.84	0.41	AM.BLACK1	490	20880	≤290	105	6510	6950		
AM.WHITE1	56.4	11.4	12.5	1.88	0.88	4.67	0.42	AM.WHITE1	0.025	8.76	0.81	0.46	AM.WHITE1	565	295	≤235	815	5690	1295		
AM.YELLOW1	51.1	10.6	6.06	2.72	0.89	2.75	0.80	AM.YELLOW1	17.6	3.73	0.223	0.76	AM.YELLOW1	450	290	≤360	1180	4840	3515		
AM.BLUE4	62.9	11.0	8.26	1.08	1.61	2.26	0.92	AM.BLUE4	2.82	3.45	0.459	1.28	AM.BLUE4	705	3070	3185	430	3705	≤1265		
AM.YELLOW2	66.5	2.5	6.67	1.73	2.33	4.23	1.17	AM.YELLOW2	5.59	4.29	0.355	0.10	AM.YELLOW2	810	1735	1180	615	4000	3770		
AM.WHITE2	56.5	9.1	7.52	2.71	0.44	2.07	0.35	AM.WHITE2	0.037	17.6	0.212	0.53	AM.WHITE2	415	260	≤95	≤46	3600	≤1210		
AM.BLUE5	77.6	4.2	4.42	2.95	1.10	3.83	0.37	AM.BLUE5	0.0014	0.25	2.75	0.27	AM.BLUE5	≤115	210	≤90	≤24	1110	≤790		
AM.BLUE6	67.5	11.8	7.90	1.56	1.72	3.93	0.58	AM.BLUE6	0.036	0.73	0.218	0.57	AM.BLUE6	410	1840	3095	≤39	2470	≤685		
AM.WHITE3	62.2	8.7	7.35	1.93	0.54	2.96	0.30	AM.WHITE3	0.032	13.0	0.115	0.48	AM.WHITE3	≤225	185	≤75	≤36	2795	≤810		
AM.WHITE4	49.2	10.3	6.68	3.14	0.51	3.38	0.45	AM.WHITE4	0.108	24.1	0.334	0.37	AM.WHITE4	1120	265	≤505	1915	3390	2470		
AM.YELLOW3	56.1	10.8	9.03	1.71	0.85	3.27	0.76	AM.YELLOW3	8.85	2.54	0.179	2.63	AM.YELLOW3	860	245	≤485	680	3700	1370		
AM.GREEN2	62.5	15.2	9.69	1.82	0.90	4.01	0.58	AM.GREEN2	0.0056	0.25	2.09	0.37	AM.GREEN2	585	280	≤435	≤50	6705	≤1940		

\* The caption of fig. 4 provides descriptions and museum registration numbers.

TABLE 2. Normalized Batch Recipes\*

	<i>Amarna Faience Glazes</i> (n=3)	<i>Amarna Glasses</i> (n=17)	<i>Beth Shan Sm. Obj. Faience Glazes</i> (n=7)	<i>Besh Shan Vessel Faience Glazes</i> (n=5)	<i>Beth Shan Sm. Obj. Glasses</i> (n=36)	<i>Beth Shan Vessel Glasses</i> (n=8)
SiO <sub>2</sub>	91.2	68.9	93.0	92.1	85.2	89.3
Na <sub>2</sub> O	1.15	12.4	0.29	0.83	1.55	0
CaO	2.47	10.1	1.78	2.50	3.75	5.22
K <sub>2</sub> O	0.65	2.51	1.63	1.03	3.32	1.76
MgO	1.04	4.12	0.74	0.81	1.54	0.65
Al <sub>2</sub> O <sub>2</sub>	1.64	1.26	2.04	1.11	3.51	2.12
Fe <sub>2</sub> O <sub>3</sub>	1.93	0.72	0.54	1.59	1.14	0.96
	<i>Thebes Faience Glazes</i> (n=9)	<i>Tell el-Yahudiyeh Faience Glazes</i> (n=12)		<i>Serabit el-Khadem Faience Glazes</i> (n=3)		
SiO <sub>2</sub>	91.7	92.2		95.1		
Na <sub>2</sub> O	3.15	1.66		1.94		
CaO	1.66	2.82		1.55		
K <sub>2</sub> O	0.29	0.16		0.17		
MgO	2.08	1.52		0.56		
Al <sub>2</sub> O <sub>3</sub>	0.93	1.31		0.33		
Fe <sub>2</sub> O <sub>3</sub>	0.25	0.54		0.36		

\*The calculations exclude samples containing excess alumina or iron as a result of colorants added to the batch mixture, including cobalt blue glass (four examples from Beth Shan and three examples from el-Amarna), cobalt blue faience overglaze (on a Beth Shan vessel), cobalt-colored grayish blue faience glazes (two Theban examples), cuprous red glazes with admixture of cobalt (two Theban examples), hematite red frit overglazes (two examples each from Beth Shan and Thebes and one from el-Amarna), and manganese-iron brown/black overglazes (three examples from Serabit el-Khadem and two examples, associated with cobalt, from Tell el-Yahudiyeh).

Sm. Obj. = Small Object

The last is most likely due to ferrisulfide, a very intense colorant (Sayre and Smith 1974; Brill 1988). The iron and sulfur levels of AM.BROWN1, however, are respectively below and only slightly above the el-Amarna glass averages (cf. Tables 1, 2).

Several colorants are found in el-Amarna samples, but not in the Beth Shan group, and they immediately distinguish each group. To date, no examples of a cupric light blue or green, cuprous opaque red, or combined lead antimonate yellow and cupric opaque green have been confirmed for Beth Shan. Yet, all of those colorants are very characteristic of the New Kingdom glass industry (Kühne 1969; Kaczmarczyk and Hedges 1983: 148). Egyptian craftsmen were very proficient in manipulating the sodium/potassium oxide ratio and sometimes concentrations of specific metals (e.g., lead) in the batch recipe, to achieve a range of colors between light blue and green.

One glaze colorant at el-Amarna is violet (AM.VIOLET1), with the exact coloration dependent on the relative amounts of copper (10.8%), manganese (0.179%), and cobalt (0.635%) in this instance. Although such dark colors, made by combining the elements, are not uncommon in Egypt (Kaczmarczyk and Hedges 1983: 32–34) and are even the predominant means of coloration in some areas of Palestine (McGovern 1986),<sup>8</sup> only a single example of the colorant on a vessel has thus far been attested at Beth Shan.

On the other hand, some Beth Shan colorants (e.g., silver colloid, hematite red frit with a transparent glaze) appear to be less prevalent or nonexistent at el-Amarna.

