A STUDY OF VITREOUS MATERIALS FROM MINOAN CRETE[1]

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The present study of vitreous materials focusses on the techniques used for their manufacture. By "vitreous materials",[2] I mean, glass and materials which contain *glass* in the form of a glaze or as a connective agent such as *faience and frit*.

A thorough visual examination of the objects combined with optical microscopy revealed physical characteristics of the body, which point to the method(s) of production. Archaeometric analyses are currently underway with the same aim. They are being conducted by Prof. M.S. Tite and Dr Y. Maniatis. A scanning electron microscope (SEM) with an attached energy dispersive x-ray spectrometer determines the chemical compositions and in the case of faience, the surviving glaze or interstitial glass. We are especially interested in the methods used to glaze the faience objects. Our analytical results are being compared to results obtained from contemporary vitreous materials from Egypt and the Near East. We are, thus, in a way, trying to find out, how much of the technical knowledge the Minoan pyrotechnologist had was borrowed and how much was the outcome of his own experimentation..

Such analytical studies have been extensively applied to Egyptian[3] and Near Eastern[4] vitreous materials. This is, however, the first time they have been conducted for the Minoan ones[5]. I should point out, though, that our analytical work is still in its beginning.

The first vitreous material to be examined, is *faience*. This is known in Crete in EM II[6], (2900-2300/2150 B.C.[7]), but had appeared in Mesopotamia in the fift millennium[8] and in Egypt in the fourth.[9] "Porcelain", "enamel" or "faience" are the names used by the excavators of Knossos[10], where Minoan faience was first encountered. "Faience" is the name that has prevailed, although it is a misnomer[11].

When a broken surface of faience is examined, it seems to consist of two distinct layers: the body or core and an outer vitreous layer, the glaze (FIGURES 1-2). When the core is examined microscopically, it consists of angular grains of quartz, which are bound together with some lime and an alkali, which is either natron or plant ash. In Minoan faience, the guartz grains are ground to a fine powder - very rarely are they less finely powdered. The glaze is a form of glass and it should ideally look glassy. In archaeological contexts, however, the glaze has often lost its sheen because of unfavourable conditions in the ground. Sometimes, only a tint of what was a brilliant blue or green glaze survives.

The faience mixture, since it consists mainly of silica, is thixotropic, which means that it is thick and difficult to manipulate at first, but becomes soft and flowing as it is worked[12]. When the mixture is ready it can be pressed into a mould, modeled by hand, or even thrown on a potter's wheel. The object is subsequently fired, perhaps at between 800-1000 °C[13]. After firing the material hardens to varying degrees, according to its composition and perhaps its firing temperatures. Often, the object is decorated (before firing), either by using a slurry in a contrasting colour, or by being incised and then inlaid, again using a contrasting colour paste. Firing will produce the glaze, which, as experiments on Egyptian faience have shown, could be created using three different methods[14]: *efflorescence, cementation, and application*.

Efflorescence. This is a so-called "self-glazing" technique, in which alkali salts (such as carbonates, sulphates and chlorides of sodium and potasium) are mixed together with the core material. During drying the salts gather on the surface as a white crust. During firing the crust melts and fuses with the fine quartz, the lime and the copper oxide,

FIG. 1 Faience arm (Ashmolean Museum 1938.697) s howing a turquoise glassy glaze.

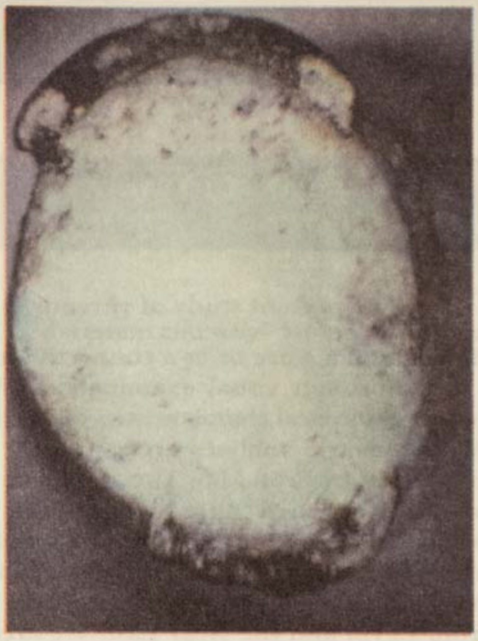

FIG. 2 Lower end of faience arm (Ashmolean Museum 1938.697) consisting of a fine, white core and a thin layer of turquoise glaze.

forming an overall glassy glaze. This method is easy to recognize visually because the thickness of the glaze varies; it is thinner where the body is scraped during its modeling and thicker on the highly exposed surfaces where the salts migrated freely. Under a scanning electron microscope a large amount of interstitial glass (glassy phase among the quartz particles) is observable and the interface between core and glaze is very clear.The method was greatly favoured by the Egyptians.

