

X-RAY ANALYSIS OF GREEK BRONZE AGE PIGMENTS FROM THERA (SANTORINI)

S. PROFI, B. PERDIKATIS and S. E. FILIPPAKIS

Abstract—Samples of pigments from excavated wall-paintings at the great civilization center of the Greek Bronze Age, Thera, have been analysed by the non-destructive methods of X-ray fluorescence, X-ray diffraction and mineralogical microscopic examination. The results showed that three types of blue pigment were used, namely the well-known Egyptian blue, glaucophane, which is a sodium magnesium (or iron) aluminium hydroxide silicate which occurs as a natural mineral on Santorini, and a mixture of Egyptian blue and glaucophane. Black pigments were rather puzzling in that some of them are carbon as expected, and some are manganese compounds. The rest of the pigments are very similar to those previously examined from Mycenae and Knossos.

1. INTRODUCTION

Santorini is the name given to three islands, Thera, Therasia and Aspronissi, which are the remains of the volcanic island of Stronghyle, lying about 78 miles NNE of Crete. This island was the scene of a cataclysmic volcanic eruption followed by the collapse of the whole interior of the island, with consequent tidal waves, which had disastrous effects on the Aegean and Eastern Mediterranean coasts (e.g. Amnissos and the whole of N. Crete, Keos, etc.) [1–4]. It has been generally accepted that the eruption occurred in *c.* 1500 B.C. and may well be the historical core of the Atlantis legend [4–6].

Only in the latter part of the nineteenth century did French excavations arouse some interest in Santorini. The volcanologist Fouqué with the Greeks Alaphouzos and Nomikos excavated on Therasia shortly after the eruption of 1866 and the archaeologists Corceix and Mamet of the Ecole Française of Athens dug on Thera and Therasia in 1870. Their findings showed that the original island had a very advanced culture before the submersion of its central part and the covering of the remainder with a thick layer of pumice. Among the findings was a painted plaster wall in one of the Minoan houses uncovered near Akrotiri in SE Thera. These excavations were abandoned, however, and Robert Zahn who came to Thera in 1899 dug on a different spot near Kamara on the eastern part of the island [7–10]. Seeking a physical explanation for the catastrophic break-up of the Minoan civilization, Professor S. Marinatos began his excavations in 1967 near Akrotiri on Thera. These excavations have revealed the buried but intact ruins of a considerable Minoan township of the most sophisticated period, overwhelmed with the world's most stupendous outpouring of pumice and volcanic ash some 3500 years ago. Fresco paintings of great artistic value have been uncovered, on which plant and bird designs appear, blue monkeys, palm trees and people, some of them thick-lipped.

No technical examination has been carried out yet on these wall-paintings. Therefore an X-ray analysis of the pigments used, in order to determine their composition, is attempted in the present study.

2. SAMPLES

Most of the samples (TH 1–TH 52) were kindly provided by the Centre of Conservation of Antiquities in Athens. They had already undergone some treatment which, however, after several tests, proved not to affect the results obtained by our methods at all. Eight painted

plaster samples, labelled TH-W throughout the paper, were provided by Miss L. Weier; these were collected locally at Santorini without having undergone any treatment. All the samples were taken from the same destruction level of the Akrotiri excavations and can therefore be dated to the period between 1600 B.C. and 1500 B.C. In total, 61 pigment samples were examined, among them 8 white, 6 black, 1 grey, 13 blue, 16 red, 2 pink, 7 yellow, 2 orange, 6 brown. The painted plaster fragments varied in size from 1–2.5 cm², while the plaster varied in thickness from 0.4–0.8 cm.

3. EXPERIMENTAL TECHNIQUES

Since the samples were of an archaeological nature, the non-destructive methods of X-ray fluorescence analysis (XRF), X-ray diffraction analysis (XRD) and mineralogical microscopic examination with a polarizing microscope were used throughout the study. The equipment and techniques employed were identical to those of earlier studies reported in this journal [11, 12] and will not be repeated here.