Even a colorant like lead antimonate opaque yellow, which is common to both sites, shows such marked minor and trace element differences that one must conclude that different raw materials

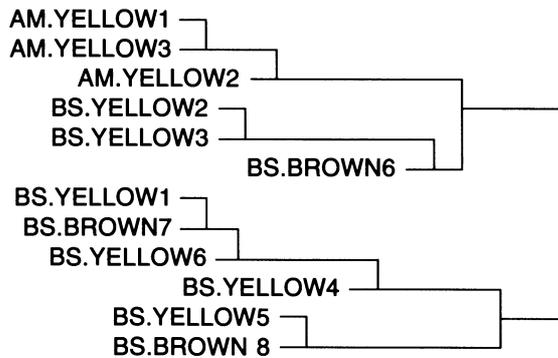


Fig. 6. Beth Shan and el-Amarna: Dendrogram of lead antimonate yellows and browns.

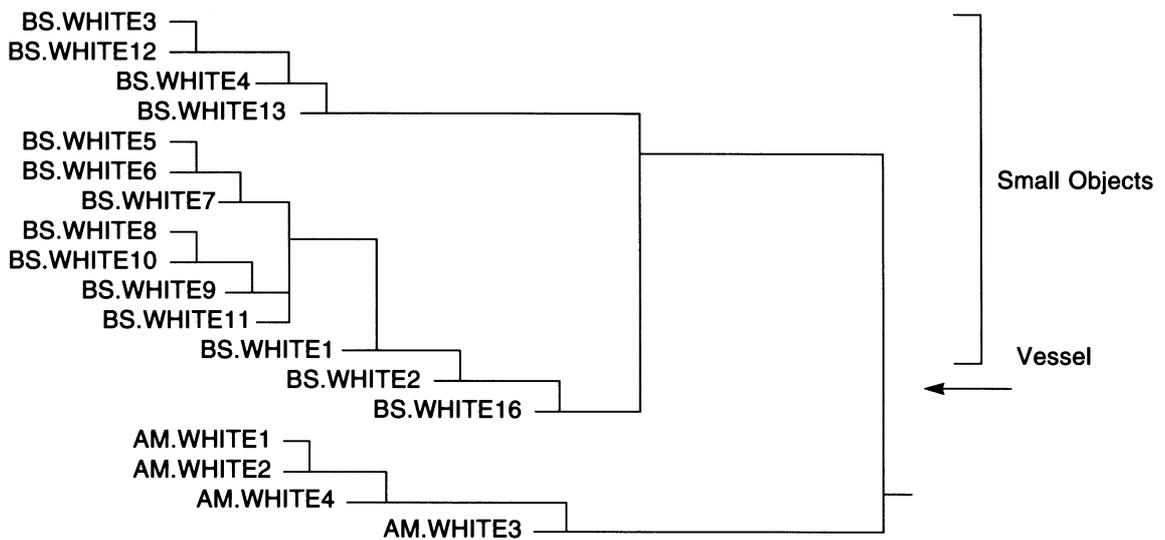
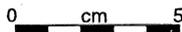
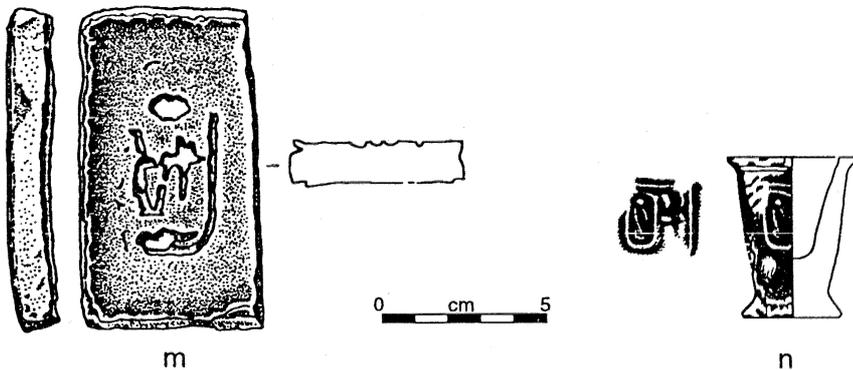
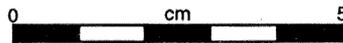
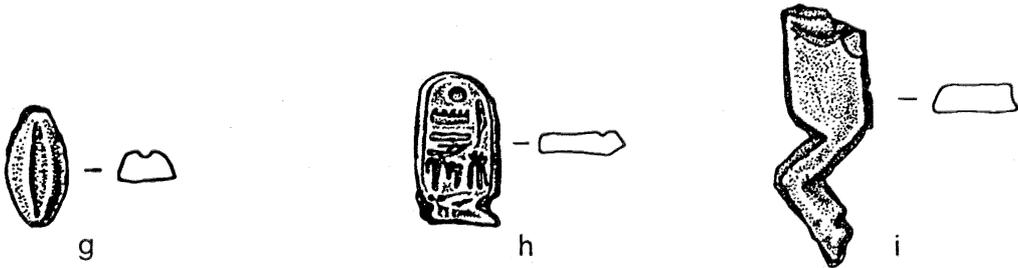
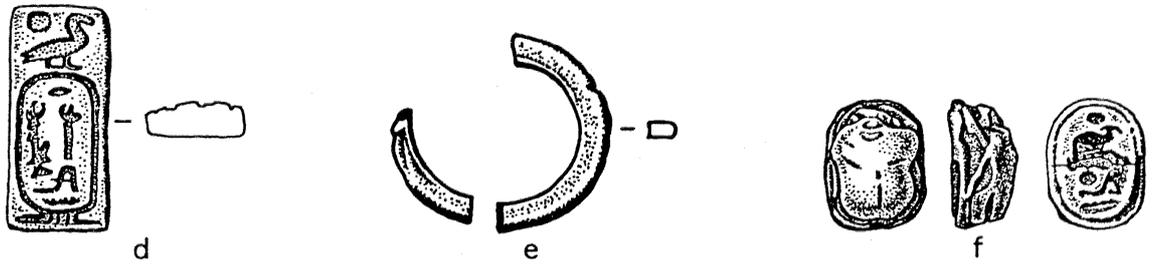
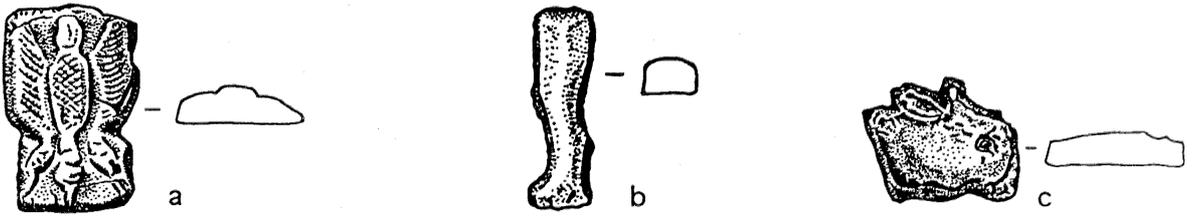


Fig. 7. Beth Shan and el-Amarna: Dendrogram of calcium antimonate whites.

were used or that different recipes were followed. The ratio of lead oxide to antimony pentoxide in the el-Amarna glasses is 3.04:1, which exceeds the 1.4:1 stoichiometric ratio. This is closer to the ratio of the Beth Shan vessels (3.45:1) than to that of the small object glazes and glasses at Beth Shan (1.51:1). If the mean Euclidean distances of seven additional heavy metals are included in calculating the chemical relationships of the Beth Shan and el-Amarna yellows (see fig. 6), the excellent separation between the colorants by site supports the hypothesis of different manufacturing origins. Several minor and trace elements (in particular, copper, tin, arsenic, and strontium [which often covaries with calcium]) in elevated amounts in the Amarna glass group as a whole contribute to the segregation of the groups.