Cementation. This too is a "self-glazing" technique. The dry core is embedded in a glazing powder. When heated the powder which touches the object reacts with the surface materials of the core, melts and forms a glaze round the object. It can be visually recognized because it shows as a uniformly thin layer and it does not exhibit any drying or firing marks (see below). Under a scanning electron microscope there is very little interstitial glass but the interface between core and glaze is well defined. The technique is also known as the "Quom technique" because it was still used in Quom, a village in Iran, in the 1960s[15].

Application. The glaze materials are made into a liquid, which is applied to the object. This is the method used in modern times to glaze ceramics. The method can be recognized visually because it consists of a thick layer of glaze, which exhibits brush marks, drips and drying or kiln marks. Under a scanning electron microscope very little interstitial glass exists and the interface of glaze and core is not well defined.

Our SEM analyses[16] have so far shown that the typical Minoan faience body consists of quartz particles up to 100-200 mm across; the silica content is in the range of 94-98% SiO_2. Some of the white bodies contain about 1% copper oxide. The grey bodies examined contain higher concentrations of iron oxide than the white bodies (0.6-2% FeO as compared to 0.2% FeO). When there is interstitial glass (eg. AM 1938.863-9553), it confirms the presence of iron oxide (3.3% FeO) and copper oxide (2.2% CuO) and establishes that potash (7.3% K_2O), from plant ash, is the dominant surviving alkali rather than soda (0.5% Na_2O) from natron. The latter is the alkali normally used in the production of faience glazes in Egypt[17]. The green glaze contains mainly silica (51.3% SiO_2) and copper oxide (45.6% CuO) with a negligible concentration of alkali (0.2% K_2O). The brown inlaid material most probably owes its colour to a mixture of iron and copper.

Most of the objects visually examined and analysed so far point to the application method of glazing. It should, however, be pointed out that our analyses on the glazing methods have not been completed.

The earliest Minoan *faience* appears in EMII[18] period (2900-2300/2150 B.C.) in the form of *beads* found at Knossos, at Mochlos and at Platanos[19]. One or two vases which belong to the same period have not been found and we cannot tell whether they were of Minoan make. A small vase from a MM IIB context[20] (1700/1650 B.C.) is of interest since the faience body is trimmed with gold[21].

A series of *plaques* from the East Wing of the Palace at Knossos probably belong to MM IIB or MM IIIA date[22] (1700/1650-1640/1630 B.C.). They depict house facades but also human and animal figures and plants[23]. The faience core exhibits a great variety in colour: different shades of grey and brown but also green, white and red[24]. The plaques are made in moulds as the tiny knobs and the minute inlaid work on them could not have been achieved otherwise. The human figures are formed separately and stuck on to the flat plaque, creating, thus, low reliefs. A lot of the plaques are inlaid: the plaque came out of the mould with the design in the form of shallow channels/grooves, which were subsequently filled with a paste of glaze material of contrasting colour. White paste is inlaid in a grey or brown core; grey or brown paste in a white. The glaze survives only as little patches; it is white or green, but other colours too may have originally adorned these plaques. Inlaid work appeared first in Egypt[25] but nowhere was it developed the way it was in Minoan Crete. The Minoan inlaid pieces have quite intricate designs and colour combinations and they are done on such a small scale that they recall the miniature frescoes at Knossos. Inlays are difficult to achieve; the paste to be inlaid has to go into the prepared groove at the right moment, when the body is neither too dry nor too wet, otherwise the inlay would shrink away. The separation of the inlay from the body becomes fashionable in New Kingdom Egypt[26] but never in Minoan Crete.

