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THE BLUE COLOUR ON THE AKROTIRI WALL-PAINTINGS: FROM THE PALETTE OF THE THERAN PAINTER TO THE LABORATORY ANALYSIS

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The pigments used for the blue tones in the Theran wall-paintings have been the subject of research since the early years of the Akrotiri Excavations. Specialists have detected the use of both 'Egyptian blue' or glaucophane riebeckite, the former a man-made pigment (one of the most ancient synthetic pigments originating from Egypt) and the latter a natural pigment (inosilicate minerals belonging to the group of the alkali amphiboles). In 2011-2012, the authors implemented a research programme, funded by the University of Ioannina and the Institute for Aegean Prehistory (INSTAP), aimed at clarifying the use of the two pigments in the Thera wall-paintings, by applying the recently developed non-invasive imaging method of infrared photoluminescence for the diagnosis of 'Egyptian blue'. This paper presents the preliminary results of the project, which suggests that the selection of one or the other pigment, or even a combination of both pigments, by the painters was made on the basis of iconographic criteria, with the aim of achieving from a technical viewpoint the optimal aesthetic effect and chromatic tone, rather than of economizing or promoting a more expensive material.

Why blue colour?

Until two decades ago, it was stated stereotypically of the Theran wall-paintings that they constituted a single corpus of monumental painting in which four colours had been applied to depict the figurative, geometric, and decorative motifs: red, yellow, black and blue[1]. These basic colours are indeed applied on the white plaster ground, which, as a neutral but exceptionally bright canvas, highlights the depicted motifs, projecting them with clear outlines to the viewer, both ancient and modern[2]. However, in reality, the colours of the Akrotiri wall-paint-

[1] Yellow and red are common ochres found even today in veins in the pre-eruption rock formations in the Theran caldera, while the black used in the wall-paintings is either (a) carbon black, easily produced by charcoal or bones or (b) the mineral manganese dioxide.

[2] On the white ground of Cycladic, and in particular Theran, wall-paintings: see Davis 1990, 214-218; Doumas 1992, 17-20; Televantou 1994, 376.

ings were never just four, given that various tones of the aforementioned basic colours occur in all the known specimens[3], the most frequent being the orange of the upper zones, the colour most similar to that of the ceiling's wooden beams. Nonetheless, the colours produced by mixing the basic colours, such as green and olive green, purple and pink, brown, and grey were not mentioned, an absence that was mainly in the bibliography, rather than in reality, as was later demonstrated. Over the last decade and due to the conservation of the wall-paintings of the very densely painted building Xeste 3, certain novel colours have emerged, such as green, murex purple, pink, grey, and added white (used as overlay), significantly varying the palette of the workshop that decorated the building. These colours have been discussed on occasion in their painting context (Vlachopoulos 2003; Chrysikopoulou 2000), while concurrently a series of analyses was carried out using state-of-the-art scientific methods.

The colour blue or, more precisely, the pigments used to produce the blue tones of the Theran paintings have been the subject of research since Professor Christos Doumas assumed the directorship of the Akrotiri excavations (Doumas 1992, 18, 23). Specialists had detected the use of Egyptian blue and glaucophane, the former an artificial pigment, the latter a natural pigment, which was verified every time that samples of painted plaster were analysed over the following decades. The recent development of Visible-induced Infrared Luminescence (VIL) imaging (Verri 2009) as a method of detecting the presence of 'Egyptian blue', led to a small research project conducted by the authors in 2011 and 2012 with funding from the University of Ioannina and INSTAP, aim of which was to clarify the use of the two blue pigments on Theran paintings in the largest possible sample, given the large volume of wall-paintings added to the corpus in recent years.

What are 'Egyptian blue', glaucophane, riebeckite and blue amphiboles: applying the VIL method to detect and map 'Egyptian blue'

The term 'Egyptian blue' characterizes one of the most ancient synthetic pigments, which originates from Egypt. It first appeared in the third millennium BC, while its production and use continued until the end of the Roman period. The colour of 'Egyptian blue' is due to the tetrasilicate calcium-copper salt $CaCuSi_4O_{10}$ (the natural mineral with this crystalline structure is cuprorivaite), which is created by firing a mixture of quartz, calcite (ground limestone or sea shells) and a copper compound, in the presence of an alkaline flux that lowers the melting point of the mixture to a temperature between 850^0 and 1000^0 Celsius (Jaksch 1983). Egyptian blue, like 'Egyptian green', was used in Antiquity mostly as a pigment that was applied to various substrates, primarily wall-paintings, and secondarily as a material for making minor objects, such as beads, scarabs, seals, small figurines, etc. The earliest find of Egyptian blue is on a wall-painting

[3] For example, the differentiation of the colour tone on the body, which reflects their age difference, had been observed in the wall-paintings of the 'Naked Boys' of Xeste 3 some time ago: Doumas 1987; Doumas 1992, 23-24; Doumas 2000, 971-972, Table 1.

from tomb 3121 in the Saqqara necropolis, dating to the reign of 'Ka-sen', the last ruler of the 1st Dynasty (~2900 BC). However, Egyptian blue was widely diffused in Egypt from the 4th Dynasty (~2600 BC) onwards, continuing in use until the Ptolemaic period (Hatton *et alii* 2008). During the second millennium BC, Egyptian blue was employed widely in the Eastern Mediterranean, Egypt and Mesopotamia (Hatton *et alii* 2008), the Aegean (Filippakis *et alii* 1976; Profi *et alii* 1974; 1976; 1977), and the Middle East (Miletus, Tel Kabri, Tell Sakka: Brysbaert 2008, 134-139). The raw copper material, which is added and homogenized in a mixture with quartz, calcium carbonate, and soda, possibly derives either from a copper mineral (e.g. malachite) or from filings of the (oxidized) metal or an alloy (e.g. bronze). The detection of tin at a percentage greater than 0.2-0.3% in the elemental micro-analysis of a large number of Egyptian blue samples seems to confirm the practice of recycling useless fragments (primarily of bronze and secondarily of other copper alloys) in the preparation of the synthetic pigment, in the majority of cases. The recycling of bronze, as demonstrated by the analyses, was a common practice all over the Eastern Mediterranean (Brysbaert 2008, 135-136) – in Egypt and Mesopotamia (Hatton *et alii* 2008), the Aegean[4], as well as in the Middle East (Brysbaert 2008) – during the second millennium BC.

Glaucophane and riebeckite are silicate minerals belonging to the group of alkali-amphiboles (rich in sodium) with the general formula $Na_2(Mg,Fe^{+2})_3(Al,Fe^{+3})_2Si_8O_{22}(OH)_2$ and are characterized as blue amphiboles. In this group of amphiboles are included Ferro-Glaucophane $Na_2(Fe^{2+}{}_3Al_2)Si_8O_{22}(OH)_2$, Glaucophane $Na_2(Mg_3Al_2)Si_8O_{22}(OH)_2$, the intermediate phase of Crossite $Na_2(Mg,Fe^{+2})_3(Al,Fe^{+3})_2Si_8O_{22}(OH)_2$, Riebeckite $Na_2(Fe^{2+}{}_3Fe^{3+}{}_2)Si_8O_{22}(OH)_2$ and Magnesio-Riebeckite $Na_2(Mg_3Fe^{3+}{}_2)Si_8O_{22}(OH)_2$ (Katagas 1974). Their colour depends on the relative concentration of iron/magnesium. In fact, only magnesio-riebeckite is blue, while glaucophane has a dark grey-bluish colour that becomes grey when ground (Perdikatsis *et alii* 2003).

The Visible Induced Luminescence imaging method was applied, to detect and to map the use of Egyptian blue on the wall-painting compositions. This method was proposed by G. Verri (2009) and is based on Egyptian blue cuprorivaite's property of emitting infrared luminescence when excited in the visible area. The exact conditions of excitation and acquisition were improved by taking into consideration the spectroscopic behaviour of the material (Accorsi *et alii* 2009). This exceptional property of Egyptian blue allows us to distinguish it from all other natural or synthetic blue pigments that are not photoluminescent in the spectral range under study.

