The first direct evidence for the production of Maya Blue: rediscovery of a technology

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Maya Blue is a colour that is more than a pigment; it had roles in status, ritual and performance, being daubed onto pots and people before sacrifice. Here researchers use experimental and historical evidence to discover how it was made, including direct scientific analysis of Maya Blue on a pot thrown into the sacred well at Chichén Itzá. The results indicate that the formation of the colour was actually part of the ritual.

Keywords: Maya, Chichén Itzá, Maya Blue, sacrifice, ritual, incense, palygorskite, indigo

Method

Introduction

An unusual blue pigment applied to pottery, sculpture and murals, Maya Blue is '... *one of the great technological and artistic achievements of Mesoamerica*' (Miller & Martin 2004: 252). Used predominantly during the Classic and Postclassic periods (AD 300–1519) from northern Yucatán to highland Guatemala and central Mexico, production also appears to have survived into colonial times (Cabrera Garrido 1969; Gettens 1955; 1962: 560; Haude 1998; Ortega *et al.* 2001a & b; Polette *et al.* 2000; Reyes-Valerio 1993; Sánchez de Río *et al*. 2004; Tagle *et al.* 1990; Torres 1988). Maya Blue was not based on copper, ground lapis lazuli or azurite (José-Yacamán *et al.* 1996), but consists of a unique pigment in which indigo is chemically bound to the clay mineral palygorskite (Cabrera Garrido 1969; Chianelli *et al.* 2005: 133; Fois *et al.* 2003; Gettens 1955; 1962: 563; Giustetto *et al.* 2005; Hubbard *et al.* 2003; Kleber *et al.* 1967: 44-6; Ortega *et al.* 2001a: 755-6). It is resistant to diluted mineral acids, alkalis, solvents, oxidants, reducing agents, moderate heat and biocorrosion and shows little evidence of colour deterioration even after centuries of

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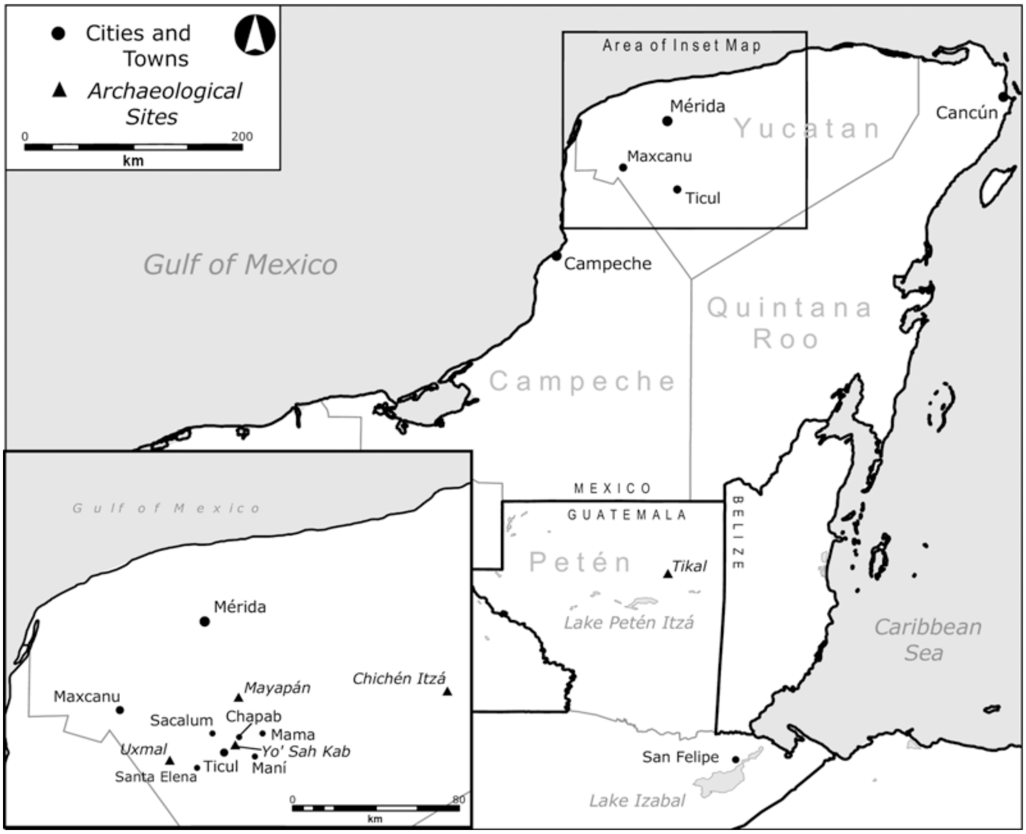

Figure 1. Map of the Yucatán peninsula and adjacent area showing cities, towns and archaeological sites mentioned in the text (map originally drawn by George Pierce and reprinted by kind permission of Latin American Antiquity*, Vol. 18, no. 1: 46, © 2007 Society for American Archaeology, see Arnold* et al. *2007).*

exposure to the harsh tropical climate of southern Mesoamerica (Fois *et al*. 2003; Gettens 1962; Sánchez del Río *et al.* 2006).