4. EXPERIMENTAL RESULTS

4.1. *Plaster*

Although detailed plaster examination was beyond the scope of the present study, two types of plaster have been examined in regard to their composition: wall and roof plaster. The essential composition is the same for both. The elements detected with XRF are mainly Ca and traces of Cu, Fe, Zn, Mn and Ni. The XRD powder patterns show the line of CaCO₃, frequently accompanied by SiO₂ lines and some lines which cannot be identified. The mineralogical examination reveals, in addition to calcite and quartz, the presence of various clay minerals and iron oxides and hydroxides. These may well be the source of the trace elements detected with XRF and of the additional lines of the powder patterns. The amounts of quartz, clay and Fe-minerals vary widely among the various wall plaster samples. But in general the wall plaster gives the impression of being a purer lime plaster than the one used for covering the roof, which also contains small quantities of straw.

4.2. *Pigments*

The plaster contaminates the XRF spectra and the powder patterns of the pigments. Thus the calcite, quartz and certain clay minerals containing the above mentioned trace elements present in all samples should be attributed to the plaster, along with a small amount of iron oxides and hydroxides. The characteristic constituents of each pigment are therefore determined after comparison with its plaster by subtraction of the common peaks or lines.

White Pigments

The XRF spectra of the white samples are identical to those of the plaster, as can be seen in Table 1, which contains a compilation of our results. The Debye-Scherrer patterns exhibit either merely calcite lines (TH 3 and 4), or calcite accompanied by quartz lines (TH 5 and 7), or by clay mineral lines (TH 1 and 6), or by both (TH 2 and TH-W 1/2). Since the polarizing microscope reveals quartz and clay minerals in all the samples examined, this indicates that these constituents which accompany the calcite vary in quantity among the various samples. The mineralogical examination also reveals additional slight quantities of iron hydroxides and/or hematite in some of the samples. In TH 7, which is somewhat beige in colour, some twinned crystals similar to feldspars could also be observed.

Black Pigments

These fall into two groups: TH 8, 11 and 13 exhibit the plaster XRF spectrum, while TH 9