Statistical evaluation of the calcium antimonate opaque whites from the two sites reveals a similarly distinct separation by site and object type (fig. 7). Again, the Beth Shan small object whites, a single Beth Shan vessel white (BS.WHITE16), and a group of el-Amarna white glasses (vessels and manufacturing debris) are distinguished by their minor and trace element profiles. The antimony pentoxide to calcium oxide ratio (1.94:1) for the el-Amarna group, however, exceeds the 1.1:1 stoichiometric ratio. The average antimony pentoxide content of six nonwhite, nonyellow samples (AM.BLUE2-6; AM.RED2), which were opacified with calcium antimonate, is 2.78%. That compares well with the amounts of antimony pentoxide in opacified samples of other Egyptian and Near Eastern glasses of New Kingdom date.



Chemical discrimination between the cupric blues/blue-greens and cobalt colorants at the two sites is not as clearcut. Elevated levels of tin and other associated trace elements deriving from bronze refuse used as a copper colorant most likely account for the comparability of many of the cupric blue and blue-green glasses and glazes. Since at least one el-Amarna sample (AM.WHITE4) has a high tin oxide value (0.247%) that cannot be explained by the presence of copper, the intentional addition of tin, as at Beth Shan, is again a possibility.

With the confirmation of cobalt blue ingots aboard a 14th century B.C.E. merchant ship off the coast of southern Turkey (R. H. Brill, personal communication, 1989; see also Bass et al. 1986: 9), the likelihood of a common ore source for Eastern Mediterranean cobalt blue glasses has been strengthened. Alums high in cobalt exist in the oases of the Western Desert of Egypt (Kaczmarczyk 1986). Yet, the elevated level of manganese in this alum does not accord with a relatively low correlation ( $r = 0.45$ ) between it and cobalt in the Beth Shan artifacts (BS.BLUE1, BS.BLUE2, BS.BLUE8 [Level IX], BS.BLUE11), nor with an inconsistent correlation between the two elements in the el-Amarna artifacts (AM.BLUE2, 4, 6). Increasing sample sizes, experimentation in processing the cobalt alum, and chemical analysis of the glass ingots may help to explain this apparent anomaly. Given the close economic and political ties between Egypt and Beth Shan, an Egyptian cobalt source would make good sense. The only other known Near Eastern source of cobalt is in Iran, but ores here are high in arsenic (Garner 1956a; 1956b).

***19th and 20th Dynasty Egypt and the Sinai: Thebes, Tell el-Yahudiyeh, and Serabit el-Khadem***

The technological and stylistic transformation that the Egyptian silicate industry underwent in the early New Kingdom carried through into the 19th and early 20th Dynasties, approximately 1300–1150 B.C.E. Thereafter, Egyptian political and economic fortunes declined, which is reflected in a wholesale return to the blue/green glazes and rigid, formalized styles. Before the “Dark Age” set in, however, “local idioms” of colorants had already developed at Egyptian sites other than el-Amarna, where local silicate industries are also attested archaeologically.

Thebes, the paramount city of the early 18th Dynasty, appears to have had factories in operation by the reign of Amenhotep III, father of Akhenaten. These operations probably continued into the later New Kingdom (Keller 1983). Well-dated groups of faience jewelry (Quibell 1898: 6, pl. 15; Petrie 1897: 14, pls. 16, 18; Weinstein 1973) from the foundation deposits of the mortuary temples of Ramesses II (1279–1213 B.C.E.), Siptah (1194–1188 B.C.E.), and Tewosret (1188–1186 B.C.E.), rulers of the 19th Dynasty, were analyzed (fig. 8). We also examined a group of multicolored rosette tiles (Griffith 1890: 40–41) from a palace of Ramesses III (ca. 1184–1153 B.C.E.), a 20th Dynasty pharaoh, at Tell el-Yahudiyeh in the Delta, and three blue-green glazed faience artifacts (Petrie 1906: 141–45, 151, pls. 147, 156) from the Serabit el-Khadem in the Sinai. The latter were inscribed with the cartouches of two 19th Dynasty pharaohs (Ramesses II and Tewosret) in black overglazes (fig. 9).

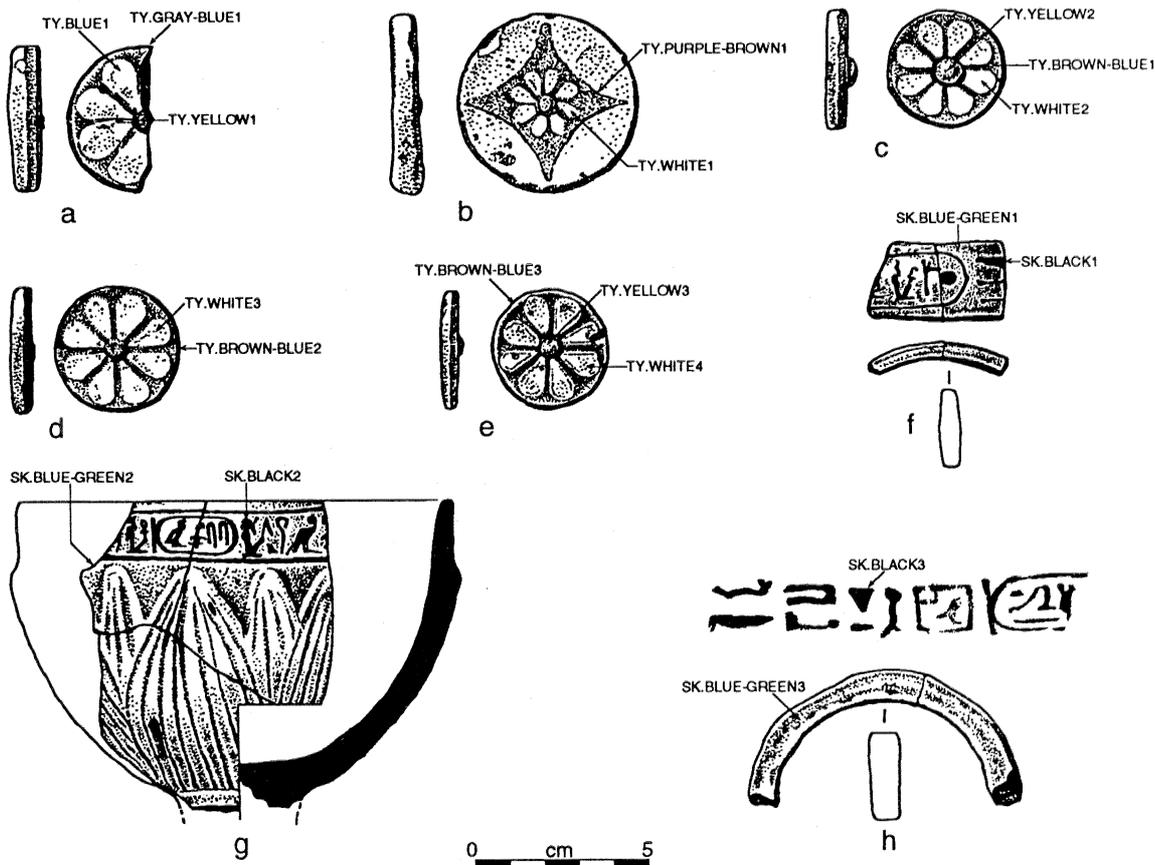
**Fig. 8.** Analytical corpus of Theban silicate small objects.