These characteristics and the widespread use of Maya Blue in ritual contexts have stimulated the interest of archaeologists, chemists and material scientists since the pigment was first identified by Merwin (1931) on the murals of the Temple of the Warriors at Chichén Itzá (Figure 1). Its use in ritual contexts implies that it was highly valued, and this inference is borne out by its association with sacrifice, priests and Maya deities, especially the rain god Chaak (Arnold 2005; Reyes-Valerio 1993: 86; Tozzer 1957: 203). Indeed, the recent exhibition *The Courtly Art of the Ancient Maya* features pottery, murals and sculpture with headdresses, clothing and jewellery painted with Maya Blue (Miller & Martin 2004).

The production of Maya Blue

Two kinds of approaches have hitherto provided information about the production of Maya Blue: experimental approaches and contextual approaches. Experiments have produced a number of key results (Cabrera Garrido 1969; Littmann 1982; Reyes-Valerio 1993; Torres

1988). First, sustained low heat (<150°C) is critical in order to create the pigment, fix its colour and acquire its unique chemical and physical stability (Torres 1988; Van Olphen 1966). Second, very little indigo is necessary to make Maya Blue; the pigment can be synthesised using only 0.5-2 per cent indigo (Hubbard *et al.* 2003; Sánchez del Río *et al.* 2006; Van Olphen 1966). Experiments using sepiolite, a clay mineral similar to palygorskite, failed to produce a stable Maya Blue-like pigment with all of its unique characteristics (Sánchez del Río *et al.* 2006).

Contextual approaches to Maya Blue have also provided insight about its production. Data from the contemporary Maya have revealed probable sources of the palygorskite used in the pigment. Using a triangulation of ethnographic techniques and data from X-ray diffraction provided by clay mineralogist B.F. Bohor, Arnold demonstrated the link between the Yucatec Maya semantic category *sak lu'um* and palygorskite (Arnold 1967; 1971). The contemporary Maya of Ticul and Sacalum recognise the unique properties of palygorskite, refer to it as *sak lu'um* ('white earth'), and use it for pottery temper as well as for medicinal purposes (Arnold 1967; 1971; 2005; Arnold & Bohor 1975; 1976; Folan 1969). Evidence suggests that sources of *sak lu'um* in or near Sacalum and Ticul were likely pre-Columbian sources of palygorskite (Arnold 2005; Arnold & Bohor 1975; 1976; Folan 1969). The name of the town of Sacalum itself is a hispanicised form of the Yucatec Maya phrase, *sak lu'um*, and the town has been so named since before the conquest (Folan 1969). By 1968, massive amounts (>600 m^3) of palygorskite had been removed from a mine at the bottom of the cenote in the centre of the town (Arnold & Bohor 1975; 1976), and informants reported that during the last third of the twentieth century, the cenote continued as a source of *sak lu'um* that was sold widely for medicinal purposes (Arnold 2005). Archaeological evidence for the antiquity of mining comes from both Ticul and Sacalum. A Terminal Classic site formerly existed on top of the *sak lu'um* source (Yo' Sah Kab) near Ticul (Arnold 2005), and Folan (1969) found Terminal Classic pottery at the bottom of the cenote and near the entrance to the mine.

A second contextual approach focuses on the other component of Maya Blue – indigo. One species of the indigo plant (*Indigofera suffruticosa*) is widespread in the Americas and probably has a pre-Columbian origin. Mexico, however, has more species than anywhere else (Arnold 1987) and this diversity indicates a long time depth of the plant in Mesoamerica. The Yucatec Maya recognise the indigo plant, call it *ch'ooh*, and like palygorskite, use it for medicinal purposes (Arnold 2005). A third contextual approach involves some understanding of copal incense. Copal (called *pom* in Yucatec Maya) comes from the sap of a tree (*Protium copal* among others, Tozzer 1957: 209) and was also a critical symbol with practical significance. Among some contemporary Maya groups, copal is linked with maize as a foodstuff for the gods. Because it was gathered as a sap from a tropical tree, it was regarded as the blood of the tree and was imbibed by the gods in the form of smoke when it was burned as incense (Stross 2007). Just as maize was the staple of the Maya diet, so copal was the staple of deities. Copal was also used for medicinal purposes (Stross 2007).