TABLE 1
ANALYTICAL DATA ON PIGMENTS FROM THERA

Sample	Colour	X-ray fluorescence (XRF)	X-ray diffraction (XRD)	Mineralogical examination	Identification
Wall plaster		Ca, Cu, Fe, Zn, Mn, Ni (tr.)	Calcite, quartz, unidentified lines	Calcite, quartz, clay, hematite, Fe-hydroxides	Lime plaster
Roof plaster		Ca, Cu, Fe, Zn, Mn, Ni (tr.)	Calcite, quartz, unidentified lines	Calcite, quartz, clay, hematite, Fe-hydroxides	Lime plaster
TH 1	White	Ca, Cu, Fe, Zn, Mn, Ni (tr.)	Calcite, unidentified lines	Calcite, quartz, clay, Fe-hydroxides, hematite	Unpainted plaster
TH 2	White	Ca, Cu, Fe, Zn, Mn, Ni (tr.)	Calcite, quartz, unidentified lines	Calcite, quartz, clay, Fe-hydroxides	Unpainted plaster
TH 3	White	Ca, Cu, Fe, Zn, Mn, Ni (tr.)	Calcite	Calcite, quartz, clay	Unpainted plaster
TH 4	White	Ca, Cu, Fe, Zn, Mn, Ni (tr.)	Calcite	Calcite, quartz, clay	Unpainted plaster
TH 5	White	Ca, Cu, Fe, Zn, Mn, Ni (tr.)	Calcite, quartz	Calcite, quartz, clay, Fe-hydroxides	Unpainted plaster
TH 6	White	Ca, Cu, Fe, Zn, Mn, Ni (tr.)	Calcite, unidentified lines	Calcite, quartz, clay, Fe-hydroxides, hematite	Unpainted plaster
TH 7	White	Ca, Cu, Fe, Zn, Mn, Ni (tr.)	Calcite, quartz	Calcite, quartz, clay, feldspars (?)	Unpainted plaster
TH 8	Black	Ca, Cu, Fe, Zn, Mn, Ni (tr.)	Plaster	Black particles, Fe-hydroxides	Carbon (?)
TH 9	Black	Mn, Ca, Cu, Fe, Zn, Ni (tr.)	Plaster, MnO (?)	Black particles	Mn-oxide (?)
TH 10	Black	Mn, Ca, Cu, Fe, Zn, Ni (tr.)	Plaster, Mn ₃ O ₄ (?)	Black particles, goethite	Mn-oxide (?)
TH 11	Black	Ca, Cu, Fe, Zn, Mn, Ni (tr.)	Plaster	Black particles, Fe-hydroxides	Carbon (?)
TH 12	Black	Ca, Cu, Fe, Zn, Mn, Ni (tr.)	Plaster	Black particles, Fe-hydroxides	Carbon (?)
TH 13	Grey	Ca, Cu, Fe, Zn, Mn, Ni (tr.)	Plaster	Clay, black particles, Fe-hydroxides	Clay + carbon (?)
TH 14	Blue	Fe, Cu, Ca, Zn, Mn, Ni, Sn (tr.)	Plaster, glaucophane, CaCuSi ₄ O ₁₀	Amphibole crystals, blue particles, quartz, sericite	Egyptian blue + glaucophane
TH 15	Blue	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster, glaucophane	Amphibole crystals, quartz, calcite, sericite	Glaucophane
TH 16	Blue	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster, glaucophane	Amphibole crystals, quartz, calcite, sericite	Glaucophane
TH 17	Blue	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster, glaucophane	Amphibole crystals, quartz, calcite, sericite	Glaucophane
TH 18	Blue	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster, glaucophane	Amphibole crystals, quartz, calcite, sericite	Glaucophane
TH 19	Blue	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster, glaucophane	Amphibole crystals, quartz, calcite, sericite	Glaucophane

Table continued on page 110

TABLE 1 (continued)

Sample	Colour	X-ray fluorescence (XRF)	X-ray diffraction (XRD)	Mineralogical examination	Identification
TH 20	Blue	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster, glaucophane	Amphibole crystals, Glauco-phane quartz, calcite, sericite	
TH 21	Blue	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster, glaucophane	Amphibole crystals, Glauco-phane quartz, calcite, sericite	
TH 22	Blue	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster, glaucophane	Amphibole crystals, Glauco-phane quartz, calcite, sericite	
TH 23	Blue	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster, glaucophane	Amphibole crystals, Glauco-phane quartz, calcite, sericite	
TH 24	Blue	Fe, Cu, Ca, Zn, Mn, Ni, Sn (tr.)	Plaster, glaucophane, CaCuSi ₄ O ₁₀	Amphibole crystals, Egyptian blue + blue particles, glaucophane quartz, sericite	
TH 25	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb (tr.)	Plaster	Hematite << goethite, clay, quartz	Ochre
TH 26	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb, Cr, Ti, Ba (tr.)	Plaster, hematite, kaoline	Hematite >> goethite, clay, quartz	Ochre
TH 27	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb, Cr, Ti, Ba (tr.)	Plaster, hematite, kaoline	Hematite > goethite, clay, quartz	Ochre
TH 28	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb, Cr, Ti, Ba (tr.)	Plaster, kaoline	Hematite < goethite, clay, quartz	Ochre
TH 29	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb (tr.)	Plaster, hematite	Hematite >> goethite, clay, quartz	Ochre
TH 30	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb, Ti, Ba (tr.)	Plaster, hematite, kaoline	Hematite >> goethite, clay, quartz	Ochre
TH 31	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb, Cr, Ti, Ba (tr.)	Plaster, kaoline	Hematite > goethite, clay, quartz	Ochre
TH 32	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb (tr.)	Plaster, hematite	Hematite >> goethite, clay, quartz	Ochre
TH 33	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb (tr.)	Plaster	Hematite ≈ goethite, clay, quartz	Ochre
TH 34	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb, Cr, Ti, Ba (tr.)	Plaster, hematite	Hematite >> goethite, clay, quartz	Ochre
TH 35	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb (tr.)	Plaster	Hematite > goethite, clay, quartz	Ochre
TH 36	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb, Ti, Ba (tr.)	Plaster	Hematite < goethite, clay, quartz	Ochre
TH 37	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb, Cr, Ti, Ba (tr.)	Plaster, hematite, kaoline	Hematite ≈ goethite, clay, quartz	Ochre
TH 38	Pink	Fe, Ca, Zn, Mn, Cu, Ni, Pb (tr.)	Plaster	Clay, Fe-hydroxides, goethite, hematite	Ochre
TH 39	Pink	Fe, Ca, Zn, Mn, Cu, Ni, Pb (tr.)	Plaster	Clay, Fe-hydroxides, goethite, hematite	Ochre
TH 40	Yellow	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster	Clay, Fe-hydroxides	Ochre
TH 41	Yellow	Fe, Ca, Zn, Mn, Cu, Ni, Pb (tr.)	Plaster	Clay, Fe-hydroxides, hematite	Ochre
TH 42	Yellow	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster	Clay, Fe-hydroxides, goethite, hematite	Ochre

