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The materialisation of colour: Reconstructing Egyptian blue manufacture on late Hellenistic Kos

ARIADNE KOSTOMITSOPOULOU MARKETOU

Contrasting Western views of colour as a de-materialised, abstract value, this paper approaches the technologies of colourant production in Mediterranean antiquity as the active processes of colour materialization by examining the late Hellenistic workshop found on the Aegean Island of Kos as a case study. The challenging pyrotechnological process of Egyptian blue production is the focus of this paper, which aims to illustrate the sequence of material transformations followed to create this saturated blue pigment. Despite the widespread use of Egyptian blue in the ancient Mediterranean world, only scarce archaeological evidence of production sites exists. The Koan workshop, containing an assemblage of successfully and unsuccessfully produced Egyptian blue pellets alongside amorphous lead lumps, litharge rods, and earth pigments, provides the material remains to study the pigment's manufacture. The process of making blue in the context of this workshop can be broken down into two phases. The first phase includes the production of the initial Egyptian blue pellets and the second the further processing for the creation of different tonalities of blue. Bridging the dematerialised notion of colour to the material remains of production, this paper brings us closer to appreciating ancient conceptualizations of colour.

INTRODUCTION

This paper explores the relationship between the contemporary perceptions of colour as a 'dematerialised' value (cf. Young 2006) and the materials produced and used to colour things in antiquity, i.e., ancient colourants. The production of the artificial pigment Egyptian blue works as a case study to understand the processes of colourant manufacture and to explore the ways craftspeople perceived and exploited natural resources to produce materials with desired hues and colouring properties in the late Hellenistic period.

Egyptian blue is an artificial, multicomponent material that owes its saturated blue colour to the presence of bivalent copper ions (Cu^{2+}), which lie in a calcium copper tetrasilicate crystalline phase ($CaCuSi_4O_{10}$) (Pozza *et al.* 2000, Berke 2002). The impressive deep colour and artificial origin of Egyptian blue have attracted the interest of several scholars, making it one of the most thoroughly researched colourants, with complementary archaeological, literary, and scientific data illuminating aspects of the manufacturing process and its receptance in different sociohistorical contexts (see

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Skovmøller *et al.* 2016, for an overview of recent research). Starting from a finely ground mixture of non-blue materials, including a copper source (metallic copper, copper alloys, or minerals), silica- and calcium-containing sand, and alkali fluxing agents, Egyptian blue was produced though a demanding pyrotechnological process, which required several hours of high-temperature firing (850–1080°C) in a controlled, oxidizing atmosphere (Pradell *et al.* 2006, Hatton *et al.* 2008). The earliest confirmed evidence of Egyptian blue use can be dated back to ca. 3300–3200 BCE Egypt (Corcoran 2016), making it the earliest artificial pigment that has been archaeologically recorded. This can be related to Egyptian blue's remarkable chemical stability, a material property that may have contributed to its appreciation in antiquity.

Egyptian blue was invented in a world where stable inorganic blue materials were rare, but not absent. The semi-precious blue stones turquoise and lapis lazuli were used for the creation of small objects and jewellery (Winter 1999, Corcoran 2016) and early literary evidence underlines the relationship between the naturally occurring semi-precious stones and a novel, artificially produced blue material. The Egyptian term *ḫsbḏ iryt* (ca. 2450 BCE) describes a colourant used for inscriptions that can be translated as 'manufactured lapis lazuli', as opposed to the naturally occurring blue rock, most likely referring to Egyptian blue (Faulkner 1962, Baines 1985, p. 286, Delamare 2013a, Becker 2022). Similarly, the Akkadian term *uqnū kūri* (17^{th} century BCE), which has been translated as lapis lazuli from the kiln, in contrast to *uqnū šadî*, lapis lazuli from the mountain, might also refer to Egyptian blue (or to blue-tinted glass) (Delamare 2013a, Panagiotaki *et al.* 2015, Becker 2022). Like lapis lazuli, the new blue material was symbolically associated with brilliance and linked to the creative force of the sun and the cosmos, suggesting that the use of this blue pigment in Egyptian contexts could give life to an 'inanimate work of art' (Corcoran 2016, p. 42).

The symbolic associations of lapis lazuli with the night sky, the sun, the growing fields, or the Nile (Duckworth 2012, Corcoran 2016), were not arbitrarily connected to the dark blue stone. Rather, such symbolic associations 'emerge from the characteristics of the material mineral world' and are linked to the physical properties of the material (Boivin 2012, p. 16), which, in this case can be perceived as both the colour and the lustrousness of lapis lazuli. As a material, lapis lazuli, this sparkling, saturated blue stone, lacked Egyptian blue's versatility. The latter, having in principle the properties of a vitreous material, could be moulded to create small objects and at the same time could be ground to colourful powder and mixed with various binding media to create paint.

