Ancient Mesoamerica (2024), **35**, 81–96
doi:10.1017/S0956536121000353

Special Section: Recent Research on Iron Ore Mirrors in Mesoamerica and Central America

All that glitters is not pyrite: A geochemical assessment of iron-ore objects used by the Classic Maya

Tomás Barrientos Q.[a], Andrea Sandoval[a], Yoshiyuki Iizuka[b] and Tanya Carías P.[a]

[a]Centro de Investigaciones Arqueológicas y Antropológicas, Universidad del Valle de Guatemala, Guatemala and [b]Academia Sinica Taiwan, Taiwan

Abstract

Different types of iron ore and pyrite were used to craft a wide variety of reflective artifacts in pre-Columbian Mesoamerica, including “mirrors,” pectorals, necklaces, and dental inlays, among others. In the Maya region, most of these have only been visually assessed, without using analytical techniques. Consequently, our understanding of the diversity of raw materials used in artifact production has been limited. This article presents preliminary results from a pilot study aiming to identify the raw materials used in the manufacture of different reflective objects from a small sample of finds from the sites of La Corona and Cancuen, located in Guatemala, through the use of scanning electron microscopy with EDS detectors (SEM-EDS), energy-dispersive X-ray fluorescence (EDXRF), X-ray diffraction (XRD), and Raman spectroscopy. Although further analyses are needed to confirm the representativeness of the sample, these results indicate the use of hematite and goethite (iron oxides), but not pyrite (iron sulfide). This study also shows how improved knowledge of raw material use can elicit previously unknown patterns of distribution and exchange, and highlight patterns of inter- and intrasite variability in the production, use, and exchange of reflective objects over time in the Maya region throughout the Classic period.

Resumen

En la Mesoamérica prehispánica, se usaron diferentes tipos de óxidos y sulfuros de hierro para fabricar diversos artefactos reflexivos, los cuales incluyen principalmente los llamados “espejos”, así como pectorales, collares e incrustaciones dentales, entre otros. En la región maya, la mayoría de éstos han sido identificados de forma visual, sin usar técnicas analíticas, lo que ha resultado en un pobre entendimiento de la diversidad de materias primas usadas para producir estos artefactos. Mediante una revisión detallada de la literatura arqueológica publicada con relación a los artefactos reflexivos en la región maya, se ha observado una inconsistencia en la terminología usada para referir a las materias primas que fueron utilizadas para su manufactura. Por lo tanto, esto ha generado que, de forma casi automática, se identifique a la pirita como el material usado para estos artefactos, ignorando la posibilidad que se hayan usado otros tipos de minerales reflexivos que estaban disponibles en la época prehispánica, especialmente los óxidos de hierro como la hematita. Para afrontar este problema, se ha demostrado que los análisis geoquímicos como microscopía electrónica de barrido con detector EDS (SEM-EDS), fluorescencia portátil de rayos X de energía dispersiva (EDXRF), difracción de rayos X (XRD) y espectroscopia Raman, proporcionan una solución clara al identificar la presencia o ausencia de azufre en la composición química de estos artefactos. De una pequeña muestra inicial de 14 objetos analizados de los sitios de La Corona, El Achiotal y Cancuén, prácticamente ninguno mostró azufre, indicando que no fueron hechos con pirita, sino con algún óxido de hierro, posiblemente hematita o goethita. A pesar de que se ha argumentado que la ausencia de azufre es el resultado de procesos de transformación o descomposición química, es poco probable que esto haya sucedido en todas las muestras, especialmente las que muestran un buen grado de conservación de sus superficies reflexivas. Por lo tanto, tal como ha sucedido con la obsidiana, cerámica, concha y piedras verdes, la posibilidad de realizar identificaciones precisas de las materias primas permitirá definir sus fuentes, y de esta manera, definir modelos económicos sobre su extracción, producción e intercambio. Por ahora, a pesar de que se han realizado solamente algunos análisis preliminares, se propone que la identificación visual de pirita en objetos reflexivos no es confiable, por lo que es necesario reconsiderar las interpretaciones que se basan en esos datos. Si bien la pirita tuvo un uso importante en el período clásico temprano en sitios como Nebaj y Kaminaljuyu, el rompimiento de la red de intercambio relacionada con Teotihuacán pudo provocar un aumento en el uso de la hematita en la región de las tierras bajas durante el clásico tardío, tal como lo sugieren los