Table continued on page 111

TABLE 1 (continued)

Sample	Colour	X-ray fluorescence (XRF)	X-ray diffraction (XRD)	Mineralogical examination	Identification
TH 43	Yellow	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster	Clay, Fe-hydroxides	Ochre
TH 44	Yellow	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster	Clay, Fe-hydroxides, goethite	Ochre
TH 45	Orange	Fe, Ca, Zn, Mn, Cu, Ni, Pb (tr.)	Plaster	Clay, Fe-hydroxides, goethite, hematite	Ochre
TH 46	Orange	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster	Clay, Fe-hydroxides, goethite	Ochre
TH 47	Brown	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster	Clay, goethite, Fe-hydroxides	Ochre
TH 48	Brown	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster	Clay, goethite	Ochre
TH 49	Brown	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster	Clay, Fe-hydroxides	Ochre
TH 50	Brown	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster	Clay, Fe-hydroxides, goethite	Ochre
TH 51	Brown	Fe, Cu, Ca, Zn, Mn, Cu, Ni, Sn (tr.)	Plaster, unidentified lines	Clay, Fe-hydroxides, goethite, blue particles	Ochre over Egyptian blue
TH 52	Brown	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster	Clay, Fe-hydroxides	Ochre
TH-W 1/2	White/Red	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Calcite, quartz, unidentified lines, hematite (?)	Calcite, quartz, clay, Fe-hydroxides, goethite, hematite	Unpainted plaster/ochre
TH-W 3	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb (tr.)	Plaster, hematite, kaoline	Hematite > goethite, clay, quartz	Ochre
TH-W 4	Red	Fe, Ca, Zn, Mn, Cu, Ni, Pb (tr.)	Plaster, hematite	Hematite < goethite, clay, quartz	Ochre
TH-W 5	Yellow	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster	Clay, Fe-hydroxides, goethite	Ochre
TH-W 6	Yellow	Fe, Ca, Zn, Mn, Cu, Ni (tr.)	Plaster	Clay, Fe-hydroxides, goethite	Ochre
TH-W 7	Blue	Cu, Ca, Fe, Zn, Mn, Ni, Sn (tr.)	Plaster, CaCuSi ₄ O ₁₀	Blue particles, quartz	Egyptian blue
TH-W 8	Blue	Cu, Ca, Fe, Zn, Mn, Ni, Sn (tr.)	Plaster, CaCuSi ₄ O ₁₀	Blue particles, quartz	Egyptian blue
TH-W 9	Black	Mn, Ca, Cu, Fe, Zn, Ni (tr.)	Plaster, unidentified lines	Black particles	Mn-oxide (?)

and 10 and TH-W 9 show an enormous increase of their Mn-content. The powder patterns of the first group are similar to the plaster patterns, those of the second group show additional lines. Under the microscope the opaque black particles of the pigments of the first group are reminiscent of the ones observed in black pigments from other localities, while those of the second group are more black and rather lack the brown iron hydroxide particles which surround them in the samples of the first group.