Despite the confirmed application of lapis lazuli as a pigment in antiquity (Brøns *et al.* 2020, and references therein), the difficulty in separating lazurite (the blue mineral phase of lapis lazuli) from the rock, together with the lapis lazuli's high value and 'exotic' provenance, impeded its wider application us a pigment until the Middle Ages, when ultramarine blue dominated Western art (Delamare 2013b). Azurite, a naturally occurring copper carbonate mineral ($Cu_3(CO_3)_2(OH)_2$), was also used as a blue pigment in antiquity. However, azurite does not share the stability of Egyptian blue and tends to transform into its green counterpart, malachite ($Cu_2CO_3(OH)_2$), in the harsh chemical environment of fresco painting or when exposed to outdoors conditions (Berke 2007, Delamare 2013a). Finally, even though cobalt blue glass wasproduced through an organised manufacture from the 17^{th} or 16^{th} century BCE, cobalt blue was used as a pigment (Amarna blue) only within limited Egyptian contexts (Uda *et al.* 2002, Tite and Shortland 2003, Duckworth 2012).

The material properties of Egyptian blue, its saturated blue colour, the presence of quartz particles that allowed the reflectance of light and thus sparkle, the pigment's stability in harsh environmental conditions, and the maintenance of a blue hue when ground to powder (even if becoming lighter), favoured the dominance of the pigment in ancient Mediterranean art from the mid-third millennium BCE until the 4th century CE, when, with the fall of the Roman Empire and the re-organisation of production networks, its use became less frequent (Riederer 1997, Nicola *et al.* 2019, Dariz and Schmid 2021).

Egyptian blue has been identified in ancient polychrome art of various cultures throughout its long history of use (Kakoulli 2009, Delamare 2013a, Skovmøller *et al.* 2016), reaching as far north as Norway (Rosenqvist 1959). However, and despite the widespread use of Egyptian blue across the ancient Mediterranean world, archaeological research has so far brought to light only scarce evidence of production (Fig. 1). Among the so far identified Egyptian blue production sites, the Island of Kos provides the exceptional opportunity to study the manufacture of Egyptian blue within a well-defined 1st century BCE (late Hellenistic-early Roman) pigment and metallurgical workshop context.

The Island of Kos is located on one of the most important trade routes of the Aegean, connecting the Black Sea with Egypt and Anatolia (Sherwin-White 1978, p. 225, Höghammar 2016). The fertility and rich mineral resources of Kos favoured the development of the island, which was inhabited by the 4th millennium BCE (Marketou 2004). During the Hellenistic period (approx. 4th to 1st centuries BCE), Kos was established as an important commercial hub, renowned for its products and exports, including the widely distributed Koan amphorae, wine, silk textiles, and perfumes (Sherwin-White 1978, pp. 224–255). The relationship of Kos with Ptolemaian

Fig. 1. *Egyptian blue production sites in the Greco-Roman world according to archaeological and literary evidence. Among the indicated sites, Egyptian blue production at Memphis and Kos is supported by the identification of a workshop-space.*

Egypt was particularly tight, with Ptolemy II Philadelphus being born on Kos (283 BCE) when his mother, Berenice, visited Kos to receive 'the best medical care' of that period (Sherwin-White 1978, p. 26, 83–131). Indeed, Kos, the Island of Hippocrates, with the important Hellenistic School of Medicine, is considered 'the birthplace of scientific medicine' (Sherwin-White 1978, pp. 256–288) and Koan doctors, researchers, workers, and soldiers, were often travelling to Alexandria to serve the Ptolemies (Sherwin-White 1978, p. 106), transferring and exchanging knowledge and skills.

The presence of a pigment producing site in the sociohistorical context of late Hellenistic Kos is therefore not surprising, especially given the shared knowledge between colourant manufacture and pharmacology, with the Greek term *pharmako* (medicinal substance) being used interchangeably for both pigments and medicinal substances by Theophrastus (Theophr. *Lap*. 55) and pigments and medicinal substances being sold in the same shops during Roman times (Wood and Osbaldeston 2000, p. xxiii). The location of the workshop at the eastern sector of the ancient agora of Kos, an area linked to mercantile activities, and its proximity to the ancient harbour, illustrates the incorporation of pigment manufacture in the ancient city's commercial and manufacturing life (Kantzia and Kouzeli 1991, Livadiotti 2018, Kostomitsopoulou Marketou 2019).

The workshop was excavated in the 1980s by the 22nd Ephorate of Prehistoric and Classical Antiquities of the Greek Archaeological Service, under the supervision of Charis Kantzia (Kantzia and Kouzeli 1991). The material remains of production include numerous earth pigment lumps (Kostomitsopoulou Marketou *et al.* 2019), amorphous lead, and tubular litharge (PbO) rods, and approximately one hundred Egyptian blue pellets, in the context of several destroyed fire-structures. Recent scientific analyses of selected Egyptian blue pellets from the Koan workshop have shed light on the locally adapted variation of the production process (Kostomitsopoulou Marketou *et al.* 2020, 2021), forming the foundation for the theoretical and methodological approach for the study of colourant manufacture as the materialisation of colour presented in this paper.