During the application of the aforementioned method on the Akrotiri wall-paint-

[4] In the elemental analysis by the XRF method of a large number of Egyptian blue samples from various sites on the mainland and the islands, it is observed that the tin percentages are higher in the samples collected from Mycenaean sites and in particular Mycenae (Profi *et alii* 1976).

ings, LED PAR lights were used for excitation (Eurolite LED PAR56 RGB spots 20W, (151 LEDs), 45°), of which the red LEDs were used selectively), a visually opaque polyester filter (LEE polyester IR filter 87 – visually opaque filter with transmission starting at 730) was placed in front of the lens of the digital photographic camera (SONY camera A300, 10.2 Mpixels) to absorb unwanted visible light. The camera's built-in IR-blocking filter, which is placed in front of the CCD sensor, was removed.
For all shots, a specifically designed Egyptian-blue scale was placed next to the sample. The scale consists of colour gradations of Egyptian blue resulting from mixing pure Egyptian blue pigment with white in a gradually increased concentration. The scale allows a rough estimate of the relative concentration of Egyptian blue in the sample examined.
We were able to identify the following cases, which were crosschecked against the analytical study of representative layered cross-sections:
-Complete absence of Egyptian blue, which is diagnosed in the cases of absolute absence of luminescence. In these cases we conclude that the blue pigment is riebeckite.
-Egyptian blue mixed with riebeckite, in the cases where the surface exhibits weak fluorescence that does not correspond to the visible coverage of the blue layer (in these cases we assume that Egyptian blue is present in the mixture in low concentration).
-Pure Egyptian blue in the cases where the surface shows intense fluorescence corresponding to the visible coverage of the blue layer. In some cases the Egyptian blue layer seems to be greatly diluted (the layer is translucent like a glaze), which is also reflected in the photoluminescence images.

A brief history of the research on Theran wall-paintings and their pigments
The earliest wall-painting fragments found at Akrotiri were badly eroded pieces of painted plaster that came to light in 1967, inside the building later called Building Beta (Marinatos 1967, 39-47, figs. 64-66; cf. Georma 2010, 58 ff.). This is the first time that the blue colour is mentioned[5]. In the following year, larger and smaller groups of painted plaster fragments were gradually revealed in the same building, and later on in the 'Porter's Lodge' (the vestibule of an unexcavated building in the north sector of the excavation), in Building Gamma, in the 'House of the Ladies', in the West House and – especially during the final years of the excavations conducted by Professor Spyridon Marinatos – the large building complexes of Xeste 3 and Xeste 4.
In his excavation reports, Marinatos does not address issues such as pigments and

[5] The first fragments of wall-paintings from the Akrotiri Excavation were cleaned and studied by Professor E. Vermeule (Marinatos 1967), with no specific plan and specialized knowledge, as recorded by conservator-painter T. Margaritoff (Margaritoff 2006, 97), who from 1968 was responsible for the scientific conservation of the fragments, which until that time were cleansed with water.

colour conventions. He focuses on the iconography of the wall-paintings, especially from 1969 onwards, when their concurrent conservation allowed for more confident approaches. However, immediately after the discovery of the monkeys from Building Beta, he immediately called them "blue monkeys" (Marinatos 1969, 33; cf. Georma 2010, 61, 197). And yet, for the long Flotilla wall-painting from the West House (Marinatos 1973), where sea water is predominant, he makes no observation on the absence of a homogenous blue pigment, even though this is the colour used to depict the 'life-giving water' of the rivers of the 'Miniature Frieze' (Marinatos 1972, 40, 42). The only case in which he commented on the blue colour in the wall-paintings is the grey-blue (shaven) heads of the fishermen and the young priestess from the West House (Marinatos 1972), and the young girls from Xeste 3[6]. When describing the Boxing Children from Building Beta, he had assumed the presence of a head cover (wig) before realizing that their heads were shaven (Marinatos 1970, 47-49, fig. 3, colour pl. E, F). After Doumas had brought to light the 'Naked Boys' ensemble from Xeste 3, he returned to the issue of the blue heads, ascertaining that this colour denotes the shaven hair of the head, where a few locks are left to grow, according to the age or the stage of initiation of the figure depicted[7]. In his synthetic presentation of the Theran wall-paintings, he deals with the blue pigment, noting the use of blue in thematic cycles and commenting on its tones (Doumas 1992, 19, 23-24).

The first analyses of Theran pigments that confirmed the use of Egyptian blue, but also showed the use of 'blue amphiboles', were carried out in the 1970s by S. Filippakis (Filippakis *et alii* 1976; Filippakis 1978) and later by V. Perdikatsis (Perdikatsis 1998), a key researcher in this field. These analyses identified the blue amphiboles as glaucophane. However, with the analytical methods used at the time – a combination of X-ray Diffraction (XRD) and X-ray Fluorescence (XRF) – no distinction could be made between ferro-glaucophane and magnesio-riebeckite, since the amphibole group minerals, such as tremolite, actinolite, hornblende, riebeckite, and glaucophane, appear to have the same characteristic peak $2\theta=10.70$ with d=8.3Å in the XRD spectrum (Westlake *et alii* 2011), while the XRF elemental analysis, which identified iron as the main element of the colour compound, was unable to detect light elements such as magnesium or sodium. Furthermore, the characterization of the identified blue amphiboles as glaucophane is open to question, since glaucophane is a dark blue-grey pigment that becomes grey when ground. On the contrary, magnesio-riebeckite produces blue-grey and in some cases plain blue that is encountered extensively in the compositions of Building Beta, the 'Porter's Lodge', and elsewhere.

At the *First International Symposium on the Wall-paintings of Thera* (1997), the next generation of researchers presented together with Perdikatsis the then latest data from laboratory analyses, including elemental micro-analyses using the

[6] Marinatos 1972, 36-38, fig. 4, pl. 88, 90; Marinatos 1973a, 35 colour pl. A-E; Marinatos 1973b, 199-200.

[7] Doumas 1992, 46-47; Doumas 2000, 972-973, Table 1. Cf. Davis 2000, 868-870, Table 1.

Scanning Electron Microscope (Perdikatsis *et alii* 2000), as well as from experimental tests (Chrysikopoulou *et alii* 2000). On the basis of these analyses and thanks to the detection of magnesium in the elemental micro-analysis of amphibole granules in the stratified cross-section of samples with blue details, the blue amphiboles were identified as magnesio-riebeckites, which give the blue-grey colour observed on the wall-paintings of Akrotiri, as well as of Knossos (Westlake *et alii* 2011).

The aforementioned publications were the outcome of the first programmes of coordinated collaboration between archaeologists and physicists, without whose synergy corresponding research projects are doomed to be one-sided. Detailed analyses of the blue pigments on samples from the wall-paintings from Xeste 3 (rooms 3, 5 and 15), from the West House and from buildings Alpha and Delta, had shown that Egyptian blue and amphiboles are present in equal measure on the Theran wall-paintings, either separately or mixed or superimposed in varying relative amounts. In fact, it has been suggested that it were Theran artists who first introduced amphiboles into the 'Minoan' painting palette of the second millennium BC (Perdikatsis 1998; Aloupi *et alii* 2000). This hypothesis is difficult to document, however, as earlier (Perdikatsis 1998; Perdikatsis 2000) and more recent analyses suggest that the widespread use of magnesio-riebeckite during the second millennium BC was a privilege of the Aegean (which is documented mainly on Thera and Crete, on the basis of the analytical data available), in contrast to Egypt and the Middle East, where blue amphiboles have been recognized on extremely few wall-paintings (Brysbaert 2008, 130, Table 6.7a; Hatton, 2008).

The presence of Egyptian blue was confirmed by the XRF method on two wall-paintings from Xeste 3 (on the blue head of the little boy from the composition of the 'Naked Boys' and on the belt of the 'Lady with the Flying Fish' (Pantazis *et alii* 2003, 157-158, pl. XXXIX.c), where it was also shown that the green pigment on the rocks of the same zone and on the bouquets of wild roses held by the homonymous figure from the 'Ladies with the Bouquets' was produced by mixing yellow ochre with Egyptian blue (Pantazis *et alii* 2003, 157-158, pl. XXXIX.c).

Over the decade 2001-2011 a large number of macroscopic observations on the various pigments of the Theran wall-paintings was made[8], thanks to the increasing rate of conservation achieved in the Wall-paintings Conservation Laboratory (Doumas 2007, 29-30). The use of organic purple pigment obtained from the murex mollusc was confirmed[9] and its presence was noted on the wall-paintings

[8] The laboratory analysis of the blue pigments of the Theran wall-paintings was the subject of a specialized project at the University of Aarhus in Denmark, whose researchers were supplied with a large number of samples during the period 1999-2001. However, their findings have not been shared with the Akrotiri Excavations, nor has there been any relevant publication.