In MM IIIB/LM IA (1600 B.C.) or LM IA period (1600/1580-1480 B.C.) the Minoan faience-maker is a skillful painter and sculptor. A series of *plaques* with inlaid bands continues the MM IIB/IIIA tradition[27]. There is a tendency to use a white or cream faience core with brilliant green or turquoise glaze, only patches of which survive. A series of *marine creatures* in relief or in the round show how the material was worked or moulded. The *argonauts*[28], for instance, were probably made in a two-piece mould and then the two halves were joined. One of the argonauts (in the Ashmolean Museum) exhibits kiln or setter marks (created on the underside of the argonaut) and probably incomplete *efflorescence*, suggesting thus, the method of producing its glaze. Another series of *plaques with animals in relief*[29] were probably made in a mould for the basic shape, but many body details were subsequently ground on, when the faience was not too dry, but certainly before firing. Some body lines were enhanced using a black slurry. A brilliant glaze was applied perhaps as a liquid.

Some other *plaques* take the form of dresses on which crocus or papyrus flowers are painted before the glaze was applied[30]. A fragmentary dress[31] has an extra layer of fine, white quartz, between the core material and the glaze. The Egyptians also used such a layer (Variant A)[32] when the core material was not of sufficiently fine quality - something that would have an effect on the colour of the glaze. The Minoan faience core material is usually white and very fine, but in the case of this dress the core consists of slightly larger grains and this is why Variant A was applied.

Some *vases* were made in parts, in moulds, and the pieces were subsequently joined together in a way that they support each other. A *tall cup* from Knossos[33] was made in two pieces, the cylindrical body first, while the rim was made separately and was placed on the 'rim' of the body. The plants are stuck on, as a thick paste; so too is the rose branch which spreads from the handle and trails across the wide part of the rim. The inside of the vase is partly covered in glaze (the lowest part is free of it), drips suggest that the vase was immersed upside-down in a liquid glaze (the method of *application*) and then stood upright to dry so that the liquid glaze created a kind of a rim with runnels and drips on the inside of the vase.

The *human figures* in the round[34] probably exemplify to the full the skill of the Minoan faience-maker as a sculptor. They are made in pieces and then joined together. Details are stuck on, such as the eyes, eyebrows, locks of hair and snakes. The tight bodice gives the impression of a fine, almost transparent material which has been embroidered and is trimmed with black straps.

The next period (LM IA/B 1600/1580-1425 B.C.) also sees some large pieces of faience sculpture. The faience-maker continues to draw his inspiration from the animal world: a large *argonaut*[35] rendered in a very naturalistic way and the *heads of lions and lionesses36* come from the Palace of Zakro.

Faience making seems to stop at this period, giving way to glass making (see below).

Frit, or "glassy faience" as it is occasionally called[37], is the second "vitrous material" to be examined (FIGURES 3-4). It may have first appeared in Crete in EM II (2900-2300/2150 B.C.). Frit lies between glass and the material known as Egyptian Blue (see below); it can be easily distinguished because it is homogeneous, is coloured throughout and it does not have a glaze layer[38].In reality, it is of the same composition as glass, but incompletely fused, (i.e. it is not fused to the state of vitrification). A two-stage process is required to produce frit: first you fire the raw material, then grind

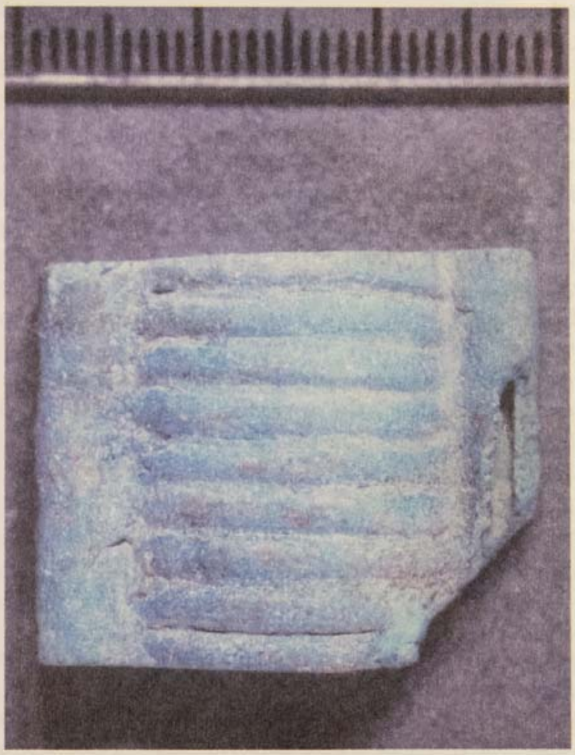

FIG. 3 Frit spacer bead (Ashmolean Museum 1938.540).