THE MATERIALISATION OF COLOUR(S)

Despite the physiology of vision being considered 'a transhistorical and transcultural absolute' (Squire 2016, p. 3), anthropological research sees colour as a 'highly encultured construct' (Young 2006, p. 3), suggesting that the ways of seeing, understanding, and attributing meaning to colour and light, are influenced by the cultural background of the observer. Contemporary views on colour are laid on philosophical and artistic traditions of Enlightenment and are largely based on Newton's scientific experiments with light (Newton 1952, Thompson 1995, pp. 10–18). According to classical (Newtonian) optics, colour is not a primary quality of matter, such as volume, mass, or density. Rather, the colour of things is considered a secondary property that emerges from the interactions of matter with light. If the frequency of the emitted light happens to belong in the small portion of the electromagnetic spectrum that the human eye can detect (400–700 nm), the brain interprets this information as a specific colour (Tilley 2011, p. 3, 24–33). The (Western) perception of colour as an abstract phenomenon has been described by Diana Young as the process of 'colour dematerialisation' (Young 2006, p. 2).

The perception of colour as a dematerialised neurological response to electromagnetic radiation and the possibility to think of abstract colour terms may come effortlessly to most of us; our monitors expose us to hundreds of hues and a plethora of different shades, while an industrial abundance of colourants shapes our environments. Our 'disembodied' perception of colour and light however (cf. Stager 2016), the idea that colour is an elevated experience that happens in the brain/mind, does not necessarily correspond with the ways colour and colourful materials are understood in other cultural systems. Indeed, several anthropological examples show that qualities of colour and brilliance are often linked to the material world (Saunders 1999, 2001, 2003, Young 2006, Bradley 2014).

The idea that colour is connected to the material world seems to be common in the Classical world.Even if the translation and understanding of the phenomenon of colour through Greek and Roman literary sources is challenging (Bradley 2009, pp. 56–57), colour terms (as individual hues) seem to have been directly related to materials (Stager 2016, p. 98). Characteristic of this notion is that Pliny the Elder, who included a substantial contribution on pigments and painting-techniques in his encyclopaedic work on Natural History, uses the Latin term *color* to refer to a single colourant (pigment) that is directly linked to a specific material (Bradley 2009, p. 101). Various Greek and Latin literary sources are preoccupied with colour and colourants, ranging from philosophical treatises to poetry (Bradley 2009), among which, the systematic works of Theophrastus (*On Stones*, written in ca. 315–314 BCE), Vitruvius (*On Architecture*, written in ca. 27–23 BCE, and especially Book 7), Pedanius Dioscorides (*On Medical Materials*, written in ca. 64–77 CE, and especially Book 5, *On Metallic Stones*), and last, but certainly not least, Pliny the Elder (*Natural History*, written in ca. 77–79 CE, and especially Books 33 and 35) provide relevant information on ancient colourants, their provenance, and their value, as well as descriptions of the production processes.

Complementing the literary sources, archaeological finds demonstrate the employment of a highly sophisticated understanding and use of colours: from dyed textiles to wall paintings and from richly decorated sculptures to tinted glass and glazed ceramics, ancient societies have left us with a rich heritage of colour. Colourants, the category of materials intentionally made and used to exploit their colouring properties, derived from a wide range of different sources and include natural and artificially made materials (Siddall 2018), holding perhaps the most concentrated material evidence for the application of colours in the past.

If colour-perception is culturally specific and contemporary understandings of colour are heavily biased, how can the varied evidence of ancient colours, literary or archaeological, be approached? Methodologically, it seems easier to break down the evidence based on disciplinary categorisations (Cleland *et al*. 2016, p. 140). The study of the applied colourants, or what is commonly referred to as the study of ancient polychromy, can be approached through the direct observation of archaeological finds and archaeometric analyses. The symbolic significance of colours on the other hand, could perhaps be better understood through the study of the colour-connotations based on the analysis of ancient literary sources. Such disciplinary approaches, however, may bear limitations. Colour terminology is notoriously challenging to interpret since it involves a series of sensory experiences (Bruno 1977, p. 47), resulting to sometimes biased modern interpretations of ancient literary sources (see for example Gladstone's interpretation of Homer's colour perception, discussed in Bradley 2014, p. 127). The material record on the other hand, can be heavily biased towards the more stable colourants, enabling only a limited reconstruction of the ancient palette.

The relationship of colour and language has received the interest of several scholars from different disciplines, sparked by the (much debated) universalist theory of an evolutionary sequence of basic colour-terms, proposed by Brent Berlin and Paul Kay in 1969 (see Saunders 2000, Young 2006, for an insightful discussion and critique). However, as the interdisciplinary work of John Baines on the evolution of ancient Egyptian colour terms from the 3rd to the 2nd millennium BCE demonstrates, colour-terms failed to represent the richness of the materiality of colourants used in ancient Egypt (Baines 1985). In fact, the use of the colourants of specific hues preceded the corresponding colour-terms, demonstrating that language does not always capture the complexity of the phenomenon of colour perception.