[9] Chrysikopoulou/Sotiropoulou 2003; Chrysikopoulou 2005; Sotiropoulou 2005; Sotiropoulou/Karapanagiotis 2006.

of Xeste 3, a public building richly decorated with mural compositions depicting ritual scenes associated with the rites of passage of Theran boys and girls[10]. The demanding conservation and final restoration of the wall-painting of the 'Sanctuary', above the 'Lustral Basin' of the ground floor, revealed a leafy tree (most likely an olive tree) growing behind the portalled façade of the sanctuary, with doorway, and it was noted that riebeckite was also used to achieve the homogenous blue-grey ground of the leaves.

Similar questions have been raised regarding the very large 'Reed-bed Wall-painting', where half the reeds have been painted in a uniform grey shade, which may appear blue at the tip of a light brush-stroke, with the help of the composition's white ground (Vlachopoulos 2000; 2008).

In the analysis of samples from the wall-painting, the use of carbon black as well as of amphiboles in different concentrations was ascertained. On the contrary, a strong blue colour, though extensively lost in most parts, was used for the wicker-flowers in the wall-paintings from Room 9 of Xeste 3 (Vlachopoulos 2008, 454, figs. 41.41-42). The case of the blue pigment in the 'wall-painting of the palm trees' from Room 2 is different. Here the leaves of the two symmetrical palm trees in the composition and the body of the duck flying to the left have been painted in blue, now almost completely lost, while the pigment used for the grey reeds of the riparian landscape is better preserved (Vlachopoulos 2008, 451, figs. 41.7-9).

In the same decade (2001-2011), conservation and restoration of the immense volume of wall-paintings depicting large blue spirals, from the second floor of Xeste 3, was completed. This mural decorated the north wall of the east part of the building, that is, above the 'Lustral Basin' and the composition with the young female Saffron-gatherer, the Monkey and the 'Mistress of the Animals' ('Potnia') with dimensions 5.20 x 3.05 m (Doumas 2007, 18-21, figs 18-20; Vlachopoulos 2008; Vlachopoulos 2010). The recurring motif in this great wall-painting (the largest that has been restored in the prehistoric Aegean) is symmetrical pairs of spirals from a blue stem – on a white (above) and a red (below) ground – that create a continuous heart-shaped motif (ivy leaf), at the triangular tip of which is a monochrome blue lozenge enclosing a rosette. Smaller heart-shaped spirals are arranged horizontally in a band (frieze) of the upper part of the wall-painting. At least three friezes with similar running spirals decorated surfaces above the pier-and-door partitions or the windows of this large space (Vlachopoulos 2008; Vlachopoulos 2010).

So extensive is the bright blue that it was apparent from the outset that the largest quantity of blue pigment attested so far at Akrotiri was used for these wall-paintings (estimated surface approx. 25-27 m^2). Apart from the blue stems of the spirals, the monochrome curvilinear lozenges, and the large and small spirals, all the antithetic spiral-tentacle-shaped motifs arranged symmetrically around the main

[10] Marinatos 1984; Doumas 2000; Vlachopoulos 2008; Vlachopoulos 2010.

subject are also blue, as is the wide band sandwiched between the black bands, which separates the main composition from the overlying frieze.
Smaller quantities of equally bright blue pigment have been used on the south symmetrical wall of the same space, which was decorated with identical, but colour-reversed, red spirals on a white ground (Vlachopoulos 2008; Vlachopoulos 2010). In this case, the 16-petal rosettes of the lozenges and the disc-shaped 'suns' of the spiral-tentacle-shaped elements sprouting from the large spirals were painted in blue.
Also from the second floor, but from its northwest part, are at least two wall-paintings with white wavy lozenges in relief, inside which are groups of four 16-petal rosettes, identical to those of the wall-paintings of the spirals (Doumas 1992, figs. 136-137; Doumas *et alii* 2008). The relief lozenges with blue rosettes are arranged symmetrically and circularly around lozenges enclosing purple (now effaced) rosettes, creating a light reversed-colour effect between the central and the surrounding zone. In this case, the blue pigment is also bright and well-preserved, in contrast to the cases where it has been added to another pigment (mainly black), as in the example of the 'red spirals', where it has flaked, not during the conservation phase, but before, mainly due to the taphonomic conditions and their effect on the preservation of the pigments.
Detailed examination of the blue parts from the compositions of the 'blue spirals' and the 'red spirals' (and certainly of the blue elements on the wall-paintings of the 'relief lozenges'), using the infrared photoluminescence method, showed that they were painted in Egyptian blue, which was applied uniformly and in the same tone on the spirals (Fig. 1a-b) as well as on the rosettes (Fig. 2a-b).

Towards an iconographic quest for blue in nature: water and sky

In the North Miniature Frieze (NMF) of the West House[11], the seawater that is the setting of the dramatic event (battle?) is not painted blue, but is indicated by the white of the lime plaster, with close-set small lines (like hatching), rendered by minimal stokes of Egyptian blue, indicating the volume of the water. However, plain Egyptian blue has been used to render the blue rocky coastline of this town (Fig. 3a-b). In the South Miniature Frieze[12] (SMF) the sea is not painted in the same colour (tone) across the composition. The sea in the bay of the natural harbour of the departure town is dark blue, while the surrounding river is a brighter blue (Fig. 4a-b). From the first oared ship and further to the right, the colour of the sea is paler and has a more neutral (grey) tone[13]. However, the picture we have

[11] Doumas 1992, 47-48, figs. 26-29; Televantou 1994, 188-196, colour pl. 26-44.
[12] Doumas 1992, 48-49, figs. 35-48; Televantou 1994, 198-201, colour pl. 54-70.
[13] Amongst the Aegeanizing – as they are usually referred to – wall-paintings from the Canaanite Middle Bronze II palace at Kabri (possibly *ca.* 17th century), a miniature composition with a coastal landscape and ships has been restored, where the sea is rendered with a net pattern, just like in the minor arts and pottery of the early Late Bronze Age. There, as well as at contemporary Alalakh in Syria (Cline *et alii* 2011, 245, 256), the use of blue pigment was widespread (Cline *et alii* 2011, 250, 252, figs. 7-8, 11).

today is due to the taphonomic conditions of the wall-painting, judging from the fragment of the upper limit of the sea, behind the cabin of the captain of the central elaborately bedecked ship, where dolphins swim (Doumas 1992, figs. 36-37). Here the sea is painted in a dark purple shade, markedly different from the blue back of the dolphins (Fig. 5a-b). The sea in front of the harbour of the arrival town is also grey-blue, intensifying the questions regarding the extent to which the present image of the wall-painting deviates from the distant original. Bearing in mind these macroscopic observations and in our endeavour to document the role of the composition of the pigments in the above chromatic inconsistencies, we applied the infrared photoluminescence method in order to map the Egyptian blue on the wall-painting. Egyptian blue was identified in the river surrounding the departure town, in blue features of the buildings in Towns IV and V, on the rocks around the towns, on the back of the dolphins and on the keel of the ships. In the sea zone, Egyptian blue was identified only in the harbours of the two towns, up to the first oared ship in Town IV and along the coastline of town V. Thus, it was ascertained that the main sea zone on the SMF, with varying degrees of grey-blue, has been painted using riebeckite[14]. As to the reasons why this pigment was used to colour the open sea, we could say that the unsaturated, diluted grey-blue colour of riebeckite was chosen essentially as a neutral background, against which the dolphins and some elements of the ships are projected, depicted in vibrant Egyptian blue, in contrapuntal combinations with yellow and red ochre.

Correspondingly, and with consistency in the use of Egyptian blue according to the thematic repertoire of the compositions, Egyptian blue has been used for the rocks and the rocky coastline of the NMF, as well as for the great river running through the landscape of the East Miniature Frieze (EMF), where the wildcat, the palm-trees, the griffin, and the ducks were painted using the same pigment (Doumas 1992, 48, figs. 30-34; Televantou 1994, 196-198, colour pl. 45-53) (Fig. 6a-b).