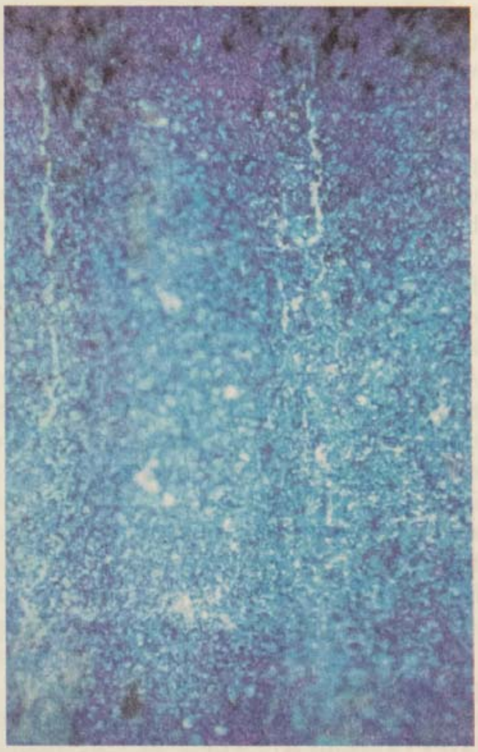

FIG. 4 Frit spacer bead (Ashmolean Museum 1938.540) under a microscope, detail of surface.

it to a fine powder and finally you refire it. Frit is much less common than faience in Minoan Crete. The earliest frit found is in the form of *beads* from the EM II Mochlos, published as of faience[39]. Tiny frit *beads*, also published as of faience, come from the MM IB Vat Room Deposit at Knossos[40]. The recovery of locally produced frit in Minoan Crete as early as EM II or MM IB is significant because it points to a considerable pyrotechnological knowledge amongst the Minoans, as early as the third millennium. But were these beads locally made? The analyses now in progress will hopefully answer this question. More frit beads and vase fragments have been identified from the excavations at

Knossos and elsewhere on the island through the present study and I am certain that a lot more awaits identification in Museum storerooms.

Egyptian blue[41] is very close to glass; it is often hard to distinguish from glass. Originally an Egyptian product, which appeared in the Old Kingdom (2613-2181 B.C.) and continued in production into the Roman period[42] (30 B.C.-A.D. 395). It is a crystalline substance which owes its colour to copper calcium tetrasilicate (CaCuSi4O10). It is a mixture of quartz sand, calcium carbonate and a copper compound together with alkali, fired in the range of 900-1000 °C; it is easily recognized by its fine texture and sometimes by the intense blue colour. Egyptian blue was used as a pigment or it was shaped into objects and fired like faience[43]. No objects of Egyptian blue have yet been recognized in Minoan Crete.

Glass probably developed out of faience-working, or rather out of the glaze of faience[44]. It was first made in Mesopotamia[45] in the sixteenth or fifteenth century B.C.; in Egypt it is with the New Kingdom (Eighteenth Dynasty, 1570-1325 B.C.) that it becomes a fully fledged industry[46]. In Minoan Crete it appears in LM IB period[47] (1480-1425 B.C.).

Ancient glass is made of silica, an alkali and some form of calcium. When mixed to the right proportions and heated (to about 1000 °C), these three materials fuse together to produce a soft, flowing mixture, which can be run into a mould, wound round a core, or it can be blown through the end of a pipe. It can also be inlaid, using contrasting colours of the same material. When it dries, it can be cut and ground and polished.

Glass makes its first appearance at the Palace of Knossos (FIGURES 5-6). Pieces probably from a workshop by the Royal Road have been recorded[48]. To these can be added some more fragments of blue glass from some manufacturing process from the excavations of Evans (unpublished). A glass plaque from Knossos at the Ashmolean shows a typical cross section (FIGURE 7): the centre in brilliant turquoise while the outer

FIG. 5 Glass plaque (Ashmolean Museum 1938. 539).

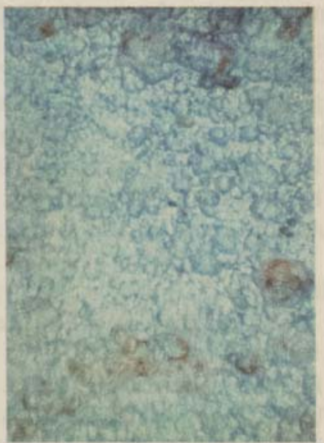

FIG. 6 Glass plaque (Ashmolean 1938.539) under a microscope, detail of weathered surface showing pitting.