All of these data suggest that Maya Blue may have been created ritually by burning incense using a mixture of copal, palygorskite and some part of the indigo plant (Arnold 2005). This inference is supported by the existence of the pigment on a ball of copal from Tikal and one from the Cenote of Sacrifice at Chichén Itzá (Cabrera Garrido 1969: 20-2; Shepard 1962;

Shepard & Gottlieb 1962; Shepard & Pollock 1971), and on fragments of incense burners and along with soot and copal that came from the Aztec market site of Tlateloco in what is now Mexico City (Cabrera Garrido 1969: 15). Copal incense burns slowly and would explain how sustained heat was used to create the pigment. Further, creating Maya Blue by burning incense, such as making offerings to the Maya rain god Chaak, would imbue this pigment with thrice its symbolic power, once for the healing properties of its constituents, twice for creating its unique colour that is symbolic of deity (Arnold 2005) and thrice for providing food for the gods. Indeed, the rich colour of Maya Blue is similar to the azure blue of the Caribbean and Gulf of Mexico and might symbolise the transubstantiation (and perhaps the incarnation) of Chaak, much like the bread and wine in the Roman Catholic mass is believed to become the body and blood of Christ.

Consequently, the ritual combination of three materials used for healing suggests that the actual performance of the creation of Maya Blue was very significant and might have had great symbolic value critical to the meaning of the pigment (Arnold 2005). Just as it elicited the social memory of the healing power of *sak lu'um*, *ch'ooh* and *pom* for the priests and their constituents, it also materialised the presence of the rain god Chaak at the end of the ritual by the creation of a pigment that symbolised the most valued commodity required to sustain human life – water. Feeding the rain god with incense presumably would cause him to respond positively. Just as rain brings healing to the parched land of Yucatán after the rainless dry season, so the ritual feeding of Chaak using a combination of three healing constituents (indigo, palygorskite and copal incense) brought the rain god into the presence of the congregants by the creation of Maya Blue because he had been properly fed.

Analysis of a bowl from Chichén Itzá

During the course of selecting samples for another project, Arnold was perusing a list of objects from the artefact catalogue of the Field Museum of Natural History in Chicago and noticed a label: 'Blue on copal in bowl'. Recognising that this context was precisely that which Cabrera Garrido (1969) believed to be one of the scenarios for creating Maya Blue, Arnold and Williams went to examine the bowl and its contents (Figures 2 and 3). Arnold noted that the white flecks on the underside of the copal looked like the palygorskite that he had seen in Yucatán.

The bowl (20cm in diameter and 10cm high) was a tripod pottery bowl dredged from the Sacred Cenote at Chichén Itzá by E.H. Thompson in 1904. Close inspection of the underside of the copal from the bowl revealed that blue and white phase fields were dispersed throughout the sample. Scanning electron microscopy revealed the presence of indigo and palygorskite, the two main components of Maya Blue. Secondary electron and backscattered electron images of the white component showed fibrous or needle-like features analogous to the structure of palygorskite. Energy dispersive X-ray analysis of both components showed compositions that were approximately analogous to previous experimental data, with one carbon peak-dominated spectrum indicating the presence of an organic material, likely indigo. These data suggest that the blue and white fields on this offering were an incomplete attempt to produce Maya Blue from indigo and palygorskite by burning (or heating) copal incense. The analyses suggest that this copal offering represented an attempt to produce

Figure 2. Maya tripod pottery bowl containing copal from the Cenote of Sacrifice from Chichén Itzá, Yucatán (photograph by John Weinstein).

Maya Blue that was interrupted by its being thrown into the Sacred Cenote (for details see Technical Appendix, below).

Context

The Sacred Cenote (Figure 4) was particularly important because it was the location where many offerings were made to the rain god Chaak (Tozzer 1957: 195-6, 203). Bishop Landa, a Spanish priest in Yucatán between 1549 and 1563, mentions that offerings such as human sacrifices and '*. . . a great many other things, like precious stones and things which they prized*' were thrown into this sacred well (Tozzer 1941: 180-811; 1957: 191). Blue paint was a significant part of this ritual, and blue was painted on objects and on the altar (Figure 5) upon which human sacrifices were made (Tozzer 1957: 211). Landa also provides a chilling description of how human victims were stripped and painted blue before being thrown backwards on the altar where their beating heart was cut from their body (Tozzer 1941: 117-9; 1957: 107, 203).