The context of the applied colourants, the choice of specific pigments over others for certain objects or details, is an important aspect of the symbolic power of colourants (Brecoulaki 2014). In this sense, colour can be seen as an autonomous medium of communication, acting as an agent independent (or complementary) to language (Young 2006, p. 7). The materiality of colour, which is according to Young the 'material stuff of colour' (Young 2006, p. 2), can be crucial to understand the perception of colour in the past, complementing the written sources. 'Things' have transhistorically been categorised based on their colour. As Bradley notes, the idea of colour being connected to things, an object-centred experience, is found across different Greek and Roman philosophical approaches of perception, which see colour as the surface of an object: 'what defined it and made it visible' (Bradley 2014, p. 132). Moreover, as Mark Peters notes, the use of colourants can be seen as a controlled, transformative process an object's 'character and understanding' (Peters 2008, p. 189). Thus, the materiality of ancient colours could be explored to bridge past and modern conceptualisations of colour.

Beyond the study of colour as the 'surface' of things, colourant production technologies can be approached as the 'dynamic acts of social and material transformation' (Dobres 1999, p. 128), enhancing our understanding of ancient technological systems and their social implications. The process of the 'transformation of ideas, values, stories, myths, and the like into a physical reality' has been termed as 'materialisation' by Elizabeth DeMarrais *et al.* (1996, p. 16). Moving beyond the symbolic value or meaning, DeMarrais (2004, p. 13) recognises that 'objects can materialise the techniques and skills involved in [their] manufacture and procurement', reflecting the artisan's 'mental template' and cultural background. Through the study of the technological processes of colourant manufacture, these dynamic acts of material transformation to produce 'colours' can be approached, in an attempt to link the material remains of colour to the people that manufactured them.

Even though archaeological research commonly frames unused colourants as raw materials, substances that will eventually be applied as paint layers, throughout this paper, colourants are seen as technological products, i.e., artefacts that enter the commercial/trade cycle as commodities, recognising that this may be the first phase of the material's biography. Raw materials, on the other hand, are defined as the starting materials, such as copper-alloys or untreated mineral ores, which are eventually transformed into pigments through technological processes. Throughout the process of colourant production, the materials under process, the raw materials, are in a 'dialogue' with the person treating them, defining the process by means of their physical properties and constraints and at the same time being defined by the technological processes (Schlanger 1994). Colourant manufacture is thus defined as the purposeful treatment of (mainly) inorganic substances to produce materials that can be used to colour things. Extracted, transported, shaped, fired, ground, and mixed, raw materials undergo a series of material transformations to become pigments. In this manner, borrowing the term from DeMarrais *et al.* (1996, p. 16), the process of pigment production can be considered as the materialisation of colour: the intentional exploitation of raw materials for their tinting properties and their ability to colour different substrates.

In the following section, based on previous archaeometric analyses, the pyrotechnological process of Egyptian blue production will be discussed as the process of materialising the colour blue within the context of late Hellenistic Kos.

MATERIALISING THE COLOUR BLUE: THE PROCESS OF EGYPTIAN BLUE PRODUCTION ON LATE HELLENISTIC KOS AS A CASE STUDY

The invention of Egyptian blue in the fourth millennium BCE, i.e., the production of a stable, blue material through mixing and firing of non-blue starting materials, should not be imagined as a mentally preconceived experimental procedure aimed to the creation of blue. Rather, the invention of the material demonstrates the interwoven relationship of colour perception with the material world and material transformations, which can be seen as the result of 'creatively and somatically grappling with matter' (Dakouri-Hild 2013, p. 320). The widespread use and long history of Egyptian blue for approximately four millennia (Corcoran 2016) demonstrates how the manufacture of a blue material shaped ancient Mediterranean art, with most instances of blue being identified as Egyptian blue.

Despite the widespread use of the material, however, archaeological research has so far brought to light only a limited number of production sites (Fig. 1). Evidence for Egyptian blue production in Hellenistic and Roman times has been found in Memphis in Egypt, Cuma, Literno, and Pozzuoli in central Italy, and on the Aegean Island of Kos (Cavassa 2018, pp. 22–34). Archaeometric analyses on Egyptian blue from different localities and periods have shed light on the production process, which includes the firing of the primary raw materials (silica, metallic or mineral copper, a calcium-source, and an alkali flux) in high temperatures (850–1050°C) for an extended period of time (Delamare 1997, Pagès-Camagna *et al.* 1999, Pagès-Camagna and Colinart 2003, Hatton *et al.* 2008, Grifa *et al.* 2016, Giménez *et al.* 2017, Nicola *et al.* 2019, Kostomitsopoulou Marketou *et al.* 2020, 2021, Dariz and Schmid 2021).

Contributing to the archaeological evidence and the scientific data, the detailed description of Egyptian blue production in the 1st century BCE workshop of Vestorius in Puteoli, as seen and understood by his contemporary Vitruvius (Vitr. *De arch.* 7.11.1), is particularly insightful (translation by Granger 1934):

> Sand is ground with flowers of soda (*nitri flore*) to such fineness that it becomes like flour. Cyprian copper is sprinkled from rough files like fine dust so that it combines with the mixture. Then, it is rolled by hand into balls and they are put together to dry. When dry they are collected in an earthenware jar, and the jars are put in a furnace. In this way the copper and the sand burning together owing to the vehemence of the fire dry together, and, interchanging their vapours, lose their properties; and their own character, overcome by the vehemence of the fire, they acquire a blue colour.