*Temple of Tewosret and Siptah:*

- a. trussed duck model, transparent glaze (TH.WHITE1) over white faience body, P.E2118A;
- b. cattle leg model, light blue (TH.BLUE1) glazed faience, P.E2122C;
- c. cattle head model, grayish blue (TH.GRAY-BLUE1) glazed faience, P.E2123A;
- d. Tewosret cartouche plaque, transparent glaze (TH.WHITE2) over white faience body, P.E2126D;
- e. ring, blue-green (TH.BLUE-GREEN1) glazed faience, P.E2134;
- f. scarab with Siptah cartouche, blue-green (TH.BLUE-GREEN2) glazed faience, P.E2137A;

*Ramesseum:*

- g. grain model, light blue (TH.BLUE2) glazed faience, P.E2003A;
- h. Ramesses II cartouche plaque, red (TH.RED1) glazed frit, P.E2006C;
- i. cattle leg model, red (TH.RED2) glazed frit, P.E2007B;
- j. trussed cattle model, light blue (TH.BLUE3) glazed faience, P.E2008B;
- k. cattle head model, grayish blue (TH.GRAY-BLUE2) glazed faience, P.E2011E;
- l. hand model, transparent glaze (TH.WHITE3) over white faience body, P.E2012F;
- m. tile with Ramesses II cartouche, dark blue (TH.BLUE4) glazed faience with inlaid white faience, P.E2010B;
- n. miniature wooden goblet, covered with Egyptian Blue (TH.BLUE5) frit on interior and exterior, Ramesses II prenomen and nomen cartouches in white paint on exterior, P.E2012.



**Fig. 9.** Analytical corpus of Tell el-Yahudiyeh and Serabit el-Khadem silicate small objects and vessels.

*Tell el-Yahudiyeh:*

- a. wall plaque, rosette design of light blue (TY.BLUE1) glazed faience with grayish blue (TY.GRAY-BLUE1) glazed faience inlaid background and yellow (TY.YELLOW1) overglaze for stamen, P.E132d;
- b. wall plaque, rosette design of white (\*WHITE1) glazed faience with purplish brown (TY.PURPLE-BROWN1) overglaze for concave-sided square background and stamen, P.E3317;
- c. wall plaque, rosette design of white (TY.WHITE2) glazed faience with brownish blue (TY.BROWN-BLUE1) inlaid background and yellow (TY.YELLOW2) overglaze for stamen, P.E3323;
- d. wall plaque, rosette design of white (TY.WHITE3) glazed faience with brownish blue (TY.BROWN-BLUE2) inlaid background and yellow overglaze for stamen, P.E3332;
- e. wall plaque, rosette design of white (TY.WHITE4) glazed faience with brownish blue (TY.BROWN-BLUE3) inlaid background and yellow (TY.YELLOW3) overglaze for stamen, P.E3333;

*Serabit el-Khadem:*

- f. bracelet with Ramesses II cartouche, blue-green (SK.BLUE-GREEN1) glazed faience with cartouche in black (SK.BLACK1) overglaze, P.E12111;
- g. lotus cup with incised, relief petal/sepal design on exterior and Ramesses II dedication around exterior rim, blue-green (SK.BLUE-GREEN2) glazed faience with hieroglyphics in black (SK.BLACK2) overglaze, P.E12114;
- h. bracelet with Tawosret cartouche, blue-green (SK.BLUE-GREEN3) glazed faience with cartouche in black (SK.BLACK3) overglaze, P.E12126.

The normalized amounts of soda and magnesia in the late New Kingdom samples from Thebes and Tell el-Yahudiyeh were somewhat elevated compared to the faience glazes at el-Amarna (Table 2). Potassium oxide and alumina, on the other hand, were depressed.

At Beth Shan, small object faience glazes also had a low magnesia content (0.74%), which is less

obviously the case for the small object glasses (1.54%). The normalized alumina contents of both the small object glazes and glasses at Beth Shan (2.04% and 3.51%, respectively), however, exceed the el-Amarna glaze value (1.64%). The most distinctive feature of the Beth Shan small object batch recipe is its relatively high potassium oxide content: 1.63% (glazes) and 3.32% (glasses) versus 0.65%

for el-Amarna faience glazes, 0.29% for Thebes, 0.16% for Tell el-Yahudiyeh, and 0.17% for Serabit el-Khadem; only el-Amarna glasses (2.51%) have as much potassium oxide. Although the lime content of the Beth Shan small object glasses is higher (3.75%) than that of any of the late New Kingdom Egyptian groups, that result probably is not significant, especially since the 1.78% lime content of Beth Shan faience glazes falls midway in the Egyptian 1–3% range. On the whole, the batch mixtures of the Beth Shan vessel glasses and glazes appear to be most similar to those of the Beth Shan small objects; among the more important differences are relatively high magnesia (3.54%) and lime (5.22%) contents for the vessel glasses and the depressed potassium oxide contents for both vessel groups.

A similar picture emerges when the transparent glazes and glasses, which are depleted in heavy metals, are compared (Tables 3, 4, 5). As fig. 10 shows, the Theban and Tell el-Yahudiyeh samples group separately from the Beth Shan small object and vessel examples, as well as from one another. While different glassmaking recipes no doubt account for some of the variability, the availability of more or less pure raw materials at each site may well be the decisive factor.