Corresponding author: Tomás Barrientos Q., email: tbarrientos@uvg.edu.gt

Cite this article: Barrientos Q., Tomás, Andrea Sandoval, Yoshiyuki Iizuka, and Tanya Carías P. (2024) All that glitters is not pyrite: A geochemical assessment of iron-ore objects used by the Classic Maya. *Ancient Mesoamerica* **35**, 81–96. https://doi.org/10.1017/S0956536121000353

datos de La Corona, Cancuén y Aguateca. De cualquier forma, este estudio ha demostrado que la diversidad de métodos geoquímicos disponibles constituye una herramienta importante para mejorar los modelos económicos definidos para la región maya, especialmente al considerar la importancia económica que tuvo la producción e intercambio de artefactos reflexivos en las diferentes regiones y períodos cronológicos.

The present study discusses how visual identification of reflective ferrous minerals recovered in archaeological contexts throughout the Maya region has led to misleading results. A detailed review of scholarly literature focused on reflective artifacts, such as mirrors, clearly demonstrates the inconsistent terminology used to refer to the raw materials that composed them. This confusion has led to rote descriptions that, by default, identify pyrite as the most used and preferred material, failing to recognize that a more varied repertoire of reflective raw materials was available for use. To address this problem, we demonstrate how geochemical analysis can correctly identify these minerals. As in the case of obsidian, ceramics, shells, or greenstone, ascertaining the precise identification and source of these materials is necessary for the accurate modelling of economic activities involved with raw material extraction, trade route distribution, and political alliance between sites and regions. In this study, we present the preliminary results of a geochemical analysis of reflective objects from the sites of La Corona, El Achiotal, and Cancuen, demonstrating that visual identification of these objects is unreliable. We then propose that the diverse battery of geochemical methods now provides Maya archaeology with an opportunity to improve on previous economic models, as well as beginning to consider the economic importance of reflective artifacts in the different regions and chronological periods of the Maya region.

Reflective objects in the Maya region

Since Paul Kirchhoff first proposed the concept of Mesoamerica in 1943, "pyrite mirrors" were recognized as one of the distinctive elements that define this geographic and cultural region (Kirchhoff 1960:8, 13). Subsequent archaeological research has shown that mirrors and other reflective objects were important ritual and ornamental paraphernalia for the various elites of different pre-Columbian Mesoamerican cultures.

Pre-Columbian reflective artifacts were made in a wide variety of forms, sizes, materials, and techniques. The most common were mirrors, typically circular in shape, although some were quadrangular, and with a flat or convex surface. Based on their characteristics, they have been classified according to their components (Gallaga M. 2016a:11), their raw materials (Mata 2003:831), or iconographic representation in painted polychrome ceramics (Blainey 2007:124). For the present study, three basic types are considered, defined according to their manufacturing technique: (1) one-piece mirrors; (2) mirrors made with a mosaic of polygonal pieces or tesserae; and (3) composite mirrors, made with small grains of reflective mineral, attached to a matrix made from a different mineral (Nelson et al. 2005). Regarding the function of mirrors, although they could have been used for purely aesthetic and ornamental purposes, there is a general consensus that their main function was symbolic and ritual (Blainey 2016; Freidel et al. 1993:244; Healy and Blainey 2011; Saunders 1988; Schele and Mathews 1998:222; Taube 1992, 2016). It is argued that this is why the contexts where they have most often been found in a complete state correspond mainly to burials and caches (Blainey 2007:41, 113; Zamora 2002:89), as well as why many have iconographic motifs and hieroglyphic texts that were carved or painted on the back.

In addition to mirrors, other reflective artifacts manufactured in Mesoamerica include dental inlays, pectorals made of mosaics, necklaces made with differently shaped beads, and a wide variety of small objects used for decorative purposes, including for textiles, mosaic masks, and headdresses, as well as for inlays and as accessories for figurines, censers, and other effigies. Some of these artifacts are considered in greater detail below.

Reflective minerals

The reflective properties of Mesoamerican "mirrors" and other artifacts were most commonly achieved through the use of iron oxides and sulfides. Other minerals with similar qualities, but used less widely, include obsidian (Saunders 2001; Smith 2014), mercury (Gallaga M. 2016b:30), and micas such as muscovite, fuchsite, biotite, phlogopite, and glauconite (Rosales 2017).