Vitruvius' concluding observation encapsulates the notion of colour materialisation as seen from a contemporary: starting from non-blue materials, the carefully orchestrated technological process leads to the creation of a blue substance. This process of material transformation, visually perceived by the change in colour of the materials throughout the body of the produced pellets and followed by the change of the mechanical properties after firing, can be perceived as a demonstration of knowledge and control over the materials, similar to the production of blue glass as discussed by Chloë Duckworth (2012).

The study of the Egyptian blue pellets from the workshop of Kos, as well as the multi-analytical examination of selected samples, illustrate the complex manufacturing process followed for the production of the blue pigment (Kostomitsopoulou Marketou *et al.* 2020, 2021). The process can be broken down into two phases: the initial production of the Egyptian blue pellets and the subsequent processing for the creation of various tonalities of blue (Fig. 2).

The first phase includes the selection of the raw materials: sand, copper, and the natural mineral evaporite natron, all of which are included in Vitruvius' description (Vitr. *De arch*. 7.11.1). Previous research has indicated that various sources of raw materials could have been used, including copper alloys instead of metallic copper and plant ashes instead of natron (Delamare 2013a). However, calcium, necessary for the synthesis of the copper-calcium tetrasilicate crystals responsible for the blue colour of the material (corresponding to the naturally occurring mineral cuprorivaite, $CaCuSi_4O_{10}$), is not mentioned in Vitruvius' account. While the 'neglect' of calcium has led to the recipe being considered incomplete (Delamare 2013a, p. 8), researchers have argued that a calcium-rich silica-sand (Hatton *et al.* 2008, Grifa *et al.* 2016) or adulterated natron (Davidovits 2016) would provide sufficient amounts of calcium for the production. The choice of the starting materials, copper-containing minerals or alloy scrap, calcium-rich sand or intentionally added calcium, natron or plant ashes, etc., is an important aspect of the production that can deepen our understanding of the value and perception of the material in the specific socio-historical context (Sillar and Tite 2000). At the same time, the choice of raw materials can illustrate networks of trade

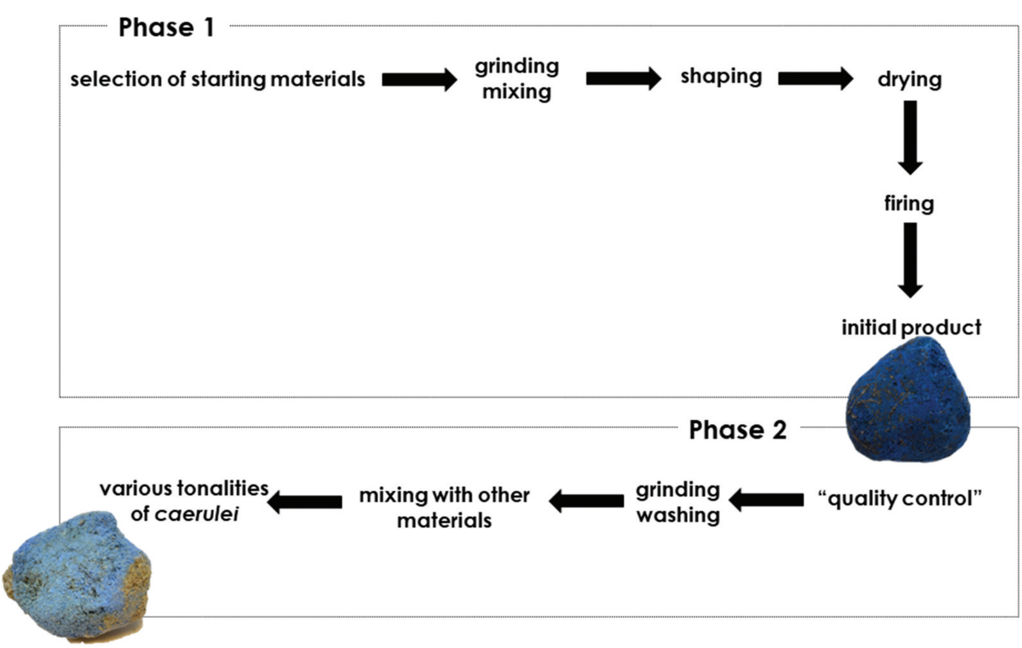

Fig. 2. *Graphic reconstruction of the Egyptian blue production process at the workshop of Kos.*

and knowledge transfer, with the materials themselves acting as 'knowledge repositories' that can highlight innovations or local adaptations of the production process (Rebay-Salisbury *et al.* 2014, p. 2).