Different mixtures of transition metal colorants and their associated minor and trace element profiles further distinguish the Ramesside groups from one another and from the Beth Shan and Amarna groups. For example, a combined manganese-copper grayish blue glaze (TH.GRAY-BLUE1 and TH.GRAY-BLUE2), in one instance associated with a minor amount of cobalt, was prevalent in the Theban group, whereas a combined manganese-cobalt brownish blue glaze (TY.BROWN-BLUE1, TY.BROWN-BLUE2) was confined to the Yahudiyeh group. By increasing the relative amount of manganese in the batch mixture, a purplish brown glaze (TY.PURPLE-BROWN1), again associated with cobalt, was produced at Tell el-Yahudiyeh. Such combinations are a predictable outcome of the prior use of colorants combining all three elements—manganese, cobalt, and copper—at Amarna and even earlier at other Near Eastern sites (above). The groupings of those colorants, as clearly distinguished from groups of Beth Shan manganic brown small objects (fig. 11) support the view that each group was locally manufactured according to specific recipes or using different raw materials. Among the minor/trace elements, titanium is noticeably depressed in the Egyptian and Sinai samples as contrasted with those from Beth Shan.

The late New Kingdom Egyptian “palette” of faience glaze colorants has other peculiarities. Not a single example of calcium antimonate opaque white, nor of opacification with that compound, was noted, yet such was common earlier in the New Kingdom and is documented during the same period at Beth Shan. Intriguingly, two lead antimonate opaque yellow glazes (TY.YELLOW1 and TY.YELLOW3) from Tell el-Yahudiyeh were combined with cobalt blue, just the reverse of a cobalt blue el-Amarna sample (above). The latter contained minor amounts of lead antimonate yellow. In both instances, accidental admixture of the two colorants at some stage in the production process is likely. The anomalously high cobalt levels (average of 0.33%) of the Theban red glazes (TH.RED1 and TH.RED2), although otherwise analogous to two Beth Shan specimens (BS.RED1 and BS.RED2 [Level IX]), might also be explained as accidental. But since the copper levels of the Theban examples also significantly exceed those of the Beth Shan reds (average of 0.15% versus 0.06%), copper and cobalt were quite possibly intentionally added to the batch mixture. When fired in a reducing atmosphere, red cuprous and pink cobaltous ions would result.

The single example of Egyptian Blue frit (TH.BLUE5) from the late New Kingdom that was analyzed is very close chemically to an Egyptian Blue frit cake from Beth Shan (BS.BLUE12). Each sample has depressed levels of soda, magnesia, and alumina, which is characteristic of late New Kingdom faience glazes but not of any of the Beth Shan groups (note that the three Egyptian Blue frit small objects—BS.BLUE5, BS.BLUE6, and BS.BLUE9 [Level IX]—from Beth Shan fit most nearly the small object faience composition). Furthermore, the cupric oxide and lime contents of the two samples are comparable, and both contain above 1.5% stannic oxide. Without analyzing additional Egyptian samples, it cannot be determined whether or not these samples derive from the same copper ore source or manufacturing center; but their compositions suggest that they originated in Egypt or the Sinai. Although a number of colorants were prepared as flat, circular cakes in Egypt (Saleh et al. 1974), only Egyptian Blue frit cakes have been found outside Egypt. Egyptian Blue frit might therefore have been shipped abroad from Egypt or one of its colonies.

The chemical compositions of the late New Kingdom cupric blues and blue-greens is not definitive enough to distinguish them from the Beth Shan

TABLE 3. Constituents of Theban Faience Glazes

Color Reference*	Batch Constituents Oxide Content (% by weight)							Minor Constituents Oxide Content (% by weight)					Minor and Trace Elements Oxide Content (parts per million, by weight)						
	SiO <sub>2</sub>	Na <sub>2</sub> O	CaO	K <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	MgO	Fe <sub>2</sub> O <sub>3</sub>	Color Reference	PbO	Sb <sub>2</sub> O <sub>5</sub>	CuO	SO <sub>3</sub>	Color Reference	TiO <sub>2</sub>	MnO	CoO	As <sub>2</sub> O <sub>3</sub>	SrO	SnO
TH.WHITE1	93.9	2.68	0.66	0.070	0.79	1.01	0.18	TH.WHITE1	0.026	0.047	0.11	0.36	TH.WHITE1	1855	70	190	13	137	180
TH.BLUE1	82.2	4.38	0.49	0.204	0.51	6.50	0.13	TH.BLUE1	0.021	≤0.085	4.79	0.53	TH.BLUE1	235	200	≤42	≤36	21	200
TH.GRAY-BLUE1	82.6	3.54	1.72	0.201	2.11	1.17	0.52	TH.GRAY-BLUE1	0.090	≤0.024	6.50	0.60	TH.GRAY-BLUE1	425	1005	≤105	77	101	985
TH.WHITE2	90.7	4.96	0.69	0.054	0.80	0.77	0.065	TH.WHITE2	0.038	0.067	0.19	1.17	TH.WHITE2	115	60	43	27	146	190
TH.BLUE-GREEN1	84.4	3.30	1.14	0.270	0.17	4.65	0.16	TH.BLUE-GREEN1	0.0076	≤0.012	4.57	0.48	TH.BLUE-GREEN1	1600	230	≤40	12	100	1210
TH.BLUE-GREEN2	77.1	2.45	6.52	0.153	0.81	3.10	0.23	TH.BLUE-GREEN2	0.020	≤0.017	8.68	0.35	TH.BLUE-GREEN2	200	210	≤88	45	251	550
TH.BLUE2	81.9	0.89	2.35	0.333	1.28	0.022	0.88	TH.BLUE2	0.012	≤0.018	10.4	0.10	TH.BLUE2	3005	325	265	24	167	510
TH.RED1	87.7	4.92	0.94	0.103	2.15	1.05	2.01	TH.RED1	0.031	≤0.015	0.075	0.33	TH.RED1	160	65	2310	≤58	223	≤95
TH.RED2	81.5	6.69	1.92	0.163	2.34	1.10	4.15	TH.RED2	0.139	0.044	0.22	0.17	TH.RED2	445	235	4250	56	933	≤160
TH.BLUE3	88.5	0.99	1.20	0.328	0.82	0.20	0.27	TH.BLUE3	0.012	≤0.011	5.45	0.23	TH.BLUE3	190	130	≤61	94	98	410
TH.GRAY-BLUE2	81.7	3.25	1.23	0.181	2.30	1.61	0.50	TH.GRAY-BLUE2	0.034	0.031	7.32	0.43	TH.GRAY-BLUE2	375	3760	6870	38	120	900
TH.WHITE3	93.4	2.94	0.98	0.057	0.90	0.79	0.12	TH.WHITE3	0.067	0.021	0.22	0.050	TH.WHITE3	230	65	120	35	142	≤120
TH.BLUE4	88.8	4.21	0.28	0.960	1.85	0.67	0.11	TH.BLUE4	0.0026	≤0.035	2.12	0.053	TH.BLUE4	65	285	715	32	47	1460
TH.BLUE5	60.5	1.55	15.9	0.552	0.77	0.94	1.04	TH.BLUE5	0.022	0.057	15.9	0.36	TH.BLUE5	770	470	280	47	1070	16200

\* The caption of fig. 8 provides descriptions and museum registration numbers.