A massive number of artefacts were recovered from the cenote that included pottery, copal incense, wood, gold, rubber, jade and leather (Coggins 1992; Tozzer 1957). Except for fragments of pottery, copal incense was the most frequent item recovered and the

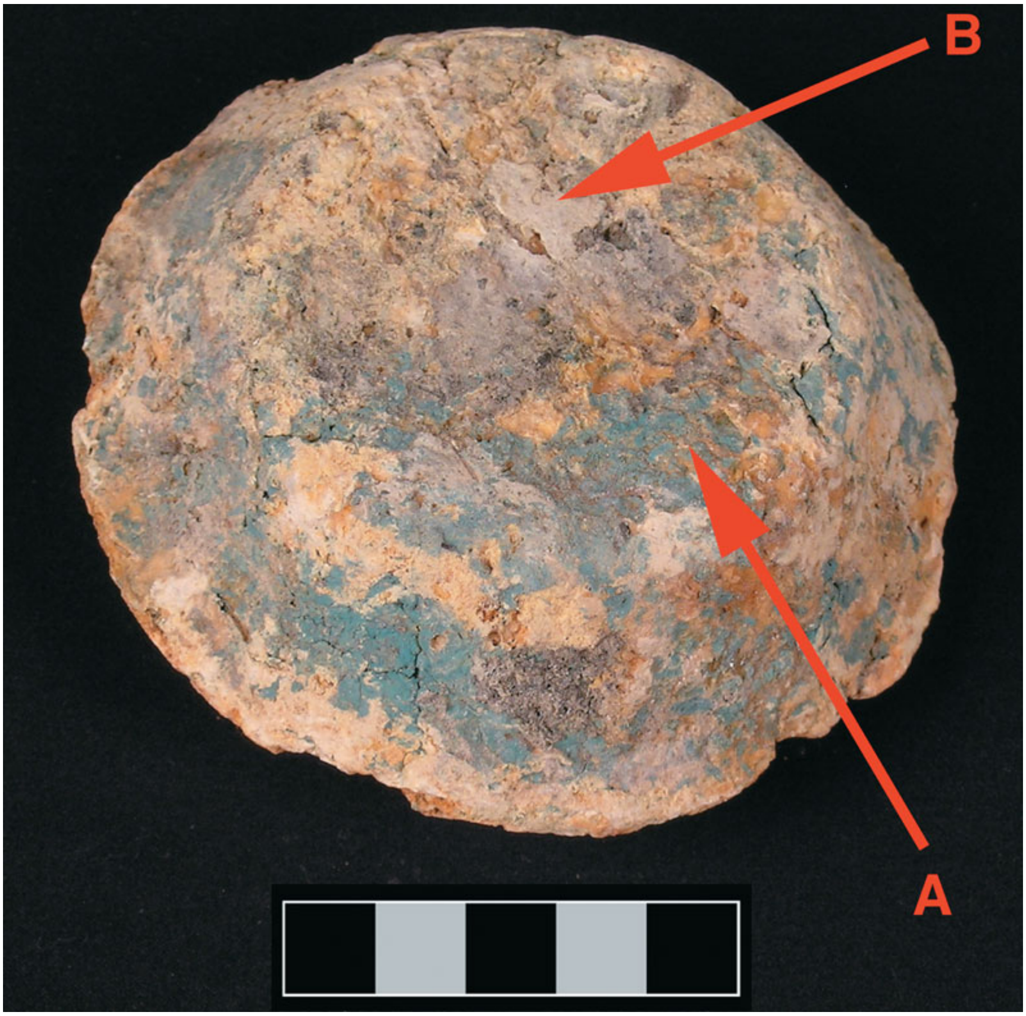

Figure 3. Underside of copal from the Maya tripod bowl in Figure 2. Fine blue grains (A) and white grains (B) were removed for analysis from the regions indicated (photograph by Linda Nicholas).

amount of incense bespeaks the significance that it played in the ritual offerings at the cenote (Coggins & Ladd 1992; Tozzer 1957: 198). Most important, many of these copal offerings had blue paint on them. Both Tozzer (1941: 117-8) and Coggins and Ladd (1992: 353) believe that this paint was indigo, but it was more likely Maya Blue.