The micromorphology of the Koan samples demonstrates that the copper calcium tetrasilicate crystals were formed directly in contact with the quartz grains, pointing to a solid-state synthesis, characteristic of a low-alkali starting mixture (Kostomitsopoulou Marketou *et al.* 2020). The detection of tin in the analysed samples may be indicative of the use of bronze as a copper source, possibly suggesting the recycling of copper alloys to produce Egyptian blue. The ratios of the starting materials (CaO/CuO and SiO/CuO) play an important role for the production of Egyptian blue (Pagès-Camagna and Colinart 2003, Hatton *et al.* 2008, Delamare 2013a). Practically, the quantities of the starting materials should approximate the stoichiometry of cuprorivaite crystals ($4SiO_2$:1CaO:1CuO), while an excess of silica has been documented. The unsuccessfully produced pellets unearthed on Kos suggest that the quality and quantity of the starting materials are a central aspect of the production (Kantzia and Kouzeli 1991, Kostomitsopoulou Marketou *et al.* 2020, 2021).

According to Vitruvius' account, after selection, the starting materials were ground into fine powder and mixed with water to produce a paste that could be then shaped by hand into small, rounded pellets (Vitr. *De Arch*. 7.11.1), a shape considered characteristic for the Hellenistic and Roman periods (Tite and Hatton 2007). Finger imprints observable on the Koan finds suggest a rough shaping of the paste by hand, following Vitruvius' description, while imprints of tools indicate handling of the still plastic pellets with tweezers or similar tools, possibly in the attempt to place them in the kiln. The production of Egyptian blue in small, rounded pellets can be understood as a technological innovation that would reduce the firing time or the required kiln temperatures, providing a more efficient process compared to the previous forms of production in larger lumps or 'cakes' (Delamare 2013a, p. 10) and at the same time, as a measure to facilitate and standardise trade (Tite and Hatton 2007). The size of the majority of the pellets found on Kos ranges from 30 mm to 40 mm across (Kostomitsopoulou Marketou 2019), which is significantly larger than what has been reported as characteristic of Hellenistic and Roman productions, which are commonly only up to 15 mm across (Tite and Hatton 2007). Since the pellets are thought to be traded without further processing, this variation in terms of pellet size could be a signifier for the different workshops (or qualities).

The material from Kos, divided into successful, unsuccessful, and partially successful pellets, brings forward another advantage of the production of Egyptian blue in the shape of small pellets: after firing, the product could be subjected to a type of 'quality control' based on the colour of the pellets, and the non-blue, or unsuccessfully produced, pellets could be easily separated (Fig. 3). If the classification into successful and unsuccessful products based on their colour resembles the perception of blue in antiquity, the presence of unsuccessfully produced Egyptian blue pellets materialises the 'conceivable choices' made by the craftspeople, which in turn are formed within their contemporary systems of knowledge, perception, and symbolism (Dakouri-Hild 2013, p. 317).

The transformation of the raw materials to the final product with the characteristic blue colour corresponds to the synthesis of the copper calcium tetrasilicate crystalline phase (equivalent to the naturally occurring mineral cuprorivaite). The synthesis of cuprorivaite is a high-temperature

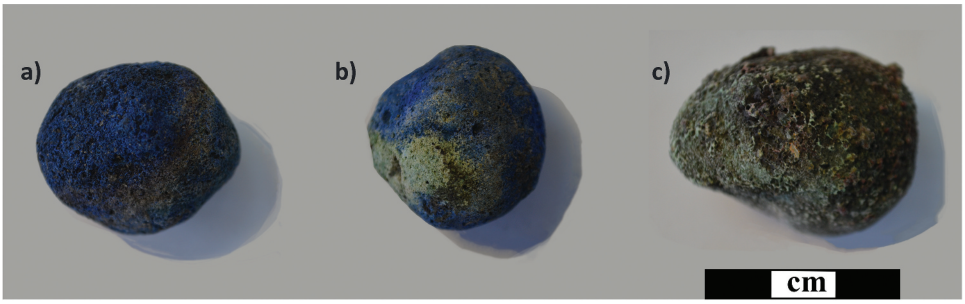

Fig. 3. *Three rounded Egyptian blue pellets from the Koan workshop, representing a) a successfully produced pellet (blue); b) a partially successful pellet (presenting both green and blue areas on the surface); c) an unsuccessfully produced pellet (no blue observable on the surface of the find). Photos: author, with permission of the Ephorate of Antiquities of the Dodecanese.*

pyrotechnological process that requires high firing temperatures (850–1050°C) for an extended period of time, possibly even several days (Pradell *et al.* 2006). More than one firing cycles may be suggested by the micromorphology of certain Koan pellets, resulting in a material with a coarser texture and green glassy phases, visible with the naked eye (Kostomitsopoulou Marketou *et al.* 2020). Based on the material found in the fire-structure where the majority of the pellets were unearthed, it is likely that pinecones and twigs were used as fuel or for ignition (Kostomitsopoulou Marketou 2019). A precise reconstruction of the firing-structures of the Koan workshop cannot be suggested based on current data, mainly due to their poor state of preservation (Kostomitsopoulou Marketou 2019).