The pigment particles of the first group are most probably carbon, those of the second some Mn-compound, which may be MnO in TH 9 and Mn₃O₄ in TH 10 according to some of the additional lines of the powder patterns.

Grey Pigment

TH 13 was the only grey pigment. Its components in the XRF spectrum and the powder

pattern are identical to the ones of the plaster; under the microscope some black particles can be observed mixed with clay and brown iron hydroxides, indicating some carbon, as is known from the black pigment samples from other localities.

Blue Pigments

Three types of blue pigment could be recognized by comparison of the XRF spectra, the relative amounts of Cu and Fe in the sample being critical for the classification: (a) pigments in which Cu is the major element accompanied by Ca and traces of Sn along with some Fe, the latter not exceeding 50% of the Cu amount, (b) pigments in which Fe is the major element, Cu being present only in very small amounts, and (c) pigments in which both Cu and Fe are present in significant quantities, neither of the elements existing in a smaller quantity than 50% of the other.

Under the microscope, samples of type (a) showed the typical image of Egyptian blue, those of type (b) the typical glaucophane image, known from the Knossos samples, while samples of type (c) showed both glaucophane and Egyptian blue particles in comparable quantities. In the samples containing glaucophane the best part of the clay is most probably sericite.

Results from the XRD patterns were compatible with the above classification of blue pigments, since type (a) pigments exhibited the $\text{CaCuSi}_4\text{O}_{10}$ lines, type (b) pigments the glaucophane lines, and type (c) pigments presented lines of both crystalline phases, thus indicating a mixture of the synthetic Egyptian blue with the natural blue pigment (cf. [13]).

Red Pigments

Fe is the major element present in all red pigments as suggested by the XRF spectra, along with the trace elements known from the plaster, plus Pb and, occasionally, Cr, Ti and Ba. But the XRD patterns do not always show the expected hematite lines in addition to those of the plaster, although in most of the samples the characteristic lines of the white clay mineral kaoline can be detected. As seen from the microscopic examination, however, all red pigments actually contain hematite and goethite (iron hydroxide); the fact that hematite does not show up in all the powder patterns indicates that its amount varies among the samples. As detected under the microscope, the hematite/goethite ratio varies widely as well. In most of the samples hematite exceeds goethite, but there are also samples with equal amounts of the two compounds, and some with less hematite than goethite.

Pink Pigments

Fe was again the major element in the XRF spectra, but in none of the samples could the presence of hematite be detected from the powder patterns. Under the microscope both pink samples were found to contain much clay, goethite, amorphous iron hydroxides attached to the clay particles and very few grains of hematite.

Yellow Pigments

XRF showed an abundance of Fe and the Debye-Scherrer patterns only the plaster lines. As determined by the microscopic examination these pigments contain mainly clay mixed with amorphous iron hydroxides. In some of the samples there exist also a very few grains of hematite and/or goethite.

Orange Pigments

Again the XRF spectrum is the one of the red pigments, the powder patterns not showing the presence of hematite, however. The microscope revealed mainly clay surrounded by amorphous iron hydroxides and a very few grains of goethite and/or hematite.

Brown Pigments

Two types of brown could be detected:

- 1 – All but one sample had the same XRF spectrum as the red pigments; the powder pattern did not show anything but the plaster lines, and the microscope revealed the presence of Fe hydroxides, either goethite or amorphous hydroxides mixed with clay particles or both.
- 2 – The sample which constitutes the second type of brown pigment is TH 51 and shows some Cu in its XRF spectrum, some additional lines in its powder pattern and some blue particles under the microscope. In more detailed examination it proved to be ochre over Egyptian blue.