The material in the bowl analysed here was part of a larger collection of 160 copal offerings recovered from the cenote by Edward Thompson (Coggins & Ladd 1992: 345-6). About half of these offerings were in their original containers. Ceramic bowls were the most common containers, and 50 of the copal offerings were in their original bowls. Edward Thompson's notes say *'Both vessels and incense* [were] *apparently painted blue before being thrown into the tzonot'* (Coggins 1992: 16). Were they painted blue, or was the blue created by burning incense before being thrown into the sacred well? The data presented here suggest

Figure 4. View of the Sacred Cenote at Chichen Itzá from the south-west showing its size and vertical walls. E.H. Thompson, who dredged the cenote between 1904 and 1910, noted a 4.5-5.0m layer of blue silt on the bottom. Undoubtedly, this was Maya Blue that had washed off of the sacrifices that had been thrown into the cenote.

that attempts at the *creation* of Maya Blue occurred before the offerings were thrown into the cenote.

In his narrative of the dredging operation, Thompson mentions an underwater layer of blue silt that is also shown in his profile of strata in the cenote (Tozzer 1957: 192). Using a scale based on the measurements in Thompson's profile, this blue silt forms a layer 14-15 feet thick (about 4.5 to 5.0m) below a layer of mud at the bottom of the cenote (Coggins 1992: 14; Tozzer 1957: Figure 707). How did the silt get there? Because Maya Blue is a post-fire fugitive paint, it is easily removed, when in water, from pottery, any other material and the more than 100 people who were apparently dispatched into the cenote over time (Hooton 1940; Anda Alanís 2007). All of the copal offerings look like they had been heated to the melting point because the copal took on the shape of each bowl. Tozzer, in fact, notes that other artefacts also were heated (Tozzer 1957: 197). To account further for the melting of the copal, Thompson believed that there was a large incense burner in the structure at the edge of the cenote (Figure 6) with air holes such that the offerings were heated before they were thrown into the depths below (Tozzer 1957: 192). If the copal offerings were also burned, most of the soot would have washed off in the plunge into the water. Furthermore, artefacts dredged from the cenote were washed with clear water after they were recovered. Even so, some soot remained on them.

The ceramic bowl reported here is a Mayapán unslipped ware bowl that is almost identical in shape to a bowl that Robert Smith (1971) illustrated in his classic work, *The Pottery of Mayapán*. The latter also comes from Chichén Itzá, and he says it was *'painted blue all over'* (Smith 1971, Vol. 2: 44, Figure 29y). Blue paint, Smith says, was almost exclusively associated with ceremonial pottery (Smith 1971, Vol. 1: 44).

The typological analysis of all of the pottery dredged from the cenote reveals that 90 per cent (100 per cent = 100 vessels) of whole or nearly whole bowls were, like the bowl described here, Mayapán wares of the Tases phase (Ball & Ladd 1992: 202). Chronologically, these wares occur in the Middle to Late Postclassic period (Coggins & Ladd 1992: 237), are associated with the Postclassic site of Mayapán and date to approximately AD 1300-1460 when the influence of Chichén Itzá had declined (Ball & Ladd 1992: 192; Coggins & Ladd

Figure 5. The altar on the Temple of the Warriors at Chichen Itzá upon which human sacrifices were made. The altar was painted blue, and after human victims were stripped and painted blue, they were thrust with their back down on the altar and their beating hearts removed (Tozzer 1941: 117-9; 1957: 107, 203).

1992: 237; Smith 1971). Chichén Itzá was still important, however, and according to the sixteenth-century Spanish priest, Diego de Landa, it was a place of pilgrimage where offerings to the rain god Chaak were made in the Sacred Cenote even during the early colonial period (Tozzer 1941 [1566]: 54, 109; 1957: 199). This historical narrative is confirmed by Smith who says that: *'In point of fact Chichén Itzá harbored a very large collection of Tases phase pottery, most of which was found not only on the surface but for the most part on top of fallen construction'* (Smith 1971, Vol. 2: 206). It thus appears that most of the complete or nearly complete offering bowls recovered from the cenote (including the one described here) were offered to the rain god during a time when Chichén Itzá was at least partially abandoned. The use of Mayapán wares as cenote offerings thus verifies the historical relationship between Mayapán and Chichén Itzá during the last half of the Postclassic period described by Landa.