Of special interest is the non-chromatic – unpainted white background – rendering of the seabed on the tripod offering table that was found in the West House, and specifically in Room 5 of the 'Miniature Frieze', where these two separate painted works were in common view (Televantou 1994, 258-259). Dolphins, corals, rocks, and marine flora decorate this portable object in naturalistic style, yet life on the seabed is developed on the white of the plaster (although the water bubbles are depicted by thick blue dots), since, as Christina Televantou observes, the Theran painter used white for the seabed and blue for the sea surface in the Miniature Frieze (Televantou 2007, 65, pls. 408, 14). However, as mentioned already, a mixed technique was employed to render the sea on that long painted composition.

The sky in the 'Miniature Frieze' is shown unpainted/white[15], as in all the Theran

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[14] As our assumption is based only on the results of the VIL imaging method and the visual examination, the use also of (carbon) black pigment cannot be excluded.

[15] The difference in the depiction of the elements of the white sky and the blue sea is clearly visible at the departure town. See Doumas 1992, fig. 36 (left).

mural landscapes, with one significant exception in the fragmentary wall-paintings from the 'Porter's Lodge', the vestibule of an unexcavated building located in the north sector of the excavation. Depicted on the frieze that probably extended along the north wall of this space (Marinatos 1968; Doumas 1992; Vlachopoulos 2007) is an elongated porticoed building (sanctuary?) with pillars in the shape of palm-trees and a roof crowned by a row of frontal double horns in 'reserved' white against the blue ground of the sky, which ends in a wavy line in the upper part of the composition. The monochrome sky is painted in thick Egyptian blue, obviously so as to ensure that the double horns can be seen when viewing the composition from below.
A spiralling blue motif in the same composition, which has been interpreted as a river (Vlachopoulos 2007, 134, pl.15.15) was also rendered in Egyptian blue, darkened in places by over-painting with black pigment. A river (or another watery element) in the lower part of the Blue Monkeys wall-painting from Building Beta, Room 6 (Doumas 1992; Georma 2010, 197, appendix, 57, 65) is also painted blue, but no Egyptian blue has been identified in this composition.

Did blue birds and blue monkeys exist in the Aegean?
Just as in Crete, it is most probable that in Thera too the blue on the birds was used to portray grey rock doves[16] and on the monkeys grey baboons[17]. Broad bands of white on both animals help to show more clearly the outlines and the volumes of their bodies. So, we see that the wall-painters of the second millennium BC in the Aegean chose bright contrasting colours (blue-white) for these two popular motifs, presumably because their palette did not offer choices that would portray them more realistically. Touches of bright red were used for the beak and the claws of the birds, and soft pink for some features of the monkeys' heads.
The at least seven blue birds of the 'Porter's Lodge'[18], which have been rendered with a vivid blue colour, were painted with riebeckite, without exception or any admixture of Egyptian blue, on the fragments examined. In the same composition, the same technique has been applied on the semi-transparent blue 'loops' rendering floral motifs or rocks. Depicted in the same, most probably, composition are at least two more blue adorant monkeys in front of the 'altar of the double horns', perhaps addressing a seated female figure[19]. The monkeys have been painted with riebeckite mixed with Egyptian blue, but not in fixed ratio, as the intensity of luminescence showed that on some pieces there is a much higher concentration of Egyptian blue, whereas on others it seems that Egyptian blue was only used in parts of the drawing, while the remainder is filled or coated with riebeckite (identified by the absolute absence of luminescence). At this point it

[16] Cameron 1968, 5, 7, figs. 1f, 3a-f, 11A, pls. 3.1-5, 4.1, colour pl. A.5; Vlachopoulos 2007, 133, fig. 15.3.
[17] Cameron 1968; Doumas 1992, 19; Georma 2010, 196-200, 200-203, appendix 55, 56, 58-59.
[18] Doumas 1992, 27; Vlachopoulos 2007, 132-133, pl. 15.2,4,6-10.
[19] Doumas 1992, 186, fig. 147; Vlachopoulos 2007, 134-135, pl. 15.1,3,4,12.

should be stressed that an additional advantage of using infrared photoluminescence imaging method is that one can very easily form groups of fragments belonging together and exclude others, thus optimising the process of wall-paintings restoration on paper or in a portable frame[20].

The most impressive monkey of the Theran wall-paintings in terms of pose and preservation is undeniably the one standing in front of the 'Mistress of the Animals' ('Potnia') from Xeste 3, offering the crocus stamens it has taken from a basket. It is obvious that saffron was placed in this basket after being collected from the nearby rocks by the female saffron-gatherers, who gradually arrive before the Great Goddess, to offer the flowers and receive her blessing. This monkey has been painted in bright Egyptian blue (Fig. 7a-b).

In contrast to the wall-paintings from Xeste 3 and the 'Porter's Lodge', no Egyptian blue was identified in the pack of monkeys from Building Beta – at least on the fragments examined – or on the rocks and the river of the same composition. Thus, it appears that in this building the palettes of the painters did not acquaint with the man-made (synthetic) pigment, challenging the validity of our opinion that the wall-painting in the 'Porter's Lodge' and especially the representation of the 'African', is by the same painter as the Boxing Children from Room 1[21]. Of course, this ascertainment can be turned the other way, that is, to formulate the hypothesis that Egyptian blue and riebeckite were both available to any painter or team of painters and could be used without specific rules, case by case, separately or in combination.

Blue in the natural world (flora)

On the Theran wall-paintings, blue or grey-blue colour has been applied on the green foliage of trees, bushes, and other plants, such as the young aquatic reeds, although it appears that Egyptian blue was used selectively here too, mainly for the miniature palm trees. The grey reeds of the extensive reed-bed from Xeste 3 yielded no trace of this pigment (Fig. 8a-b); neither did the thin blue bands which run in-between the black ones along the upper limit of the wall-painting.

In the dense iconographic programme of the 'Porter's Lodge', a rich in Egyptian blue paint has been used also to depict the leaves of the twin-trunk palm tree, towards which the so-called 'African' leans (Marinatos 1968; Doumas 1992; Vlachopoulos 2008). Identical in colour is the fragmentary palm tree on a wall-painting recovered from Building Gamma, while identical in terms of design and

[20] This was proved for example while testing the blue fragments from Building Beta, many of which do not have secure excavation or iconographic indications for identifying their subject. We would like to thank our colleague Dr. Fragoula Georma for her willing participation in the programme and her undivided assistance with the wall-paintings from this building, that she has studied (Georma 2010) and is preparing for publication.

[21] Vlachopoulos 2007, 136; however, the use of Egyptian blue cannot be ruled out for the shaven heads of the two Boxing Children, as well as for the belt of one of them, since this wall-painting, which is exhibited in the National Archaeological Museum, Athens, was not examined by this method.

colouring to those of the 'Porter's Lodge' are the palm trees of the EMF of the West House and the part of the palm tree adorning a decorated 'offering table' (Marinatos 1968; Doumas 1992; Vlachopoulos 2008). Last, the dense foliage of the two palm trees depicted on either side of a representation of quadrupeds and ducks from Room 2 of Xeste 3 is also blue, but the pigment has flaked in most parts[22].
The large papyrus plants from the 'House of the Ladies' have been painted entirely in bright blue (Doumas 1992, 34-35, figs. 2-5). However, they were not examined, as the restored wall-painting is exhibited in the Museum of Prehistoric Thera.