Traditionally, the most common iron mineral for elaborating Mesoamerican "mirrors" has been identified as pyrite, an iron and sulfur mineral (FeS_2). It is also known as "fool's gold," because of its yellowish shine and reflective luster, similar to that of gold. It can be found in cubic, radial, and amorphous shapes (Gallaga M. 2014:292), the latter with triangular, cubic, pentagonal, or more complex facets (Arrouvela and Eon 2019). Another mineral very similar to pyrite is marcasite (FeS_2), which is slightly more yellowish, and thus known as "white pyrite" (Blainey 2007:166; Johnson et al. 1995). Natural deposits of pyrite are found inside sedimentary, igneous, and metamorphic rocks, and can occur in large outcrops.

After pyrite, hematite (Fe_2O_3) was the most extensively used iron mineral in the manufacture of pre-Columbian reflective artifacts. Hematite is an iron ore that can be found in compact shapes with colors varying from black, greyish black, and shiny metallic silver luster (specular hematite), or a reddish dusty color (earthy hematite; Blainey 2007:168). Different types of hematite were commonly used for making pigments (Goodall 2007; Quintana et al. 2014) and as a ceramic temper (Postal 1935; Weeks et al. 2005:116–121).

Both pyrite and iron ores can change or transform to other minerals in specific environmental and geological conditions. When exposed to water and oxygen, pyrite can convert into different types of iron ores, such as limonite and siderite, losing its brightness and yellowish color (Santamarta 1977, in Zamora 2002:26). It can also transform into goethite (α-FeO(OH)), forming a new mineral, known as a pseudomorph of goethite after pyrite. Pseudomorphism describes when a mineral is found in an atypical crystalline form, due to the post-crystallization substitution of a former mineral with another. As a result, the shape of the original mineral is preserved, but the hardness and color change due to the mineral replacement (Nesse 2000:92). Hematite also transforms into goethite by hydration processes, acquiring a yellowish ochre, reddish ochre, or brownish ochre coloring (Beovide et al. 2015:7).

Besides pyrite and hematite, other iron ores and iron sulfides have been identified in archaeological reports and specialized studies conducted throughout Mesoamerica. These include marcasite (FeS_2; Blainey 2007:86, 93, 104; Smith and Kidder 1951:46; Zamora 2002:27), magnetite (Fe_3O_4; Blainey 2007:49; Gallaga M. 2014:280; Kovacevich 2016:74; Mata 2003:831; Nelson et al. 2005:1), titanomagnetite ($TiFe_2O_4$; Blainey 2007:173), limonite ($FeO(OH)\cdot nH_2O$; Blainey 2007:73; Gazzola et al. 2016:109; Mason 1927:206), pyrrhotite or magnetic pyrite ($Fe_{(1-x)}S$; Blainey 2007:103), chalcopyrite or copper pyrite ($CuFeS_2$; Zamora 2002:27), ilmenite ($FeTiO_3$; Gallaga M. 2014:280; Heizer and Gullberg 1981; Kovacevich 2016:74), siderite ($FeCO_3$; Melgar et al. 2014:44), and jarosite ($KFe_3(SO_4)_2(OH)_6$; Gazzola et al. 2016:109).

Additionally, ethnohistorical accounts provide further contextual evidence for the use of different minerals in the production of pre-Columbian mirrors. As part of his description of artisan activities in Mexica society, Fray Bernardino de Sahagún referred to the office of lapidaries as those that sold mirrors "made of white stone, and others of black stone," and that "they cut the white or red crystal." Furthermore, he refers to mirrors as being "polished or worked, […] like *margaxita*" (marcasite) (Sahagún 1985:573, 525, in Zamora 2002:20–21, 24). That the differentiation of colors in mirrors was recognized from pre-Columbian times also suggests that the choice of raw material could have been based upon the symbolic significance of its coloration, whether gold, silver, reddish, or metallic black (Pereira 2008:132).

A history of reflective material identification in Maya archaeology

Despite the importance of mirrors and other reflective artifacts for the ancient Maya, few studies have been carried out compared to the number of those conducted on other minerals, such as greenstones, obsidian, copper, and gold. In addition, it is only recently that analyses have begun to include geochemical methods for identifying raw materials, and tracing distribution patterns and manufacturing processes (Blainey 2007; Gallaga M. 2014; Gallaga M. and Blainey 2016; Healy and Blainey 2011, Melgar et al. 2014; Nelson et al. 2005; Zamora 2002).