Conclusion

The analysis of the blue and white materials in the copal offering bowl reported here demonstrates the components and also the ritual performance that had produced the characteristic blue colour. This colour was so important to the Maya of the late Postclassic period that their sacrificial cenote acquired a deposit of blue silt more than 4m thick.

Figure 6. The structure on the edge of the Sacred Cenote at Chichen Itzá. E.H. Thompson and Tozzer believed that the structure contained a large incense burner that heated some of the offerings before they were thrown into the cenote immediately at the left of the structure (Tozzer 1957: 192).

The project also has emphasised the potential rewards of scientific work on old museum collections and shown that scientific analysis is necessary but not sufficient for the understanding of museum objects. Such studies also require documentary, ethnographic and experimental research to establish their original context of use.

Who knows how many more ancient technologies can be understood through the application of modern technologies to museum collections using the holistic approach utilised here? A detailed examination of the 56 bowls of copal that Edward Thompson dredged from the Sacred Cenote, for example, can still yield more information and perhaps show how the indigo plant was used in the preparation of Maya Blue. Coggins and Ladd (1992: 346) mention that three copal offerings have clear leaf impressions on the bottom, and many have less clear vegetal impressions. They believe that these offerings may have been worked on a bed of leaves but these leaf and vegetal impressions need to be identified; they might be portions of the indigo plant used in the creation of Maya Blue. Further, it might be possible to identify plant materials found within these copal offerings themselves. Needless to say, the use of museum objects to solve the mysteries of the production of Maya Blue has only just begun.

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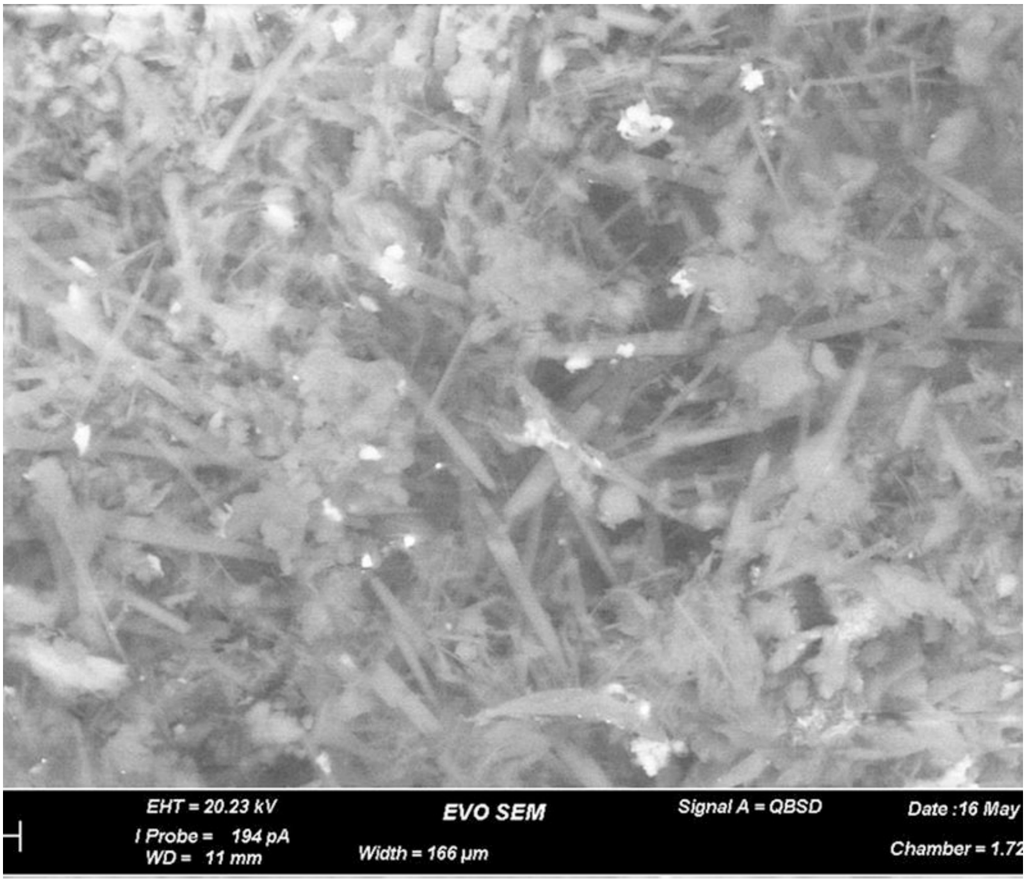

Figure 7. Backscattered electron image of white grains from the copal sample (668X magnification). The needle-like structures in the image are analogous to the known structure of palygorskite. The nature of the bright white clusters scattered throughout the sample are unknown, but could be minerals in the clay or tiny portions of the indigo plant mixed with the palygorskite before burning the incense. This latter interpretation is consistent with the carbon content in the EDX spectra of the white grains.