FIG. 7 Glass plaque edge (Ashmolean 1938. 543) showing discoloured weathered surface layers and original colour at centre.

layers have lost their colour as the result of weathering. A number of objects, from the excavations of Evans at Knossos, recorded as of faience, were recently identified as of glass by the author. Among them are the following: a series of plaque-figures[49], a sword pommel decorated with spirals in low relief; a rosette again in low relief; they all show great delicacy in their form. The glass is opaque, in different shades of blue or cream; where flaked away the surface exhibits a fine, porous texture.

A large number of beads in great variety of shape and colour, from tombs, particularly after the LM IA/B periods, seem to belong to the Mycenaean glass-making tradition. They are often found together with faience and frit beads.

Although *faience*, *frit* and *glass* consist of basically the same ingredients, silica, alkali, lime and copper, they are distinct, as they are based on different proportions of these basic materials. This means that you cannot turn faience into frit or frit into glass by, for example, simply changing the kiln conditions either by increasing the temperature or by prolonging it[50]. However, all three materials were perhaps produced in the same workshop, since they are compositionally so close.

Knossos, which has yielded the greatest numbers of such materials up to the LM IB period, may have been the centre of production of vitreous materials. The only surviving evidence for the manufacturing processes is in the form of steatite moulds[51]. Stone moulds are difficult to make but the product out of them must certainly be of higher quality.

Vitreous materials were not mass produced in Minoan Crete. This is evident by the lack of clay moulds (by contrast thousands of them were found in Egypt) and by the numbers of the objects themselves. The Minoan faience and glass maker produced unique pieces of art which decorated the Palaces, especially that of Knossos. This observation may lead to social implications: faience and glass objects may have not been available to everyone. Was the Palace controlling the artist(s) or could only the Palace afford to support the labour costs of highly priced Minoan faience and glass pieces of art? This may recall Egypt where natron (necessary in the production of Egyptian faience and glass), was "a royal monopoly"[52].

NOTES

1. I am deeply grateful to the Ashmolean Museum, especially Mr M. Norman for FIGURES 1-7; my warm thanks are also due to Dr D. Evely for reading a draft of this article.
2. On "vitreous materials" see Lilyquist and Brill, 1993, 5.
3. Vandiver, 1982, 167-79; 1983, App. 1-144; 1987, 79-90; Tite 1983, 17-27.
4. Peltenburg, 1968; Bimson, 1973, 183-4; Pollard - Moorey, 1982, 45-50; Tite in Reade, 1987, App. 35-8; McGovern 1987, 91-115; Mazzoni 1987, 65-77.
5. Foster's and Kaczmarczyk's (1982, 143-57) pioneering x-ray fluorescence analysis, on the Minoan objects in the Ashmolean, is the only analytical account on Minoan faience.
6. Cadogan, 1976, 19; Foster 1979, 56.
7. The absolute dates are taken from Warren and Hankey 1989, 169, Table 3.1.
8. Foster, 1979, 22ff.; Moorey 1985.
9. Riefstahl, 1968, 3; Lilyquist, 1993, 5; Nicholson, 1993, 6.
10. Evans, 1902-3, 67ff.; 1921, 498ff.; Mackenzie, DM/DB 1903, 87-8.
11. The term "Egyptian faience" was originally applied to vitreous materials found in Egypt and it was then extended even to materials found in the Near East. The term "faience" was eventually established in 1936 by Beck and Stone. On the etymology of the word and the relevant literature see Peltenburg, 1987, 5.
12. Nicholson, 1993, 9.
13. Nicholson, 1993, 11.
14. On the methods of Egyptian faience glazing, see Vandiver, 1982, 168-9; 1987, 80-1; Peltenburg, 1987, 10; Nicholson, 1993, 11-14.
15. Nicholson, 1993, 13.
16. I thank Prof. M. Tite for this information which comes from his analyses on Minoan faience in the Ashmolean.
17. Vandiver, 1987, 80.
18. Cadogan, 1976, 19.