Blue on garments, jewellery, constructions and other motifs
The man with the gold earring and the blue double-stemmed plume, who is probably performing a ritual in front of the blue palm trees on the frieze from the 'Porter's Lodge' (erroneously referred to as the 'African', see however Marinatos 1988), wears a necklace and anklets of blue beads, painted in Egyptian blue (Fig. 9a-b). We assume the same for the various grey-blue pieces of jewellery worn by the 'Potnia' and the Saffron-gatherers from Xeste 3, especially for the diadems the girls wear on the forehead, although no photoluminescence imaging experiments were made on them. However, the experiments on the 'Necklace Bearer' from the ground floor (adyton) of Xeste 3 were positive. Her diaphanous bodice, skirt, and necklace were painted in Egyptian blue, as was the chemise of the 'Wounded Lady' next to her, yet the grey rock of her natural environment was painted with riebeckite. The 'Potnia' wears a long skirt, painted in Egyptian blue both on its solid parts and the diaphanous parts of the hem (Fig. 10a-b), as does the young Saffron-gatherer in front of her (Fig. 11a-b). Paradoxically, the biconcave altars of the goddess's pedestal are painted with riebeckite, but the blue 'stones' on its step exhibit luminescence evidencing the use of Egyptian blue (Fig. 10c). It should be noted that on these elements (garments, pedestal parts) no macroscopic differentiation is observed in the colour and texture of the pigment. Also painted in homogenous Egyptian blue are the garments of the miniature female figure (goddess?) from the 'Porter's Lodge' (Fig. 12a-b), a coincidence that should be born in mind with regard to the importance of the motifs when the decision was made to use this pigment rather than the other.
The four female figures represented in procession along the corridor leading to Room 3 of the 'Potnia' and the Saffron-gatherers, as well as a fifth possibly

[22] Vlachopoulos 2008, 451, figs. 41.7-9. At the time the present paper was in its final preparation for publication (March 2013), the abovementioned wall-painting had been completely restored and panelled. Some infrared luminescence photographic captures (using common lamps) during its photographic documentation showed that Egyptian blue had been applied for the leaves of the palm trees as well as for the body of the duck flying above (on both motifs almost completely faded), but not for the better preserved grey reeds and other minor motifs that are depicted along the lower 'marshy and rocky' zone of the composition. We are grateful to Dr. Geert Verhoven, archaeological photographer, who enthusiastically shared this information with us.

depicted seated on the opposite wall, have been painted in the greatest variety of colours and shades encountered so far at Akrotiri, with a special emphasis on purple and green (Vlachopoulos 2003, 524-25, figs. 20-23). Equally important is the application of Egyptian blue, traced on the snood and also the eye of the 'Lily Bearer', and on the blue rocks of the skirt of the 'Swallows Lady' in the lead.
On the same wall-paintings, the green colour used for the branches of the roses on the 'Rose Bearer' (Fig. 13a-b) and the rocks of the 'Swallows Lady' (Fig. 14a-b) was identified – as shown also by the XRF analysis (Pantazis *et alii* 2003, 157-158 pl. XXXIX.c) – as a mixture of yellow ochre and Egyptian blue (Vlachopoulos 2003; Vlachopoulos 2007a, 114, pl. XXX). The same is noted on the veining of the green stone vase (Vlachopoulos 2008), possibly held by the fifth woman (Figs. 15a-b) and on the colourful (blue and green) rocks of the seabed landscape of her belt (Vlachopoulos 2007a, 114, pl. XXXI) (Figs. 16a-b).
The large-scale figures of the 'House of the Ladies' have minimal touches of blue on their garments (Doumas 1992, 35, figs 6-12), as does the young 'priestess' of the West House (Doumas 1992, 46-47, figs 24-25; Televantou 1994, 173-180, colour pl. 19a-b), while few are the blue elements on the loincloths of the male figures walking up the grand staircase of Xeste 4 (Doumas 1992, 176, figs. 138-141; Boulotis, forthcoming). Dark grey (produced by mixing blue and black) is used for part of the rich plume and the hoops/rings of the boar's-tusk helmet from the same building, where the 'metallic' blue possibly renders bronze or silver (Akrivaki 2003; 2004). It is certain that the blue and grey colours of the Theran palette usually have an anti-naturalistic objective, as seen on some of the 'stern cabins' ('*ikria*') of the West House, which clearly represent hides (Doumas 1992; Televantou 1994). However, in the strings of fish held by the Fishermen from the West House there is a closer rendition of the true colours (Doumas 1992, figs. 18-21; Televantou 1994, colour pl. 21-23), while even more realistic is the use of blue and various tones of grey in the depiction of the shiny black lava rocks of the Theran landscape, which appear in almost all the wall-painting ensembles from Akrotiri (Spring Fresco from Complex Delta, Monkeys from Building Beta, Miniature Frieze from West House), but dominate the landscape themes of Xeste 3.

Blue in the human figure

Perhaps the greatest surprise during the experimental application of the infrared photoluminescence method was on the shaven heads of the 'Naked Boys', a composition consisting of three panels shaping a tiny Π-shaped space on the ground floor of Xeste 3. There were no traces of luminescence on the shaven heads of the two older boys on the east and west panels or on the blue fold of the coloured loincloth with which the older adolescent will be robed. However, Egyptian blue has been used to paint the shaven head of the little boy following the adolescent on the left (south) panel, as well as on the eyeball, around the brown pupil (Fig. 17a-d). Some time ago, Ellen Davis has discerned that the addition of blue to the white of the eyes is a diacritic of youth (Davis 1990, 865-867, figs. 5-12), but one wonders if this minor detail (especially at a considerable height or distance from the

viewer) made any kind of difference, bearing in mind that Egyptian blue does not shine to the naked eye. Surprisingly, and contrary to what we have seen above regarding the green pigments, there were no traces of Egyptian blue in the dark green shaved lower part of the male hunters capturing a wild goat in the vestibule of Xeste 3, which probably explains its dark tone (Papageorgiou, forthcoming).

What sample analysis has shown: a picture is worth more than a thousand words

There was systematic visual observation of the various tones of blue when taking the infrared luminescence images. A clear distinction was made between certain vivid blue tones, where the photo-induced luminescence images confirmed the presence of a layer of pure Egyptian blue (see Fig. 1) and other blue-grey tones, where there were no traces of Egyptian blue (see Fig. 8).

However, in some cases the VIL method distinguished iconographic elements in the same composition for which Egyptian blue was used, most likely alone, from others where only riebeckite was applied, whereas a clear distinction to the naked eye was impossible. Such is the case of the composition of the 'Potnia' from Room 3a and the wall-paintings with the Naked Boys from Room 3b on the ground floor of Xeste 3.

This seems to have been the case also on the fragments of wall-paintings from Building Beta (Blue Monkeys) as well as from the 'Porter's Lodge', where the variations of blue tones were so slight that it was impossible to determine by naked eye the use of one pigment or the other. The photoluminescence images showed either the use of pure riebeckite or of a mixture of riebeckite with Egyptian blue. The mixing was documented in the cases where the luminescence was relatively weak and did not correspond to the visible opacity of the blue paint layer.

It should be noted that the infrared photo-induced luminescence method detects Egyptian blue on the surface, only to a depth of a few micrometres (μm), as the radiation used for the excitation is red (~630 nm). In order to crosscheck the results and to study the layers' composition (in depth) down to the plaster, some representative cases of painted plaster were selected, from which micro-samples were taken. Detailed study of the samples is in progress. This paper presents some indicative preliminary results from the visual observation of the layered cross-sections, combined with the application of FTIR spectroscopy and X-ray diffraction[23]. Two samples were taken from fragments belonging to the Spirals composition in

[23] We express our thanks to Dr. Vasilis Perdikatsis for offering to study the specific samples right away, for the needs of the present paper. X-ray diffraction was applied to the fragments *in situ*. In this case, the depth of penetration of the X rays varies according to the pigment. For Egyptian blue it has been calculated at ~25-50 μm, while for riebeckite ~5-10 μm. This means that riebeckite can be detected under a relatively thin surface layer of Egyptian blue, whereas the opposite is not possible because the X rays do not pass through a riebeckite layer more than 10 μm thick.

Xeste 3. The stratigraphy of both samples has shown that the bright vivid blue of the spirals is the result of the application of a relatively thin layer (25-50 μm) of fine-grained Egyptian blue over a layer twice as thick of coarse-grained riebeckite (up to 100-150 μm maximum diameter of elongated granules) (Fig. 18a-b). It is noted, therefore, that the layer of Egyptian blue detected by applying the VIL method, although relatively thin, is capable of producing the bright vivid blue tone on the spirals composition because of the riebeckite underlay. So, at Akrotiri the technique of the undercoat for Egyptian blue, well known from other cases, both during the Late Bronze Age (Brekoulaki forthcoming) and later (Brysbaert 2008, 126), on the one hand to give it a more saturated tone, on the other hand to allow better adhesion of the pigment to the substrate, is applied with riebeckite rather than with carbon black.

Riebeckite has been applied in a fairly coarse-grained form (up to 100-150 μm maximum diameter of elongated granules), both in the cases where it was used as an undercoat (Spirals wall-painting, Xeste 3) and in the cases where it was applied as the sole paint layer (wall-painting of the blue birds, 'Porter's Lodge') to render the light blue tone. It shows good adhesion to the plaster, although the pigment is lacking in plasticity.