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Technical Appendix

Fine grains were removed from the blue and white components for SEM and energy dispersive X-ray spectroscopy (EDX). The LEO EVO 60 Scanning Electron Microscope at the Field Museum of Natural History was used to capture secondary electron and backscattered electron images of the blue and white grains from the copal. Secondary electron images were taken under variable pressure settings (0.33 torr for blue grains, 0.86 torr for white grains) at accelerating voltages of 20kV, beam currents of 22 or 29 pA, working distances of 11 or 12mm and at 668 magnification. Backscattered electron images were taken under high-vacuum settings ($1.69e^{-5}$ torr for blue grains, $1.72e^{-5}$ torr for white grains) at accelerating voltages of 20.23kV, beam currents of 194 pA, working distances of 11 or 12mm and at 668 magnification (Figures 7 and 8).

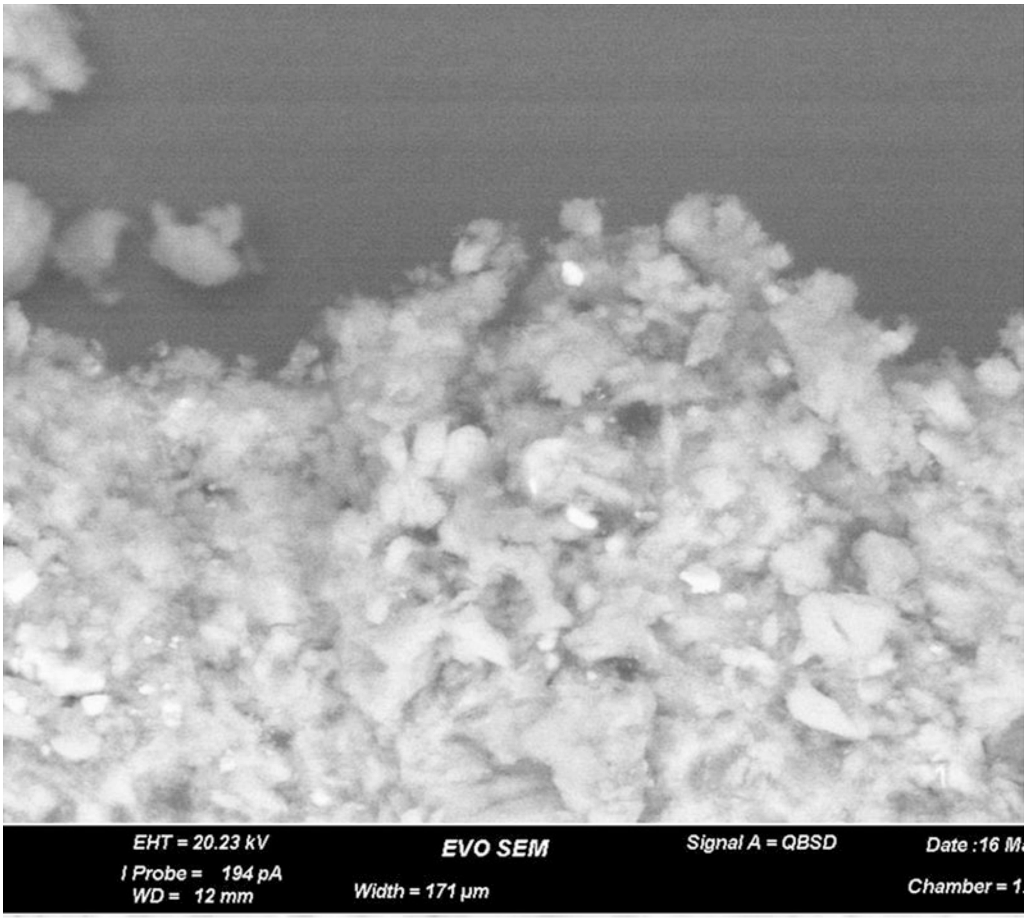

Figure 8. Backscattered electron image of blue grains from the copal sample (668X magnification). This image showed the relative homogeneous composition of the blue grains that are probably indigo.