5. CONCLUSIONS

The results of the X-ray analysis of the Thera pigments indicate that these pigments are very similar to those previously examined from Knossos [12], especially when one considers the blue pigments used: glaucophane has been identified in most of the blue painted samples. Nevertheless, some black pigment samples are Mn-oxides rather than carbon, and only one of the brown pigments is ochre over Egyptian blue, the rest being natural earth ochres.

The plaster is again a lime plaster; the content of quartz and clay is low, so that it was probably not an intentional addition. However, the amount of these constituents varies in the samples, and the fact that the roof plaster seems to be less pure than the wall plaster may suggest that special care was taken that purer plaster be used on surfaces which would later be covered with wall-paintings.

The white samples are, as usual, bare plaster 'polished' somehow to a very smooth surface.

The black pigments are rather puzzling, in that some of them are carbon as expected but some are Mn-compounds. Mn-minerals are in general not very easy to identify from their diffraction patterns or optical images. Still, all the indications we have been able to obtain from the experimental methods employed in the present study suggest that these black pigments are most probably Mn-oxides. The authors present this hitherto unreported fact fully cognizant of the shortcomings of evidence, but they feel it provides interesting pointers for further attack on the problems posed by the pigments of the Greek Bronze Age.

The grey pigment was a mixture of clay with carbon, similar to one of the grey pigments examined from Mycenae [11].

The blue pigments were again of great interest. As at Knossos, glaucophane has been identified as a blue pigment in many samples. There are, however, also some samples exhibiting pure Egyptian blue. What is impressive is the use of a mixture of the two blue pigments. This may be due either merely to colour shade restrictions, or to the fact that Egyptian blue was a pigment imported from Egypt, and thus expensive and available only in limited quantities. Glaucophane, however, leaves a lot to be desired as a pigment when compared to Egyptian blue; hence perhaps its absence from later wall-paintings (e.g. Mycenae), when commercial relations with the Nile valley became closer. The presence of tin was noticed once again in all Egyptian blue samples, in support of our previous suggestion [11, 12] associating the source of Cu in Egyptian blue with bronze.

The rest of the pigments, red, pink, yellow, orange and brown, are natural earth ochres, i.e. hematite and/or iron hydroxides, either crystalline (goethite) or amorphous (limonite). What should be noted here is that the iron hydroxides can vary in colour from yellow to red and brown, and that all these varieties occur in mixtures in the pigment samples in varying quantities, frequently surrounding or attached to the clay mineral particles. None of the Fe-minerals seems to be specifically and uniquely associated with a specific pigment, except perhaps for the hematite which occurs in large quantities only in some of the red pigments. Whether the variety of colours was obtained by mixing basic colours consisting of only one

mineral variety or whether natural mixtures exhibiting the desired colour shade were used cannot be said.

The fact that only one of the brown pigments was ochre over Egyptian blue, like the brown pigments examined from Mycenae and Knossos [11, 12], might also have something to do with the relatively limited quantities of Egyptian blue available on Thera at the time, as suggested above in connection with the blue pigments.

ACKNOWLEDGEMENTS

The authors are grateful to Mr J. Elpiziotis of the N.R.C. Demokritos for his invaluable technical assistance and help in collecting the experimental data.