The presence of mirrors in the Maya region has been known since the end of the nineteenth century, thanks to the iron-ore artifacts that Dieseldorff (1893, in Blainey 2007:52) reported from the site of Chamá, located in the Chixoy river valley. However, the earliest known identification of their raw material (as pyrite) was made by Thompson (1897) in Yucatan, a designation that was supported by Seler (1904) and Gann (1918; Blainey 2007:99, 103). Among these early studies, Mason's (1927) report on the many mirrors recovered from the sites of Kixpek, Chipal, Chihuatal, and Ratinlixul, in the Quiche and Verapaz regions, are of particular importance. As part of his detailed descriptions, he indicated that although they were made of pyrite, their surfaces had oxidized, converting into limonite, a ferrous hydrate.

At Kaminaljuyu, Kidder and colleagues (1946:126–131, Figures 155 and 156) recovered 35 complete mosaic mirrors (described as "Pyrite-Incrusted Plaques"), as part of the funerary offerings of the tombs excavated in Mounds A and B. These authors carried out the first complete review of mirrors reported at that time from sites in the Maya region, Mesoamerica, North America, and southern Central America (Kidder et al. 1946:131–133). They also wrote a detailed description of their forms and manufacturing techniques, as the Kaminaljuyu mirrors are among the most complex decorative forms: "Nothing produced in aboriginal America seem to us to rival these plaques in the matter of skilled and meticulous craftsmanship" (Kidder et al. 1946:131). Regarding their raw material, Kidder and colleagues (1946:132–133) identified all mirrors as made of pyrite, although the use of other iron ores for mirror manufacturing, such as hematite, was already reported at other Mesoamerican and Mayan sites (e.g., Kidder 1947:56; Saville 1922).

A significant contribution to the study of Mesoamerican mirrors came five years later, with publication of the excavations at Nebaj, in the western Guatemalan highlands, by Smith and Kidder (1951). The quantity of mirrors (212) recovered at Nebaj (Smith and Kidder 1951:46) surpasses that from any other Maya or Mesoamerican site. Their description complemented what had been published previously by Mason (1927) and Kidder and colleagues (1946), and especially the comments by ceramist Anna O. Shepard, who had a Ph.D. in chemistry, and specialized in optic crystallography and chemical spectroscopy (see Babcock and Parezo 1988:139). Sheppard suggested that besides pyrite, other minerals with similar reflective properties (possibly marcasite) were used for manufacturing these mosaics. Given the poor state of preservation for the majority of the mirrors, many reflective tesserae from the mosaic mirrors were found in a disintegrated state, either discolored into a yellowish substance, or else decomposed into a powdery red substance (Smith and Kidder 1951:46). To explain this anomaly, Sheppard explains how pyrite:

> alters to oxides and hydroxides of iron that are yellow, brown or red (limonite, goethite, and hematite) and also under certain conditions to a basic ferric sulphate (copiapite) and to iron

> alum (halotrichite), both of which are yellow. Marcasite has the same alteration products. It also forms a hydrous ferrous sulphate (melanterite) which is green but becomes yellowish on exposure (Smith and Kidder 1951:46).

However, Sheppard concludes that "it is impossible to say from which mineral a powdery or yellow product has been derived" (Smith and Kidder 1951:46), given the conditions in which the samples were found and to which they were exposed as part of the funerary activities. Sheppard indicates that the geochemical changes in pyrite occur under very high temperatures, fluctuating between 450°C and 665°C, something that could only occur if the samples were exposed to direct heating. A similar observation was made by Woodbury and Trik regarding the mirrors found at Zaculeu, also in the western highlands:

> When mosaic of the latter type decomposes, as all pyrite does quite rapidly, the polygons of matrix remain with a layer of soft yellow powder in the place of the crystalline pyrite … The rotted and incomplete state of most plaques is due to the fact that iron pyrite produces sulphuric acid when moisture is present (Woodbury and Trik 1954:236).

During the second half of the twentieth century, descriptions assumed that all mirrors were made of pyrite, following the precedent set by the majority of earlier works. As Blainey (2007:165) observes: "In the majority of archaeological site reports documenting the excavation of iron-ore mirrors, it is not apparent whether the designated iron-ore was tested scientifically in any way, or whether the researchers simply identified them based on experience." However, the study made by Fastlicht (1962) of a dental inlay from the site of Jaina demonstrated the usefulness of geochemical analyses of reflective materials:

> The cavities have a reddish material which at the time of the removal from the tomb had a perfectly "normal" and stone-like appearance, but which afterward underwent a surprising change. Still fitting perfectly at the edges of the circular perforation, these fillings began to expand … Apparently, this was a consequence of contact with air and resulting dehydration. At first we thought this might be an alteration of the hematite (oxidized iron pyrites) so often used for inlays. Since the graves on Jaina were not very deep, the action of sea-water that covers the island at certain seasons could have caused such an alteration. However, other specimens from graves on the same island have complete jadeite and hematite inlays in perfect state. To clarify the point … [specialists] made a spectrographic study of a fragment of the material of an inlay and found iron and calcium and recognized a mineral called goethite alfa (Fe_2O_3 H_2O) as the principal component … The geologist thinks that the original substance was powdered iron pyrites (marcasite) … it is supposed that the iron pyrites altered from iron sulfide to sulfate, and finally to iron hydroxide. (Fastlicht 1962:398–399).

