Journal of Archaeological Science 36 (2009) 370–378

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Colour in Minoan faience

M.S. Tite [a,*], Y. Maniatis [b], D. Kavoussanaki [b], M. Panagiotaki [c], A.J. Shortland [d], S.F. Kirk [d]

[a] Research Laboratory for Archaeology and the History of Art, University of Oxford, Dyson Perrins Building, South Parks Road, Oxford, OX1 3QY, UK
[b] Laboratory of Archaeometry, Institute of Materials Science, NCSR "Demokritos", 15310 Aghia Paraskevi, Attiki, Greece
[c] Department of Mediterranean Studies, University of the Aegean, 1, Demokratias Street, 85100 Rhodes, Greece
[d] Centre for Archaeological and Forensic Analysis, Department of Materials and Medical Sciences, Cranfield University, Shrivenham, Wiltshire, SN6 8LA, UK

ARTICLE INFO

Article history:
Received 6 May 2008
Received in revised form 22 August 2008
Accepted 14 September 2008

Keywords:
Faience
Weathering
Colorants
Manganese
Copper
Iron
Replication
Scanning electron microscopy
Energy-dispersive spectrometry
Crete
Middle Minoan
Late Minoan

ABSTRACT

The microstructures and chemical compositions of some 15 faience objects from Crete spanning the period from Middle Minoan IIIA through to Late Minoan IA are determined using analytical scanning electron microscopy. The Minoan faience is compared with replicate faience beads produced in the laboratory using various combinations of manganese, copper and iron as colorants. The alkali contents of the replicate beads are varied so that the colorants are present both as ions in a glass phase and as particulate oxides. These data are then used to try to infer the original colour of the Minoan faience, the great majority of which has suffered severe weathering during burial. The results suggest that instead of the present day "hallmark greys and browns" and "subtle greens and blues", Minoan faience originally exhibited a wide range of colours, including bright turquoise blue, purple and violet, and pale yellow-green and greenish turquoise.

1. Introduction

Faience, mainly as beads but also including the occasional vessel, first appeared in Minoan Crete (Foster, 1979; Panagiotaki et al., 2004, p. 150) during the 3rd millennium BC. The technology for the production of faience was almost certainly introduced from Egypt or the Near East (Kaczmarczyk and Hedges, 1983; Caubet, 2007; Panagiotaki, 1999a; Tite and Shortland, 2008), and it is probable that some of the early faience objects were also imported from these regions (Panagiotaki et al., 2004; Panagiotaki, 2008). However, well before the end of the 3rd millennium BC, the main body of Minoan faience was being made locally since the faience objects clearly match Minoan iconography in which nature is glorified in the form of animals and sea creatures or flowers and plants (Panagiotaki et al., 2004, p. 170).

During the period from Middle Minoan IIIA to Middle Minoan IIIB to Late Minoan IA (i.e., 1700–1480 BC), the manufacture of faience in Crete reached a peak (Panagiotaki, 1999a,b). A primary characteristic of Minoan faience during these periods was the production of polychrome plaques and figures in which white paste was inlaid into, what is now, a grey or brown body, and grey or brown paste into a white body (Panagiotaki, 1995, 1999a,b). The plaques include the MM IIIA Town Mosaic House facades from the Palace of Knossos in which, as described by Foster (1979): "one sees the hallmark greys and browns, subtle greens and blues, vibrant highlights of red, and confident use of white".

In producing this polychrome faience, the colorants used were various combinations of copper, manganese and iron (Foster and Kaczmarczyk, 1982; Foster, 1987, 2008). The resulting colours depend, first, on whether the copper, manganese and iron are present as ions within a glass phase or as oxide particles, and second, on whether the faience is produced in an oxidising or reducing atmosphere. Thus, with copper, in an oxidising atmosphere, Cu^{2+} ions produce a bright turquoise blue glaze whereas, in a reducing atmosphere, Cu^{+} ions do not colour the glaze. The corresponding cupric and cuprous oxide particles (CuO and Cu_2O) are black and red respectively, but these are not used as colorants in faience. With manganese, in an oxidising atmosphere, Mn^{3+} ions produce a purple glaze whereas, in a reducing atmosphere, Mn^{2+} ions produce a weak yellow-brown colour. Irrespective of their oxidation state, particles of all the manganese oxides

---

* Corresponding author. Tel.: +44 1865 558422.
E-mail address: michael.tite@rlaha.ox.ac.uk (M.S. Tite).

0305-4403/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jas.2008.09.031

(MnO_2, Mn_2O_3, Mn_3O_4 and MnO) are black. With iron, in an oxidising atmosphere, Fe^{3+} ions produce a green-brown glaze whereas, in a reducing atmosphere, Fe^{2+} ions produce a blue-green glaze. The corresponding oxide particles, haematite (αFe_2O_3) and magnetite (Fe_3O_4) are red and black respectively.

When a glass or glaze is subjected to weathering by the action of water, the alkali ions (Na^+ and K^+) are replaced by hydrogen ions (H^+) and the glass network progressively breaks up. Thus, the silica glass network structure is lost, and is replaced by an amorphous silica gel. In addition to leaching out of the alkalis, there is also some leaching out of the colorants. Furthermore, because of the destruction of the glass network, the surviving colorants will no longer be present as ions but will have been deposited as fine, amorphous or poorly crystalline particulate compounds. Therefore, the colour of weathered glass or glaze can be very different from its colour in its original unweathered state.