REFERENCES

- 1 MARINATOS, S., *Practica of the Archaeological Society of Athens*, 1932, pp. 79–80 and 91.
- 2 MARINATOS, S., *Antiquity*, XIII (1939), 425–439.
- 3 MARINATOS, S., *Acta of the 2nd International Cretological Congress*, 1967, I, pp. 198 esp. 211–12.
- 4 MARINATOS, S., 'Some Words About the Legend of Atlantis', *Archaeological Bull.*, 12 (1969).
- 5 MARINATOS, S., 'On the Legend of Atlantis', *Cretica Chronica*, IV (1950), 195–213.
- 6 GALANOPOULOS, A. G., and BACON, E., *Atlantis*, Thomas Nelson and Sons Ltd, 1969.
- 7 VON GAERTRINGEN, F. F. H., *Stadtgeschichte von Thera*, Band III, 1899, pp. 37–47.
- 8 MAMET, H., *De insula Thera*, 1874, p. 96.
- 9 VON FOUQUE, F., 'Santorin et ses Éruptions', *Comptes Rendus Paris*, 108 (1879), 107–123.
- 10 PERROT, G., and CHIPIER, S., *Histoire de l'Art*, VI, Paris, 1894, 135 ff.
- 11 PROFI, S., WEIER, L., and FILIPPAKIS, S. E., 'X-Ray Analysis of Greek Bronze Age Pigments from Mycenae', *Studies in Conservation*, 19 (1974), 105–112.
- 12 PROFI, S., WEIER, L., and FILIPPAKIS, S. E., 'X-Ray Analysis of Greek Bronze Age Pigments from Knossos', *Studies in Conservation*, 21 (1976), 34–39.
- 13 FILIPPAKIS, S. E., PERDIKATIS, B., and PARADELLIS, T., 'An Analysis of Blue Pigments from the Greek Bronze Age', *Studies in Conservation*, 21 (1976), 143–153.

Received 18 October 1976

S. PROFI, M.Sc. Natural Sciences, University of Athens. Present position: scientific collaborator, Physics Department X-Ray Laboratory.

B. I. PERDIKATIS, born 1942; Dr. Mineralogy, University of Erlangen, W. Germany. Present position: Research Associate of the Institute for Geological and Mining Research, Athens.

S. E. FILIPPAKIS, born 1933; Ph.D. Crystallography, Weizmann Institute of Science, Israel. Present position: senior scientist, group leader of X-ray Crystallography Laboratory, N.R.C. Demokritos.

Authors' address: N.R.C. Demokritos, Physics Dept., Aghia Paraskevi, Attikis, Greece.

Abstract—Des échantillons de pigments des peintures murales détérrées au grand centre de la civilisation de l'âge de bronze grec, Thera, ont été analysés par les méthodes non destructives de fluorescence aux rayons-X, de diffraction par rayons-X et d'examen microscopique minéralogique. Les résultats ont montré que trois types de pigment bleu furent utilisés, soit le bleu égyptien bien connu, le glaucophane qui est un silicate d'hydroxyde d'aluminium ou de magnésium sodium (ou fer) trouvé comme mineral naturel à Santorini, et un mélange de bleu égyptien et de glaucophane. Les pigments noirs sont assez curieux, certains étant du carbone, comme prévu, d'autres des composés du manganèse. Les autres pigments sont très semblables à ceux examinés précédemment venant de Mycène et de Knossos.

Studies in Conservation, 22 (1977), 107–115

Kurzfassung—Pigmentmuster von ausgegrabenen Wandgemälden in Thera, dem grossen Zivilisationszentrum des Griechischen Bronzealters, sind mit nicht zerstörenden Verfahren der Röntgenfluoreszenz, Röntgendiffraktion und mineralogisch-mikroskopischen Untersuchung analysiert worden. Die Ergebnisse zeigten, dass drei Arten von blauem Pigment benutzt wurden, nämlich das wohl bekannte ägyptische Blau, Glaukophan, das ein Natrium-magnesium- (oder Eisen) Aluminiumhydroxysilikat ist, welches als natürliches Mineral auf Santorini vorkommt, und eine Mischung von ägyptischem Blau und Glaukophan. Schwarze Pigmente waren ziemlich rätselhaft, da einige von ihnen, wie erwartet, Kohlenstoffverbindungen und andere Manganverbindungen darstellten. Die übrigen Pigmente sind denen, die zuvor aus Mykene und Knossos untersucht wurden, sehr ähnlich.