It becomes clear that the Theran painters had great discretion in sourcing and also applying (magnesio-)riebeckite. It seems that the raw material was available at Akrotiri, either locally or within the wider geographical region of the Cyclades (Groppo *et alii* 2009), in striking contrast to the rarity of the pigment today. A piece of blue slate material, undoubtedly associated with the pigment identified in the wall painting, was recently examined and identified as pure magnesio-riebeckite (Sotiropoulou *et alii* 2012). As for the manner of its application, it emerges that relatively coarse-grained pigment was used without any problem of adhesion to the plaster, obviously in order to achieve 'deeper-blue' colour tones approaching the hue and the intensity of Egyptian blue, which is more difficult to apply in a cohesive layer on the lime-plaster.

In the present study we have intentionally avoided any reference to the painting technique, *al fresco*, *fresco secco,* with or without the addition of an organic binder, as the relevant available data are very few and preliminary. The study of the use of organic binders on the wall-paintings of Akrotiri has only recently begun.

Egyptian blue at Akrotiri: the pigment of colour or of wealth?

Visible Induced Luminescence imaging experiments to detect Egyptian blue were conducted on the wall-paintings stored in Thera (Museum of Prehistoric Thera) or under conservation in the Wall-paintings Laboratory of the Akrotiri Excavation. Thus, for wall-paintings from buildings such as Building Beta, Sector Delta and the 'House of the Ladies' (exhibited in Thera and in the National Archaeological Museum of Athens), there are no other data available, apart from the pigment analyses carried out in the 1970s.

The use of Egyptian blue is consistent on the medium-scale (height *ca.* 0.70 m)

friezes of the practically unexcavated 'Porter's Lodge', where it is applied for many of the motifs (palm trees, jewellery, garments, sky, 'river'), but there is also evidence of its mixture with riebeckite on the body of the monkeys (but not of the birds and rocks). It is obvious that in this case the painters applied certain criteria, at least regarding colour, which macroscopically seem to correspond to the brighter blue of the respective motifs. Thematically, however, those criteria do not constitute 'rules' in Theran painting.
On the three known sides of the frieze that ran round Room 5 of the West House, Egyptian blue was used in abundance, basic criterion being to convey the brightness of the colour on certain motifs (rivers, rocks, living creatures in motion, ships, buildings). From the infrared photoluminescence images, it appears that on the SMF Egyptian blue 'flows' with the river into the harbour of Town IV (most probably mixed with riebeckite), while in the main narrative (flotilla), the open sea has been rendered with the more greyish (more neutral) hue attained exclusively with riebeckite.
The wide use of Egyptian blue in Xeste 3, but on selected iconographic motifs and with purely painterly criteria (monkey, garments and jewellery, vessels, geometric motifs in the second storey), should make us particularly cautious in assigning the use of the specific pigment in this building a privileged character, as is the case for purple[24]. We should also take into account that the frequent and dense occurrence of Egyptian blue is due largely to the fact that this fully excavated building has produced the largest volume of wall-paintings from any site in the prehistoric Aegean (Doumas 1992; Vlachopoulos 2008; Vlachopoulos 2010). There is no doubt as to its careful decoration. Nonetheless, the fact that samples of exquisite painting skill with colour refinements (pink shades, green colour, a sufficient quantity of purple, and Egyptian blue), like the 'Processing Ladies' decorated a narrow (width 1.10 m) dimly-lit corridor, in which those who passed through would barely be able to see all that we notice and admire today (Vlachopoulos 2003).

Thus, it appears that the painters of Xeste 3:
- Had access to sufficient quantities of both Egyptian blue and riebeckite, so that each pigment would be applied wherever its use had been decided upon.
- Used each of the two pigments according to 'iconographic' criteria that were clear to them, even if there was little differentiation between the pictorial themes requiring blue colour (e.g. shaven heads of boys, garments of the women with the flowers, of the saffron-gatherers, and of the 'Potnia').
- Produced green by mixing Egyptian blue, with one exception (head of the 'hunter of the wild goat') confirming the rule.
In Xeste 3 the tonal limits of each blue pigment were specific: the grey range

[24] Chrysikopoulou/Sotiropoulou 2003; Vlachopoulos 2003. The application of purple in Xeste 3 is much wider than previously recorded and its use may have been combined with bright Egyptian blue (e.g. on the relief lozenges).

grey-blue – dark blue – grey was achieved with riebeckite, while bright blue and light but vivid blue tones with Egyptian blue. However, macroscopically there is no certain distinction. Riebeckite may have a coarse-grained texture (e.g. reeds) and Egyptian-blue paint may be fine-grained and homogenous (e.g. rosettes of the spirals), but on the heads of the 'Naked Boys' the difference in the material used was ascertained only by using the diagnostic method of infrared photoluminescence.

The chromatological, macroscopic, and experimental presentation of the blue colour and its shades, which was attempted for the Akrotiri wall-paintings, gave interesting but also confusing data regarding the use of Egyptian blue and riebeckite. The ratio of their use suggests much greater use of the latter, which is never mixed when intended for large surfaces, such as reed-beds and rocks. However, in the composition of the spirals we saw that when covering large painted surfaces, the pigments' technically optimised use was more important than their cost, to achieve a more intense and brighter result, while at the same time ensuring the cohesion of the paint layers. The samples examined confirmed the good cohesion of the surface layer of Egyptian blue with the painted plaster, thanks to the interposed riebeckite layer, which due to its coarse-grained texture enhances the colour intensity of the blue figures.

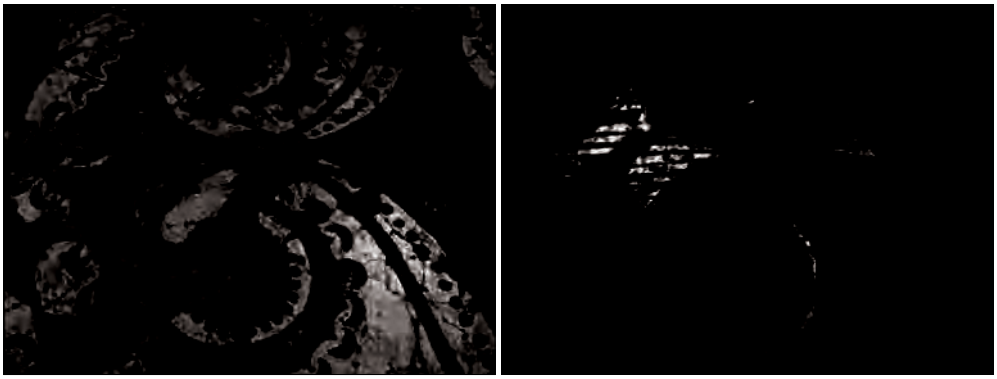
Egyptian blue appears to have been used in most of the iconographic programmes at Akrotiri, in different ratios – mixed with riebeckite or as a second thin layer over an underlay of riebeckite. Rules regarding its use were noted, strictly adhered to in certain cases – on motifs such as the spirals and the rosettes of the second storey of Xeste 3 or on the garments of the female figures from the same building – or *ad hoc* in others, such as on the blue heads of the human figures.

Conclusion

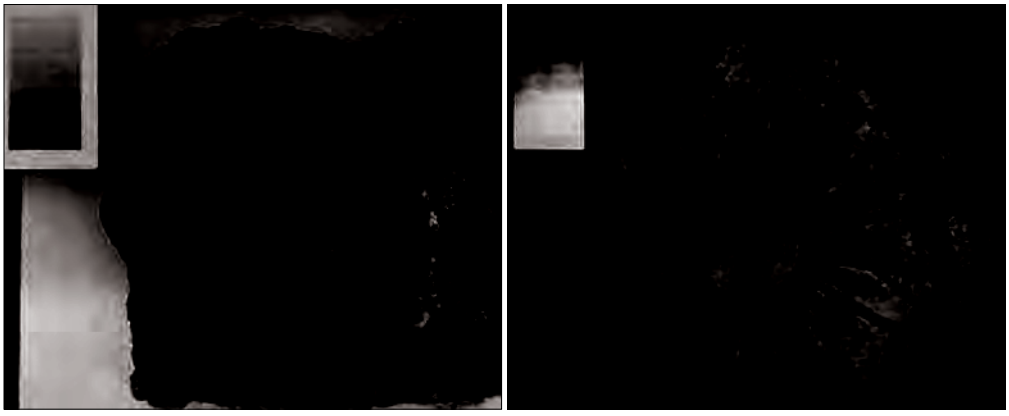
The first conclusions from the measurements and the analyses of Egyptian blue at Akrotiri tend to show the selective application of each blue pigment on the basis of the optimal technical achievement of the aesthetically and chromatically desired tone, rather than the economizing or intentional promotion of a more expensive material. We shall continue our research with a greater range of samples and from more iconographic programmes of the buildings in the settlement.