TABLE 4. Constituents of Tell el-Yahudiyeh Faience Glazes

Color Reference*	Batch Constituents Oxide Content (% by weight)					Minor Constituents Oxide Content (% by weight)					Minor and Trace Elements Oxide Content (parts per million, by weight)								
	SiO <sub>2</sub>	Na <sub>2</sub> O	CaO	K <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	MgO	Fe <sub>2</sub> O <sub>3</sub>	Color Reference	PbO	Sb <sub>2</sub> O <sub>5</sub>	CuO	SO <sub>3</sub>	Color Reference	TiO <sub>2</sub>	MnO	CoO	As <sub>2</sub> O <sub>3</sub>	SrO	SnO
TY.BLUE1	84.9	1.34	3.00	0.159	1.36	2.02	0.23	TY.BLUE1	0.29	≤0.014	2.94	2.88	TY.BLUE1	380	85	≤51	≤9	111	825
TY.GRAY-BLUE1	83.2	1.64	3.30	0.510	1.24	0.84	0.40	TY.GRAY-BLUE1	0.24	≤0.033	4.84	2.47	TY.GRAY-BLUE1	405	2015	≤185	23	123	1570
TY.YELLOW1	84.4	2.26	1.90	0.227	1.01	1.20	1.33	TY.YELLOW1	1.48	2.57	0.502	2.01	TY.YELLOW1	4290	135	1210	40	311	1800
TY.WHITE1	93.5	1.00	2.21	0.149	1.09	0.75	0.44	TY.WHITE1	0.084	≤0.015	0.091	0.51	TY.WHITE1	530	190	315	50	176	≤120
TY.PURPLE-BROWN1	86.8	2.92	2.98	0.204	1.41	1.95	0.65	TY.PURPLE-BROWN1	0.67	≤0.056	0.384	0.61	TY.PURPLE-BROWN1	910	4635	2570	330	637	≤435
TY.WHITE2	91.8	1.88	1.94	0.125	1.04	1.00	0.31	TY.WHITE2	0.96	≤0.031	0.095	0.46	TY.WHITE2	345	115	385	≤22	355	290
TY.BROWN-BLUE1	90.5	1.40	2.90	0.145	1.38	1.55	0.52	TY.BROWN-BLUE1	0.23	≤0.019	0.025	0.68	TY.BROWN-BLUE1	450	850	565	25	149	160
TY.YELLOW2	86.9	3.11	1.70	0.083	1.33	1.23	0.21	TY.YELLOW2	1.01	0.51	0.020	0.74	TY.YELLOW2	180	125	120	99	136	220
TY.WHITE3	90.7	1.24	2.68	0.119	1.58	1.53	0.29	TY.WHITE3	0.46	≤0.032	0.038	0.79	TY.WHITE3	360	145	235	48	278	≤180
TY.BROWN-BLUE2	83.2	1.72	5.10	0.310	2.00	4.44	0.67	TY.BROWN-BLUE2	0.39	0.078	0.030	0.78	TY.BROWN-BLUE2	520	1630	840	335	320	205
TY.WHITE4	93.7	0.54	2.12	0.051	0.75	0.41	0.19	TY.WHITE4	0.25	≤0.36	0.306	0.12	TY.WHITE4	180	100	≤145	≤210	384	2070
TY.BROWN-BLUE3	92.4	1.05	2.27	0.120	1.36	0.92	0.52	TY.BROWN-BLUE3	0.31	0.054	0.097	0.23	TY.BROWN-BLUE3	575	1660	280	180	311	≤235
TY.YELLOW3	88.3	0.96	2.21	0.240	1.10	0.78	0.97	TY.YELLOW3	1.37	1.54	0.129	0.47	TY.YELLOW3	1085	405	755	≤44	490	455

\* The caption of fig. 9 provides descriptions and museum numbers.

TABLE 5. Constituents of Serabit el-Khadem Faience Glazes

Color Reference*	Batch Constituents Oxide Content (% by weight)					Minor Constituents Oxide Content (% by weight)					Minor and Trace Elements Oxide Content (parts per million, by weight)								
	SiO <sub>2</sub>	Na <sub>2</sub> O	CaO	K <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	MgO	Fe <sub>2</sub> O <sub>3</sub>	Color Reference	PbO	Sb <sub>2</sub> O <sub>5</sub>	CuO	SO <sub>3</sub>	Color Reference	TiO <sub>2</sub>	MnO	CoO	As <sub>2</sub> O <sub>3</sub>	SrO	SnO
SK.BLUE-GREEN1	80.3	1.11	1.18	0.249	0.49	0.73	0.70	SK.BLUE-GREEN1	0.085	≤0.033	13.6	0.21	SK.BLUE-GREEN1	840	255	≤165	37	520	3370
SK.BLUE-GREEN2	94.7	1.88	1.44	0.081	0.28	0.048	0.048	SK.BLUE-GREEN2	0.0013	≤0.0022	0.88	0.23	SK.BLUE-GREEN2	75	30	≤10	≤4	55	110
SK.BLUE-GREEN3	87.7	2.34	1.67	0.157	0.18	0.21	0.21	SK.BLUE-GREEN3	0.058	≤0.014	6.37	0.58	SK.BLUE-GREEN3	205	220	≤60	19	130	620

\* The caption of fig. 9 provides descriptions and museum registration numbers.