The ceramic vessels (saggars) in which Egyptian blue pellets were placed during firing according to Vitruvius's description (Vitr. *De arch.* 7.11.1) have been considered crucial for the successful firing of the starting materials (Cavassa 2018). However, no saggars were found in the Koan workshop-context. The absence of saggars from the Koan context has therefore been interpreted by Cavassa as a disqualifier for the hypothesis of *in situ* production (Cavassa 2018). However, the close observation of the macro-morphology of the finds, which stand as individual rounded pellets with a slightly flattened surface – as opposed to the lumped pellets from Memphis – suggests the firing of the initially shaped paste of raw materials on a flat surface, illustrating therefore a local adaptation of the production process.

Beyond the production of the initial Egyptian blue pellets, the Koan material demonstrates that the materialisation of different tonalities of blue took place at the workshop through the further processing of the initially produced pellets (Fig. 2). The micro-analytical investigation of the finds suggests two variations of the manufacturing process to produce different tonalities of blue (Kostomitsopoulou Marketou *et al.* 2020) (Fig. 4). The first variation included the fine grinding of the initially produced pellets, the separation of the fine Egyptian blue crystals from the coarser parts, and the mixing of the ground Egyptian blue with a cobalt-rich material to produce a material with a saturated blue hue. The second, which produced paler blue tones, was restricted to grinding (Kostomitsopoulou Marketou *et al.* 2020).

Is there a relationship between the different tones of blue pigments found on Kos and the different qualities of blue described in literary sources? Further processing of blue pigments to produce different qualities

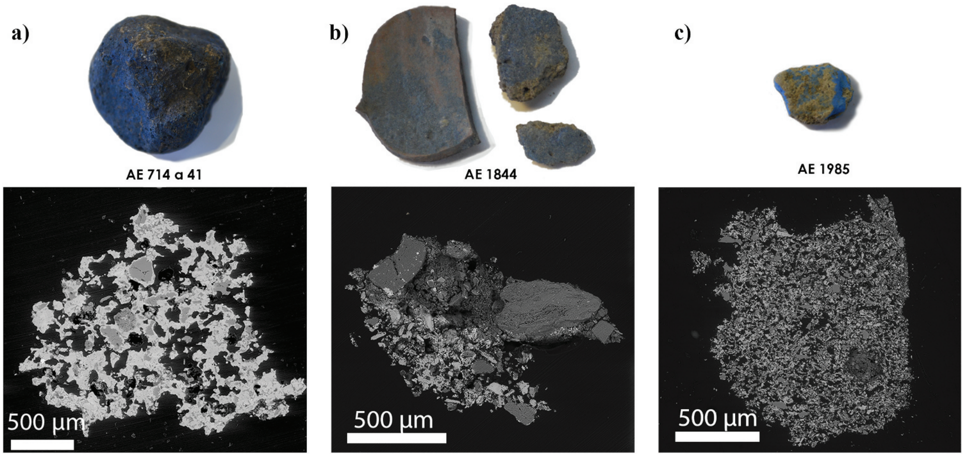

Fig. 4. *Selected finds from the Koan workshop context and corresponding backscattered electron micrographs (see: Kostomitsopoulou Marketou et al. 2020, for the experimental setup of scanning electron microscopy). a) Initially produced Egyptian blue pellet; b) crushed Egyptian blue material from a pottery sherd; c) bright blue lump composed by finely ground Egyptian blue crystals.*

and tones of blue are described by Theophrastus, who mentions four tones of blue, ranging from pale to dark blue (Theophr. *Lap*. 55, translation by Caley and Richards 1956). Pliny the Elder (Plin. *HN* 33.57, translation by Rackham 1952) also discusses various qualities of blue pigments (*caerulei*). According to Pliny, washing and grinding of *caerulei* was employed to produce a paler blue pigment, called *lomentum*, which was more valuable than regular *caeruleum*. The differentiation in terms of shades, tonalities, applications, and the reflection of the above on the value of the various blue colourants, illustrates the intentional exploitation of matter to produce colourants of desired properties and hues that would actively engage the senses. While it is perhaps impossible to confidently identify these different qualities among the Koan finds, the variations employed to produce, or 'materialise', lumps with a distinctive optical impact, could be related to the different values of Pliny's *caerulei*.

Beyond the differentiation of blue pigments in terms of tones, there seems to be a distinction between Egyptian blue (*caeruleum Aegyptium*), blue from Puteoli (*Puteolanum*) and Vestorian blue (*Vestorianum*) in terms of price, with the latter, produced in Puteoli, being more valued according to Pliny (Plin. *HN* 33.57) (Becker 2022). This distinction indicates the symbolic importance of provenance for the economic value of the pigments. Indeed, provenance played an important role in the classification of colourants in Mediterranean antiquity, with certain sources linked to symbolic connotations of specific properties (Becker 2022). The importance of provenance has been observed in a wide range of cultures, with no obvious (to the modern eye) material properties indicating the preference of certain sources (Boivin 2012, p. 8). Rather, the strenuous effort of obtaining certain materials seems to reflect the symbolism and value linked to the specific sources (Boivin 2012, p. 8), while in other contexts, as for example the early Roman Empire, provenance can be seen as a demonstration of power and sophisticated artistic, political, and economic systems of value (Bradley 2006).