Note to Figs. 1a-18c

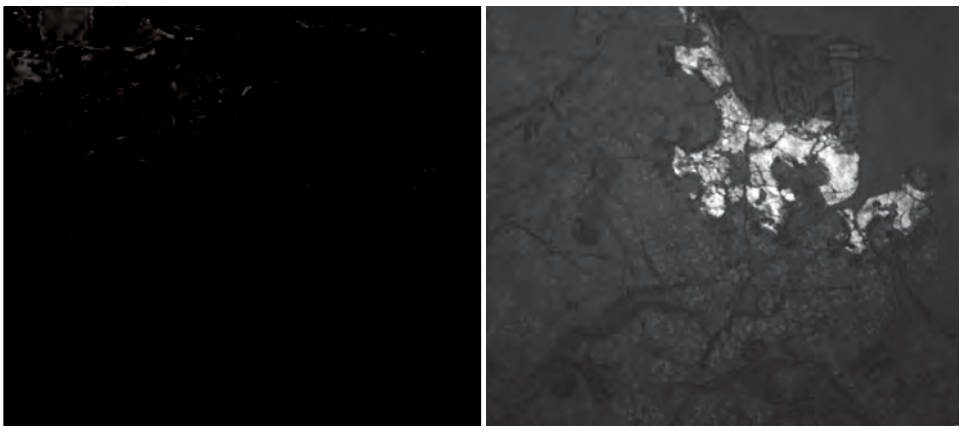
All the images are paired: on the left are the visible details of the wall-painting (a) and on the right the same details after Visible-induced Infrared Luminescence (VIL) imaging (b), unless otherwise stated (all photographs are copyright of the Excavation at Akrotiri Thera).



Figs. 1a-b. Xeste 3. Detail of the ‘Blue spirals’ composition.

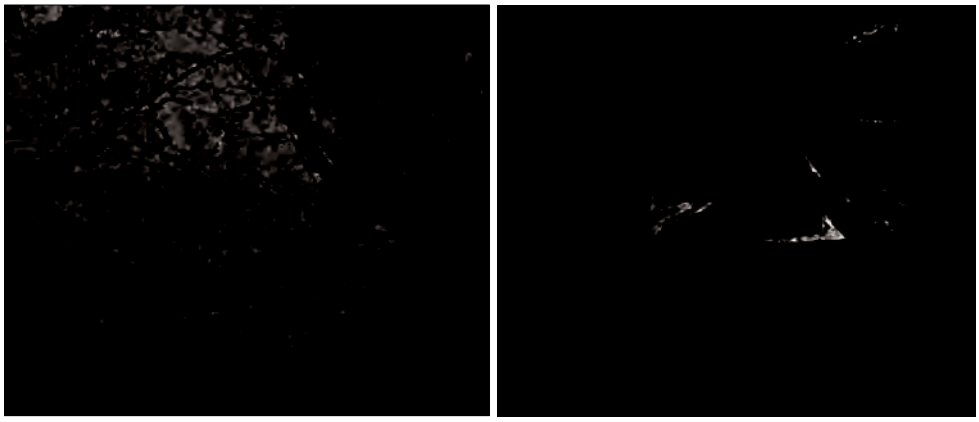


Figs. 2a-b. Xeste 3. Detail of a blue rosette from the ‘Red spiral’ composition.

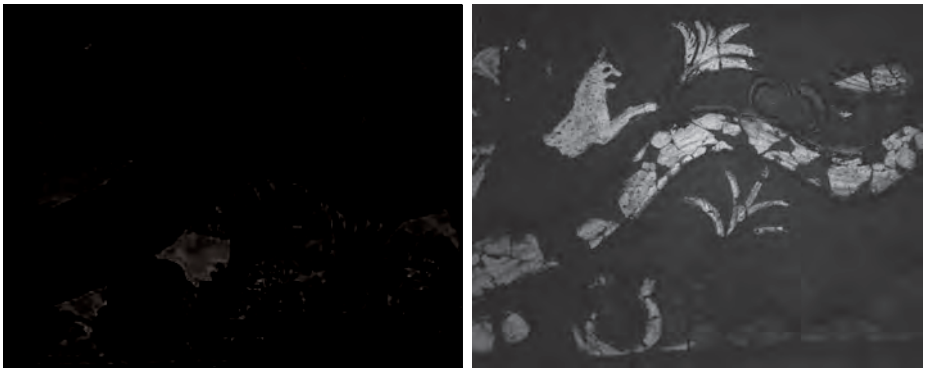


Figs. 3a-b. West House. Detail of the ‘Miniature Frieze’ (north wall).

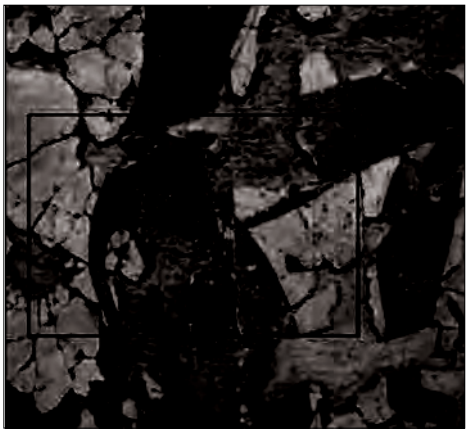
Figs. 4a-b. West House. Detail of the harbour of the Departure Town of the 'Miniature Frieze' (north wall).



Figs. 5a-b. West House. Detail of the 'Miniature Frieze' (north wall).



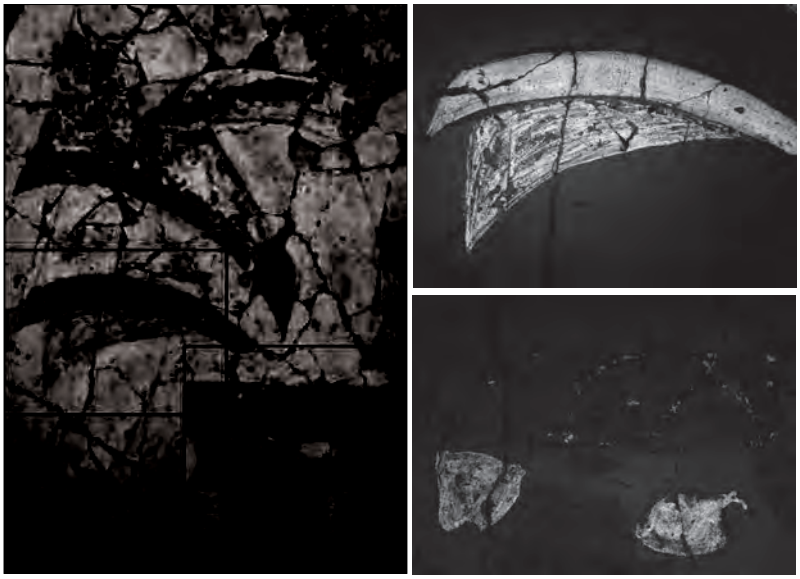
Figs. 6a-b. West House. Detail of the 'Miniature Frieze' (north wall).




Figs. 7a-b. Xeste 3, Room 3a. Detail of the monkey standing in front of 'Potnia' offering crocus stamens.


Figs. 8a-b. Xeste 3, Room 3b. Detail of the Reed-bed composition that covered all the walls of this great space.