19.Evans, 1902-3, 95, 98; 1921, 170; Seager 1912, 55; Xanthoudides, 1924, 31, 69, 124; Panagiotaki, 1995, 146.
20.Evans, 1921, 252-3; Cadogan, 1976, 19; Foster, 1979, 60-1, plate I.
21.Gold trimmed vases of faience and glass have been found in the Near-East as well as in Egypt, see Lilyquist and Brill, 1993, 9-10.
22.Cadogan, 1976, 19.
23.Evans, 1921, 301-14; Foster, 1979, 99-115.
24.On the composition of colours on the Minoan faience see Foster, 1987, 57-64.
25.Petrie, 1909, 108, fig. 116; Kaczmarczyk, 1983, 305.
26.Vandiver, 1982, 176.
27.Evans, 1921, fig. 344.
28.Evans, 1921, fig. 379.
29.Evans, 1921, figs. 366-7, 369.
29.Evans, 1921, fig. 364.
30.Panagiotaki, 1993, 59-60, fig. D.
31.Lucas and Harris, 1962, 141.
32.Evans, 1921, fig. 357a,b.
33.Evans, 1921, fig. 377.
34.Platon, 1971, fig. at page 142.
35.Platon, 1971, fig. at page 149.
36.Lilyquist and Brill, 1993, 5.
37.Riefstahl, 1968, 2; Tite, 1986, 39; Nicholson, 1993, 16.
38.Seager, 1912, 55.
39.Evans, 1921, 170.
40.Riefstahl, 1968, 2; Tite, 1984, 215-42; 1987, 39-46; Nicholson, 1993, 16.
42.Nicholson, 1993, 16; see also Lilyquist and Brill, 1993, 5: "by Dynasty 4, ca. 2400 B.C., they had manufactured Egyptian blue".
43.Lilyquest and Brill, 1993, 5, 8.
44.Oppenheim, 1973, 262; Vandiver, 1983, 136; Peltenburg, 1987, 13-14.
45.Barag, 1962, 8-27; 1970, 131-201; 1985; Oppenheim, 1973, 259-63; Peltenburg, 1987, 14-23.
46.Lilyquist and Brill, 1993, 5ff.; Nicholson, 1993, 42-50.
47.Cadogan, 1976, 18-19.
48.Cadogan, 1976, 19.
49.Evans, 1928, fig. 440.
50.Nicholson, 1993, 16.
51.On such moulds see Hughs-Brock, 1973, 121.
52.Lucas and Harris, 1962, 267.

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ΠΕΡΙΛΗΨΗ

ΜΙΑ ΜΕΛΕΤΗ ΥΑΛΩΔΩΝ ΥΛΙΚΩΝ ΑΠΟ ΤΗ ΜΙΝΩΙΚΗ ΚΡΗΤΗ

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Η Μινωική υαλόμαζα και η υάλωση πρωτοεμφανίστηκαν στην Κρήτη την 3η χιλιετία, ενω το γυαλί εμφανίστηκε στη 2η. Δεν είναι σαφές το κατά πόσον η εμφάνιση των υλικών σήμαινε επίσης και τοπική παραγωγή. Οι αρχαιομετρικές αναλύσεις μας στοχεύουν στη διερεύνηση της προέλευσης των πρωιμότερων αντικειμένων, καθώς και της πηγής της τεχνολογικής γνώσης που είχε ο Μινωίτης τεχνίτης της φωτιάς: σε ποιό βαθμό δηλαδή την είχε λάβει απο αλλού και σε ποιό βαθμό την είχε αποκτήσει μεσα απο τους δικούς του πειραματισμούς. Η λεπτομερειακή οπτική και μικροσκοπική εξέταση ενός μεγάλου αριθμού μινωικής υαλόμαζας και γυάλινων αντικειμένων δείχνουν τοπική παραγωγή.

Ο Μινωίτης τεχνίτης της φωτιάς ήταν ακόμη προικισμένος ζωγράφος και γλύπτης. Παρήγε τέτοια αντικείμενα, ώστε σε καμία περίπτωση δεν μπορούμε να τα συγχέουμε με Αιγυπτιακά ή με εκείνα που έχουν Μεσανατολική προέλευση. Τα αντικείμενα αυτά διακοσμούσαν τα ανάκτορα, ιδιαίτερα εκείνο της Κνωσού. Ίσως η Κνωσός να ήταν το σημαντικότερο κέντρο παραγωγής για τα υλικά αυτού του είδους.