Secondary electron (SE) images of the blue and white grains provided high resolution detail of the sample surfaces, and backscattered electron (BSE) images provided a visual representation of their contrasting compositions. The SE image of the white grains showed fibrous or needle-like structures on the surface that are analogous to the structure of palygorskite (e.g. Fernández *et al.* 1999: 5253; Ortega 2001a: 754; 2001b: 2230, Figure 2a-b; Sánchez del Río *et al.* 2004: Figure 6b). The BSE image of the white grains (Figure 7) showed fibrous and needle-like structures that confirmed the presence of palygorskite but also revealed a flake-like material also seen in the SE and BSE images of the blue grains. In addition, a small amount of extraneous material was dispersed throughout the sample surface. The SE image and BSE image of the blue grains (Figure 8) showed a flake-like structure of nearly homogeneous composition.

The Hitachi S-3500 Variable-Pressure Scanning Electron Microscope in the Electron Probe Instrumentation Center (EPIC) at Northwestern University was used for X-ray elemental analysis. EDX detects the frequency and intensity of emitted X-rays generated by the SEM's electron beam and provides data plotted as counts and intensity. The PGT Energy Dispersive X-ray (EDX) analyser generated spectra identifying the major components in both the blue and white phase fields acquired over of a period of 100 seconds.

The EDX spectra provided a qualitative analysis of the composition of the blue and white grains. The spectrum of the blue grains showed the largest K-alpha peak as carbon, with smaller peaks for oxygen, aluminium,

Method

Table 1. Comparison of Maya Blue component compositions from José Yacamán *et al.* (1995) and those done by Branden in the analyses reported here.

	José-Yacamán and Serra Puche (1995) Maya Blue	Analyses reported here Palygorskite	Analyses reported here Indigo and some Palygorskite (?)
Major peak	O	Si	C
elements	Si, C	Al	
Minor peak	Al, Mg, Na	Ca, Mg	Ca, O
elements	Fe, S	Fe, K, O, S	
Trace elements	Ca	C, P	Al, P, S, Si

silicon, phosphorus, sulphur and calcium. Since experimental syntheses of Maya Blue indicated that the pigment contained 2 per cent or less indigo, the high carbon peak suggests that the blue portion is indigo rather than Maya Blue because Maya Blue is a clay-organic complex and its carbon peak would be expected to be much smaller. Furthermore, in other studies, transmission electron microscopy images (Cabrera Garrido 1969: 21; Kleber *et al.* 1967: 46) and SEM images (Ortega *et al.* 2001a: Figure 6c; Ortega *et al.* 2001b: 2230) reveal that Maya Blue retains the needle-like structure of palygorskite, and other studies affirm that the unique structure of palygorskite gives the pigment its unusual properties (Chiari *et al.* 2003; Fois *et al.* 2003; Reinen *et al.* 2004; Sánchez del Río *et al.* 2006). The blue grains thus appear to be indigo rather than Maya Blue. The smaller peaks of the EDX spectra can be attributed to either (a) the simultaneous identification of a separate phase field below the surface, or (b) parts of the indigo plant or the copal that may be the extraneous material seen in the SE images of the blue grains.

The spectra of the white grains showed the largest K-alpha peak for silicon, second-largest peak for aluminium and smaller peaks for magnesium, calcium, sulphur, potassium, calcium, carbon, phosphorus and iron. Palygorskite is an aluminium and magnesium silicate (Galan 1996; Sánchez del Río *et al.* 2006: 117), but in some molecular models of the mineral, iron and calcium may also substitute for some of the aluminium and magnesium ions (Fernandez *et al.* 1999: 5247-8). In other models, magnesium replaces the aluminium, and calcium and iron replace the magnesium (Carroll 1970: 42).

The combined EDX spectra are relatively consistent with the X-ray microanalysis spectrum of Maya Blue reported by José-Yacamán and Serra Puche (1995), wherein the highest peaks were associated with oxygen, silicon and carbon and magnesium using transmission electron microscopy (TEM) and electron energy loss spectroscopy (EELS). The similarities in the components identified in both EDX spectra suggest that the white grains are palygorskite (Table 1) but they may also contain some residue from the copal incense and/or from the remains of the indigo plant and/or its derivatives that are seen as the extraneous material in the scanning images (Figures 7 and 8).

Since the occurrence of indigo and palygorskite account for the EDX spectra, it appears that the palygorskite and indigo remained uncombined. Further, much greater size of the white phase fields than the blue fields reflects the greater proportion of palygorskite in the Maya Blue recipe.

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