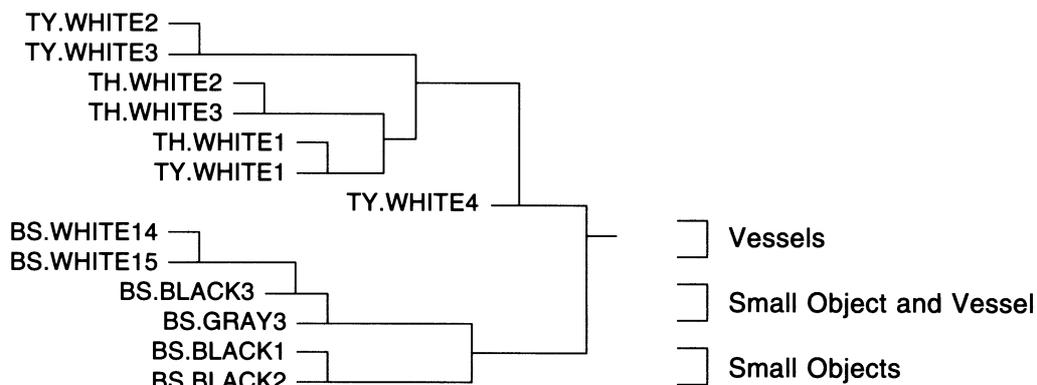


Fig. 10. Beth Shan, Thebes, and Tell el-Yahudiyeh: Dendrogram of depleted heavy metal black, gray, and white glasses and glazes.

examples, although an occasional example with elevated lead (e.g., TY.BLUE1) is only attested in the Egyptian group. The Serabit el-Khadem black overglazes (SK.BLACK1-3) are unique in that they have widely varying, often high levels of many elements (e.g., calcium, iron, tin, silver, and barium).

Late New Kingdom Egyptian silicate manufacture clearly had reached an advanced stage of experimentation in different silicate materials and colorants. The 18th Dynasty industry may have set the pattern in which colorants were employed, but the faience workers of the 19th and 20th Dynasties considerably expanded the possibilities. Even finer nuances of color (e.g., a brownish or grayish blue) were now achieved by varying the mixtures of different transition metals, and craftsmen could recreate the natural and human worlds as never before. Since the raw materials (silica, alkalis, and often metal ores) for glass and faience production are widespread, it might be anticipated that local industries would emerge over time and develop their own recipes and palette of colors.

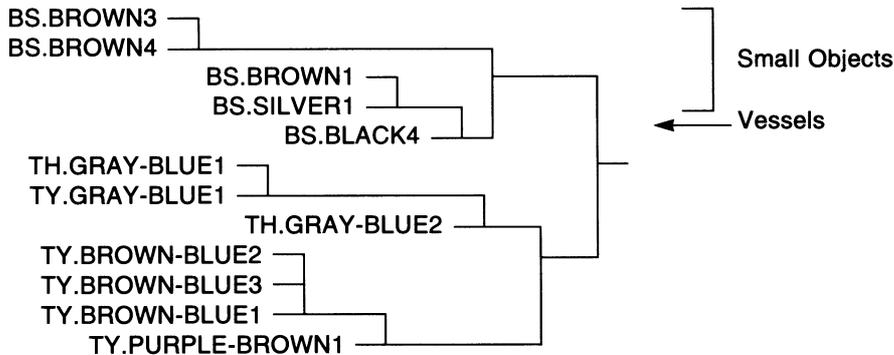
### CONCLUSIONS

The analyses of a limited corpus of Egyptian silicate artifacts from the 18th to the 20th Dynasty have shown that the batch recipes and colorants of the el-Amarna group, except for cobalt blue, are very distinct chemically from glasses and glazes produced a century later at other Egyptian sites—Tell el-Yahudiyeh and Thebes as well as at Asiatic sites influenced by Egyptian technology—Serabit el-Khadem in the Sinai and the military garrison of Beth Shan in Canaan.

The later Egyptian silicate groups are also clearly distinguishable from one another. Their

normalized batch recipes are internally consistent, but vary in one or more oxides from those of any other group. In general, the major colorant elements of the groups are of the same basic composition. Blues, blue-greens, yellows and browns, whites, blacks, etc. were achieved by using the same elements (whether cobalt, copper, lead, antimony, or manganese) in about the same amounts and combinations. However, the heavy metal colorants of the groups differ in their minor and trace element profiles, except for cupric blues and blue-greens, Egyptian Blue frit, and cobalt blue. Some colorants were exclusive to one site, such as the silver colloid glass at Beth Shan, the brownish blues at Tell el-Yahudiyeh, and the red glazed frits with elevated copper and cobalt at Thebes. The most parsimonious explanation for such marked chemical differences is that each site had its own manufacturing installation.

Where both glass and faience were available for analysis (el-Amarna and Beth Shan), the chemical evidence also suggested that the workshops for the different materials operated independently of one another. At el-Amarna, the workshops were probably functioning at the same time, in close proximity to each other. The situation at Beth Shan appears to be more complex. The fact that the glass and faience glaze chemical compositions of the Beth Shan vessels generally accord better with Egyptian recipes originally prompted the study of native Egyptian artifacts, to test the hypothesis that they had been manufactured in Egypt. None of the Beth Shan vessels, however, could be assigned to any of the Egyptian sites discussed in this article. Indeed, in some respects (e.g., normalized batch recipes) and lead antimonate yellows (fig. 6), the Beth Shan vessels are closer chemically to small objects at the site, which were most likely manu-



**Fig. 11.** Beth Shan, Thebes, and Tell el-Yahudiyeh: Dendrogram of manganese-containing colorants.

factured locally, than to the artifact groups made at Egyptian sites. Nevertheless, given the extensive development that the Egyptian silicate industry had undergone during the New Kingdom and its consequent diversity, many other sites in Egypt were probably manufacturing core-formed vessels. More sampling of other Egyptian sites is required before an Egyptian origin for the Beth Shan vessels can be definitely ruled out.

In attempting to understand how the silicate industries of late New Kingdom and Beth Shan might have interacted, one might posit that the technological and stylistic traditions of a dominant economic and political power (Egypt) are transmitted more readily to a subordinate society (Beth Shan) than vice versa (see McGovern 1989a; 1989b). According to this model, craftsmen of the lesser power would have a greater incentive, if not compulsion, to replicate styles of the dominant group and that could best be achieved by employing the techniques of the latter. Thus, in modern times (since the Renaissance), the transmission and emulation of Western culture has been an almost inevitable consequence of colonization. Borrowing, however, need not be unidirectional (the modern craze in the West for “primitive” art should dispel that notion), and the various groups that comprise an exchange network are selective in what they adopt (Woods 1975: 17–27). In adopting a technique or style, a receptive group or individual may well have to adapt it to different cultural norms and environmental conditions, thus providing the context and stimulus for innovation (Barnett 1942: 14–30; 1953; Renfrew 1978: 89–117).

Major limitations in assessing the direction and extent of interaction are the paucity of written sources and archaeological data relating to the industries and the community in general. For ex-

ample, an important consideration, about which little is known, is whether Palestinian and Egyptian workshops were separate from one another both in organizational control and output. If that was the case, we would want to know if the former continued to produce quantities of Palestinian-inspired artifacts as it had in the past and if the latter supplied Egyptian-style objects. In a broader sense, we must ask also to what extent Palestinians adopted or modified Egyptian culture, and vice versa. What impact did that exchange have on the silicate industry at the site?