Despite the rich material evidence of Egyptian blue production, ancient authors do not include Kos as a source for Egyptian blue (see for example Pliny the

Elder's account of blue pigments, discussed above). This contrast between the written sources and archaeological evidence suggests the presence of a complex network of manufacturing centres across the Mediterranean that remains to be explored.

CONCLUSIONS

The dependence of colour on a number of factors, including the sensitivity of the eye, the light source, and psychological biases, has led to the understanding of colour-perception as a subjective experience, something that cannot occur without light, matter, and an observer (Tilley 2011, p. 23, 28). It is through the human observer that colour is embedded in culture and acquires meaning, making colour perception an encultured sensorial experience, the result of 'the act of looking' (Squire 2016) (Fig. 5). The culture-dependency of colour makes the bridging of contemporary and past perceptions of colour based on archaeological or textual evidence a challenging task. This paper suggests that by focusing on the reconstruction of the processes of colourant manufacture, we can deepen our understanding of colour perception in socio-historical contexts different from our own.

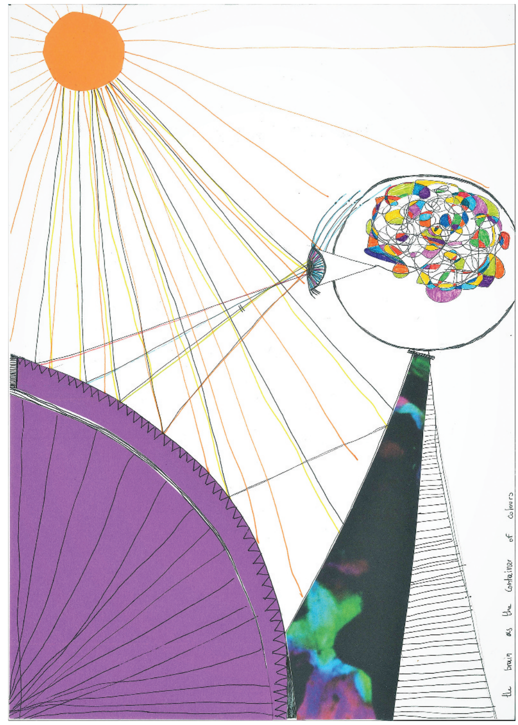

Fig. 5. *'The brain as the container of colours', mixed media, produced during the reading process of colour theories by the author of this paper.*

The complexity of colourants as a category of archaeological finds, with the variability of raw materials that may derive from a wide range of different sources, makes the study of the technological processes of production, or colour materialisation, a demanding task. The workshop of Kos is in that sense unique, providing the opportunity to study the processes involved in the materialisation of colour in a well-defined archaeological context. Focusing on the case of the Koan production of Egyptian blue and based on archaeological, written, and scientific evidence, this paper illustrates the technological processes and choices employed for the production of blue pigments and demonstrates how the manipulation of matter could be crucial for the production of colourants of varied hues and qualities.

A two-phase process is suggested for the creation of different qualities of blue (Fig. 2). The first phase includes the collection, processing, and firing of the non-blue starting materials to produce the initial pellets of a characteristic saturated blue colour and the second involves the further processing of the initially produced pellets to create blue colourants of different tonalities. It is important to note that the archaeological finds from Kos indicate that Egyptian blue production was carried out side by side with metallurgical/metal working activities and that earth pigments were also treated at the site (Kostomitsopoulou Marketou 2019). This juxtaposition of different types of production may suggest interactions across the production processes that affect and shape the technological choices and the manufacturing processes. Therefore, the suggested two-phase scheme is a simplification that may not necessarily encapsulate the complexity of production. Further research, including experimental reconstructions and colourimetric analyses, is required to understand how the choice of the starting materials and the firing-procedure, affected the final colour of the product.

When looking back to the blue materials of the past, one should bear in mind that the weathering of certain materials, the fragmented nature of the archaeological record, or even our biased perception of colour, could distort the image of ancient colour use and perception (Squire 2016, Brøns 2019). In other words, what Nicole Boivin describes as the 'mineral bias of the archaeological record' (Boivin 2012, p. 6), i.e., the stability of minerals compared to other materials, emphasises the presence of mineral blues and artificial crystalline materials, such as Egyptian blue, over organic ones. A holistic understanding of the perception of blue through the concept of colour materialisation should include the study of both pigments (inorganic) and dyes (organic) materials. On a finally note, it is important to stress that colourants are more than artefacts *per se*. The initial product, the pigment lump or dyestuff, undergoes a series of transformations before becoming a layer of applied polychromy (e.g. the blue background of a fresco painting, or the colour of textiles). The stages of colourant manufacture are therefore only the first chapters of a colourant's biography and the processes of colour transformation expand beyond these initial stages.

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