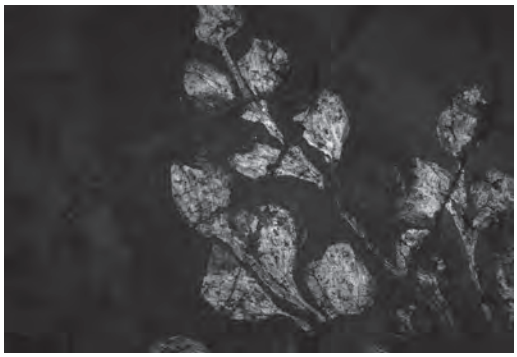

Figs. 9a-b. 'Porter's Lodge'. Fragments of the body of a man (the so-called 'African') wearing a necklace and anklets made of blue beads.



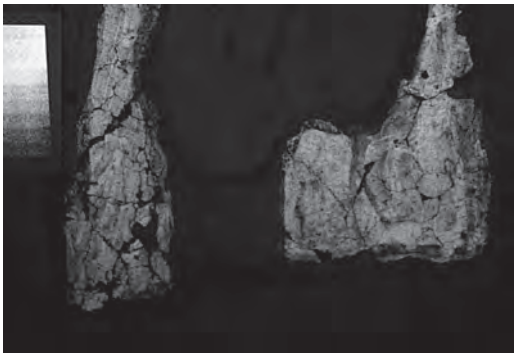
Figs. 10a-c. Xeste 3, Room 3a. Detail of the hem of 'Potnia's' skirt (b) and of the upper horizontal stand (c).

Figs. 11a-b. Xeste 3, Room 3a. Detail of the skirt of the young saffron-gatherer from the composition of the 'Potnia'.

Figs. 12a-b.
'Porter's Lodge'. Fragments of the clothes of the miniature female figure (goddess?) and architectural members from the same composition.

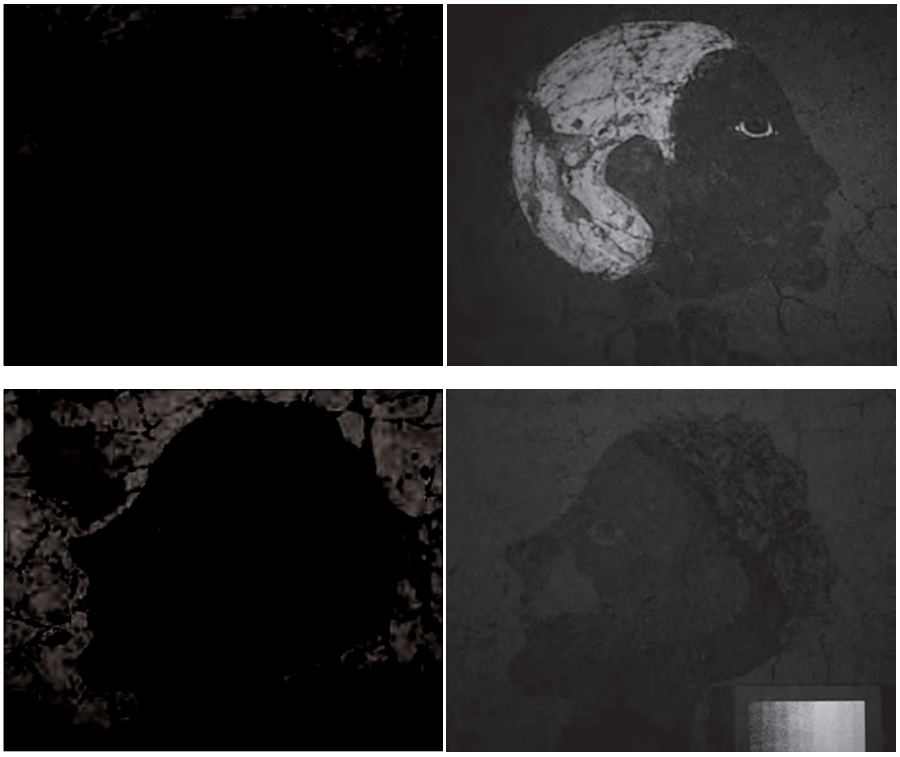


Figs. 13a-b. Xeste 3, first storey corridor. Detail of the dressing of the 'Woman with the Roses'.



Figs. 14a-b. Xeste 3, first storey corridor. Detail of the skirt of the 'Woman with the Swallows'.

Figs. 16a-b. Xeste 3. Detail of the belt with the flying fishes of the fifth woman, possibly across the corridor of the female procession.



Figs. 17a-d. Xeste 3, Ground floor, area 3a. Details of the heads of the young boy (south wall, a-b) and the adolescent (north wall, c-d).

←

Figs. 15a-b. Xeste 3. Detail of the stone vessel, possibly from the fifth woman of the female procession.

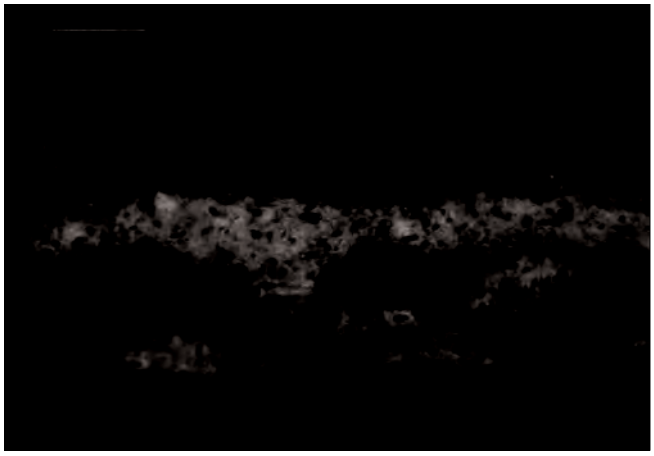


Fig. 18a.

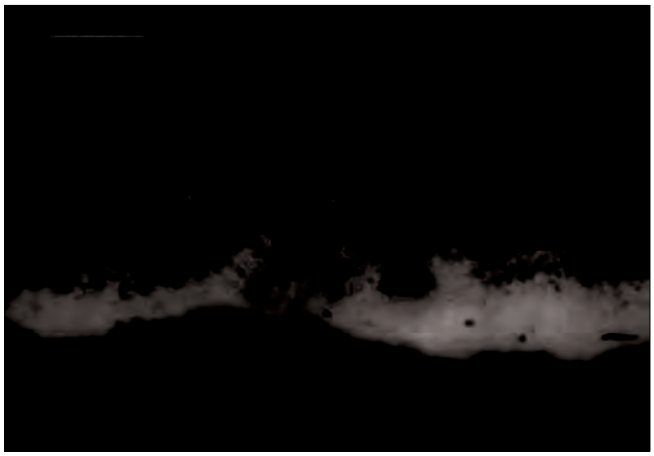


Fig. 18b.

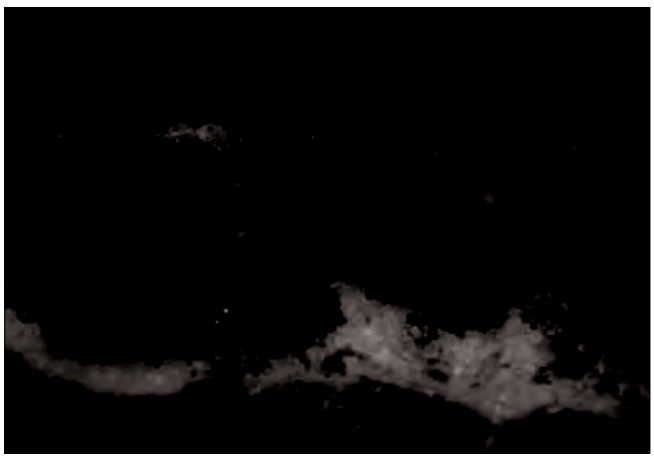


Fig. 18c.

Fig. 18a. Microphotograph of a sample cross-section from a fragment belonging to the 'blue spirals' composition from Xeste 3. Two paint layers are visible: One thicker layer (~ 100 μm) of coarse-grained riebeckite, been applied as the underpaint of a thinner (25-50 μm) fine-grained layer of Egyptian blue.

Fig. 18b. Microphotograph of a sample cross-section from fragment belonging to the 'blue birds' composition from the 'Porter's Lodge'. The thick layer of coarse-grained riebeckite is visible.

Fig. 18c. Microphotograph of a sample section from fragment that belongs to the 'blue monkeys' composition from the 'Porter's Lodge'. According to XRD and FTIR analyses, the paint layer is the result of mixing Egyptian blue with riebeckite.

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