Nevertheless, mirrors were not really studied in great detail until the twenty-first century, when Zamora (2002) analyzed 569 pyrite objects recovered in the excavations at Aguateca, in the Petexbatun region. Of these, 351 artifacts were recovered from within Structure M8-4, named "The House of Mirrors," which could have been a workshop for mirrors and other reflective mosaics (Aoyama 2007:19; Inomata et al. 2002:310–316). With the more advanced geochemical analyses available by this time, Zamora carried out mass spectrometry and specific weight tests on six pyrite samples, of which only one showed sulfur as part of its chemical composition. The results showed the typical crystallization of pyrite, but the absence of sulfur was interpreted as a result of post-depositional processes and environmental factors, which made the pyrite transform into siderite, a mineral similar to limonite (Zamora 2002:27–28). This led Zamora to conclude that:

> archaeological materials usually identified as "pyrite" correspond to other minerals or rocks, such as hematite … magnetite … gneiss … and marcasite … Given that the sulfur that characterizes pyrite is hardly found present in oxidized samples (this form is present in most iron ores buried for hundreds of years), the correct identification of this material is very difficult (Zamora 2002:27).

Around the same time that the Aguateca finds were made, another important archaeological discovery relating to Maya mirrors was made at Cancuen, in Structure K7-34 (Barrientos et al. 2001; Kovacevich 2016). Five unworked raw material nodules were recovered, as well as 10 tesserae, suggesting that the structure could have been a mirror production workshop (Barrientos et al. 2001). These materials were identified as pyrite, according to scanning electron microscopy (SEM) and X-ray diffraction (XRD) tests performed on one sample, carried out at the Smithsonian Institution (Kovacevich et al. 2004:885). Although Kovacevich (2016:88–92) performed morphological and contextual analyses of 101 "pyrite" artifacts collected from 1999 to 2003, no more geochemical methods were applied. In addition, since 2004, 197 additional iron-ore artifacts (making a total of 298) have been recovered from different parts of the site, including mosaic mirror tesserae, beads, and more unworked raw material nodules (Paola Torres, personal communication 2021). These remain unpublished as yet, but are currently subject to both morphological and geochemical analyses by the authors.

In 2007, Blainey carried out a synthesis of the distribution, economy, and symbolic significance of iron-ore mirrors throughout the Maya region, where he collated data from more than 500 objects reported from 41 sites (Blainey 2007). Based on information previously published in archaeological reports, the specific reflective mineral was only identified (mostly visually) in 192 instances, and of these, 155 were identified as pyrite (81%) and 37 as hematite (19%; Blainey 2007:113). However, these percentages are skewed by the high number of pyrite mirrors recovered from just two sites (Nebaj and Kaminaljuyu), which account for 452 of the total 500 objects. Blainey was, in any case, cautious with these numbers, stating that there is a "lack of consistent terminology and documentation, especially concerning the geological material that composes the mosaic mirror face and backing" (Blainey 2007:52), something also recognized by Taschek (1994:96): "with regards to mirrors documented in older publications, correct material identification is undetermined". Quoting Ixer (1990), Blainey adds that "although there is a tendency to label specimens as specifically pyrite, the examples of preserved polygons may indicate a mixture of iron-ores," and that "without chemical analysis, it is difficult to identify the precise geological composition of remaining iron-ore mosaic pieces simply according to whether they are decomposed" (2007:167). There is, therefore, increasing recognition that visual identification of reflective minerals from archaeological contexts, although quick, is not as reliable as scientific testing, and that application of geochemical methods is necessary to ascertain mineral identification accurately (Blainey 2007:189; Gallaga M. 2014:274; Nelson et al. 2005:1).