The available evidence, specifically the unidirectional technological and stylistic changes in the Palestinian industry that brought it into conformity with Egyptian practices, suggests that, even if the two groups had separate workshops, the Egyptians were in control at the most basic level—the preparation and supply of raw materials (at least for faience), and the firing process. Even some of the colorants (in particular, cobalt blue and Egyptian Blue frit) were very likely imported from Egypt.

Given the physical and chemical properties of the primary Egyptian material (faience) and several colorants, Palestinian silicate specialists might then have adopted concomitant Egyptian techniques (such as mold-production of small artifacts and uniformly low-temperature firings). Whether by force or as a voluntary response, innovation by Palestinian craftsmen (e.g., overglazing onto low-fired faience bodies) is also more likely under such circumstances. They had the necessary expertise in both technologies; and Levantine craftsmen, in the middle of the then-civilized world, had long been exposed to different technologies and styles, which sometimes led to the production of composite types. The emergence of a syncretistic Egyptian and Palestinian cult at the site would have encouraged

that development. Although Egyptians during the New Kingdom were more open to the assimilation of Syro-Palestinian technology and culture than perhaps at any time in their history, the silicate industries in Egypt itself were generally conservative in the materials and techniques they employed. To be sure, elaborate polychrome jewelry, tiles, and vessels were also improvised there. However, the few documented examples combining Egyptian and foreign stylistic elements come from areas like the Delta and el-Amarna, where large groups of foreigners lived and where foreign craftsmen might therefore have manufactured the pieces. Lacking evidence to the contrary, it is likely that any Egyptian craftsmen at Beth Shan probably perpetuated the conservative attitudes of their homeland.

A final point worth considering is the lack of Egyptian influence in other local Beth Shan industries, such as metals and alabaster- and bone-working. Possibly, ceramic industries were considered more central to Palestinian and Egyptian cultural life, especially since a large percentage of the cultic vessels recovered from Levels VIII and VII

were made from pottery and silicate materials. The low socioeconomic status of many ceramic specialists in societies around the world today need not have been the case in antiquity (Kramer 1985: 77–102). The materials themselves, as the earliest manmade synthetics, were viewed as almost miraculous replications of naturally occurring minerals, metals, and other substances, often associated with specific deities (the earliest glass texts are replete with invocations to the gods [Oppenheim, et al. 1970]). For example, blue-green glazed faience duplicated turquoise, the semiprecious stone almost synonymous with Hathor. The association between ceramics and Palestinian cultural life was just as intimate, as illustrated by the faience factories attached to Syro-Palestinian and Mesopotamian temples and palaces in the Late Bronze Age (Peltenberg 1977). If ceramics were more central to both Egyptian and Palestinian culture, then changes, whether by direct borrowing, imposition, or innovation, are more apt to have reflected technological and stylistic exchange between the two cultures.

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#### NOTES

<sup>1</sup>An even earlier date for the development of these materials is implied by the literary, textual, and archaeological evidence presented in Oppenheim, et al. 1970. Also see Brill 1963; McGovern, Fleming, and Swann 1991.

<sup>2</sup>According to modern scientific usage (see Parmelee 1948), frits are prefused silicate materials incorporated into a glaze/glass mixture or used separately. Glass is often treated separately from frit in the literature on ancient glass. Both materials, however, are found together in the earliest archaeological contexts that have yielded sizable groups of glass artifacts. That suggests that the origins and subsequent development of glassmaking are related to frit manufacture.

<sup>3</sup>All the silicate materials were initially examined macroscopically and under low-power magnification (up to 180×), using a stereozoom scope with fiber optic lighting. At that level of analysis, the various materials (glass, frit, and faience) could be characterized preliminarily, fabrication techniques defined, larger inclusions noted, and the extent of weathering assessed. A definitive characterization of the materials, including their vit-

rification structures and inclusions, was then carried out using a scanning electron microscope with an attached energy dispersive system for semiquantitative chemical determination. Both original surfaces and prepared cross-sections were examined.

<sup>4</sup>PIXE spectrometry is well-suited to such an investigation, given its high spatial resolution, ability to measure all of the major constituents of glass, and excellent sensitivity in detecting relevant minor and trace elements. The beam can be reduced to 0.4 mm<sup>2</sup>, which is quite adequate for a material whose homogeneity has been checked independently; for glass, analyses were conveniently reduced to an area as small as 0.04 mm<sup>2</sup>. For experimental details, see Fleming and Swann 1987; Fleming, Swann, and McGovern 1990; Fleming et al. 1990; Swann, McGovern, and Fleming 1989. Surfaces and cross sections were often ground down as much as a tenth of a millimeter with an alumina burr, to minimize weathering effects.

<sup>5</sup>Nine elements (Ti, Mn, Fe, Co, Cu, As, Sn, Sb, and Pb) were routinely included in the calculation, which

employed an unweighted pair-group hierarchical algorithm of differences in mean Euclidean distances (defined as the average of the square root of the sum of the differences for each elemental pair). The oxide data were expressed in logarithms, since many chemical elements appear to be lognormally distributed in nature and are also standardized by this procedure (Harbottle 1976). Note that a dendrogram is an inherently simplified, and sometimes misleading, two-dimensional projection of the Euclidean distances between data points in multi-dimensional space. The distance from the left-hand listing of samples to where two or more samples join (cluster) on the dendrogram is a measure of their chemical similarity, as determined by their mean Euclidean distance separation; the less distance there is from the ordinate along the abscissa, the greater the chemical similarity, and vice versa. No correction was made for the possible differential leaching or deposition of some elements, nor for covariance between elements.

Because the end-products of a totally fused material (glass or glaze) made from a variety of raw materials cannot always be disentangled, other statistical analyses are routinely done. These include histograms of elemental concentrations and their standard deviations, multiple

correlations between elements, factor analysis, etc. Although not presented here, those analyses substantiated the conclusions illustrated by the dendrograms.

<sup>6</sup>While the highest soda value for an el-Amarna glass sample (15.6%) accords with the typical composition of a sodium-fluxed glass, the group as a whole averages 12.4%. Whatever the reason for this slight anomaly (e.g., leaching out of sodium, instrumental sensitivity, etc.), the normalized PIXE data are internally consistent and can be compared with one another.

<sup>7</sup>Similarly high lime contents have been reported for other el-Amarna glasses; see Kühne 1969: 27–47, Tables 1, 2; Crowell and Werner 1973. Recent analyses of two name-beads from the reign of Hatshepsut (1479–1457 B.C.E.) indicate that high amounts of lime, together with elevated magnesia contents, were being produced in Egypt a century before the el-Amarna period (see Bimson and Freestone 1988).

<sup>8</sup>Unpublished analyses of dark-colored faience glazes from LB II Tell Yin<sup>c</sup>am, excavated by H. Liebowitz also were achieved by combining copper (mean value of 3.12%), manganese (1.20%), and cobalt (0.28%). The site is only about 30 km north of Beth Shan.

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