Since the great majority of Minoan faience has suffered severe weathering, the faience glazes and the interparticle glass bonding together the quartz particles within the faience cores are much altered in microstructure and composition, and have frequently been lost entirely. Therefore, it is extremely difficult to infer the original colours of Minoan faience from the colours observed at the present day.

In an attempt to obtain a better understanding of the changes in microstructure and composition that have occurred in Minoan faience as a result of weathering, and hence to be better able to infer its original colours, small groups of MM IIIA and MM IIIB-LM IA faience have been subjected to examination by analytical scanning electron microscopy (SEM). These analytical data are compared with the results of non-destructive analysis, using XRF operated in air, of the surfaces of some 40 faience objects from Knossos, spanning the same chronological period (Foster and Kaczmarczyk, 1982).

In addition, replicate faience coloured with various combinations of manganese, copper and iron was produced in the laboratory, and similarly examined in the SEM. These new replication experiments extend previous research which has mainly concentrated on replicating the methods of glazing (Tite and Bimson, 1986; Vandiver, 1998; Tite et al., 2007), forming (Vandiver, 1983; Griffin, 2002) and inlaying (Riccardelli et al., 2002), with only copper, and sometimes cobalt, being the colorants normally used.

2. Experimental procedures

The Minoan and replicate faience samples were examined in polished cross-sections in analytical SEMs using the backscatter detector mode in which the different phases present can be distinguished on the basis of their atomic number contrast (e.g., quartz appears dark compared to the higher atomic number phases containing copper, manganese and iron).

The compositions of any surviving glaze layers, and interparticle glass phase and other phases present in the faience were determined by spot analyses using energy dispersive spectrometers (EDS) attached to the SEMs. The bulk compositions of the faience bodies were similarly determined by analysing areas approximately 0.3 mm × 0.3 mm. The instruments were typically run at 15 kV and 5 nA, and the resulting analytical totals were automatically normalised to 100%. Because of the overlap of sodium and copper peaks, in the presence of high copper contents, the measured soda contents can be too high. The detection limits are around 0.1 wt%, and the relative errors are 5–10% for major and minor elements, and up to 15% for elements present at the 1% or less level.

2.1. Laboratory replications

For the laboratory replication of Minoan faience, small cylindrical beads approximately 10 mm in diameter and 10 mm in height were prepared from various mixtures of quartz, sodium carbonate, calcium carbonate, copper carbonate, manganese oxide

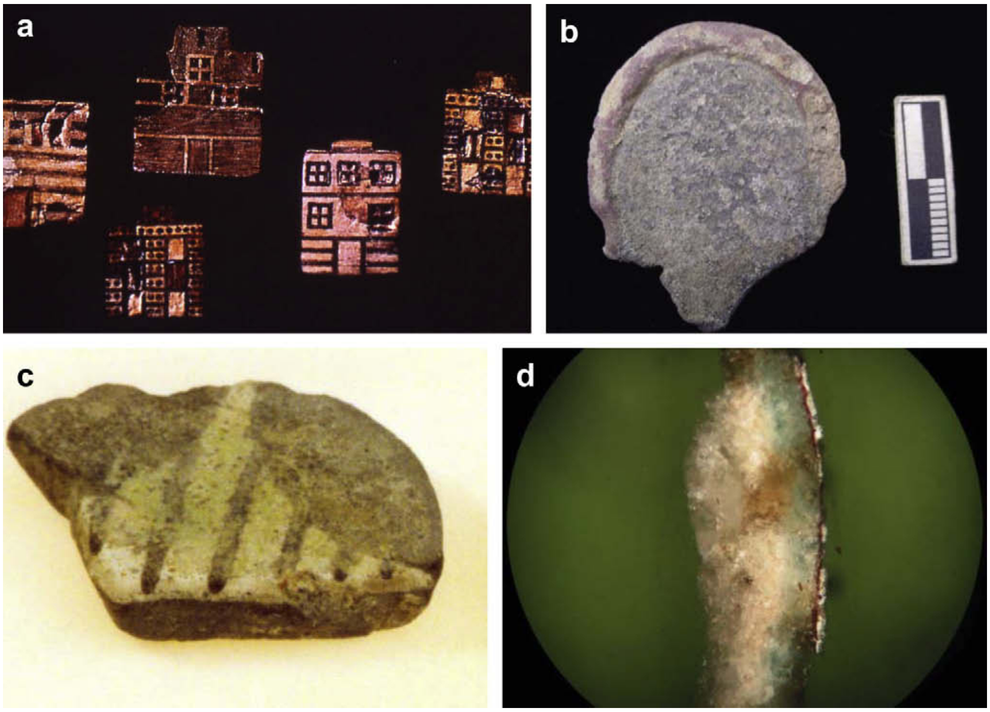

Fig. 1. (a) Fragments from Town Mosaic House facades from the Loom Weight Basement at the Palace of Knossos. (b) Feather shaped plaque from Festos consisting of white core encircling the widest part of the brown -grey body. Areas of white core are visible but the brown-grey body is concealed by a purplish coating. (c) Roundel from the Throne Room at the Palace of Knossos showing white bands in the brown-grey body. (d) Cross section, as seen under an optical microscope (section width ~1 mm), through white cord encircling the brown-grey body of a feather shaped plaque (F4) showing, from right to left, a white gypsum layer deposited during burial, a very thin purple layer, a bluish-green glaze–body interaction layer (~ 1/3rd total cross section), and underlying white body.