Up until now, few geochemical analyses have been carried out on pre-Columbian Maya mirrors. However, early results have demonstrated that not all mirrors were made of pyrite. More than 100 mirror tesserae recovered from the site of Cerros, in northern Belize, were identified using XRD analyses as having been made of specular hematite (Garber 1989, in Blainey 2007:61). The same analysis was carried out on two samples of mirror tesserae from Pacbitun, resulting in one identified as pyrite, and the other as hematite (Blainey 2007:166). In Reynosa, various iron-ore dental inlays were present in the individuals from Burials 20 and 38. Using SEM with X-ray spectroscopy, the minerals used in these inlays were identified as hematite (Burial 38) and pyrite grains inside an iron-ore matrix (Burial 20), very similar to composite pyrite mirrors (Sandoval et al. 2020; Suzuki et al. 2018).

The application of geochemical analyses not only has the potential to correctly identify the raw materials used by the ancient Maya to produce reflective objects, but also contributes to the understanding of the effects that site-formation processes can have on these minerals. As previously explained, the potential for transformation, oxidization, decomposition, and pseudomorphism in the ferrous raw materials of mirrors and other reflective objects has been recognized as an issue in the identification of their mineral composition by a number of authors over the last century (Blainey 2007:58, 85, 88, 91; Fastlicht 1962:398; Gallaga M. 2014; Mason 1927; Mata 2003; Melgar et al. 2014; Nelson et al. 2005:1; Smith and Kidder 1951:46; Taschek 1994:97–99; Woodbury and Trik 1954:236; Zamora 2002:27–28). Most recently, Gazzola (2016:108–109, 117, 121) has proposed that pyrite converts into secondary minerals under oxidation and hydration processes, including the action of bacteria (bioxidation) present in the organic adhesives used in mirrors. However, Arrouvela and Eon (2019) indicate that transformation processes of pyrite and other iron ores are still not fully understood, considering that the thermodynamic and kinetic aspects of crystal formation are a function of temperature and the concentration of certain elements within the depositional environment. Such is the case with one of the few complete "composite" mirrors found in the Maya region (to date), which was found at the bottom of Lake Amatitlan, and still retains its original brightness, probably due to being immersed "in a hot sand of volcanic origin that contains components of sulfur" (Mata 2003:834).

It is also important to note that the few geochemical analyses carried out on pre-Columbian mirrors have focused on the finished products and their commonly oxidized surfaces. Raw materials from archaeological contexts have largely yet to be found and analyzed, with a few exceptions (e.g., the nodules from Aguateca). Furthermore, given that oxidation processes mainly affect the artifact surface, it is important to conduct non-destructive analysis on the material's interior fabric when the object or fragment is found broken.

Geochemical analysis of reflective objects from La Corona and Cancuen

The present study was partly driven by the recovery of a considerable amount of iron-ore objects from the sites of La Corona and El Achiotal, as part of the Proyecto Regional Arqueológico La Corona (PRALC) between 2008 and 2019 (Barrientos et al. 2020; Iizuka et al. 2020). These include 33 mosaic mirror tesserae and 178 spherical and tubular necklace beads recovered from different parts of La Corona (Figure 1). All the beads were recovered from funerary contexts, with particularly large quantities from Burials 13 and 18, located in structures 13R-10 and 13Q-2, respectively (Figure 2). Some of the tubular beads are unique since they measure up to 5 cm in length. Other artifacts include a possible ear flare and many small unworked nodules recovered from architecture rubble fills and surficial deposits. These nodules were semi-rounded in shape, and dark in color.

Of the iron-ore artifacts recovered by PRALC, 12 were selected for geochemical analyses: four tesserae (samples CR-1, CR-2, CR-10, and CR-11); two bead fragments (samples CR-8 and CR-9); one possible ear flare (CR-5); one raw material flat piece (CR-3); and four small raw material nodules (CR-4, CR-6, CR-7, and CR-12), plus two additional samples from Cancuen (Figure 3). The latter were kindly lent for analysis by the Proyecto Arqueológico Cancuén, and comprised one mirror tessera (sample CAN-1) and one raw material nodule (sample CAN-2). The Cancuen nodule was of particular interest as it exhibits cubic morphology, which is very similar to that of goethite pseudomorph after pyrite. For its chemical analysis, one of its flat facets was carefully polished, exposing a dark color (almost black) in the interior, which was very different from its reddish-brown external surface (Figure 4). Polishing was carried out in order to have access to analyze the inner material, as the exterior layer was oxidized.

This initial sample was small due to limitations in the availability of analyses in Guatemala and export to foreign laboratories. For this reason, an arbitrary selection of specimens was used to test the effectiveness of the methods applied in different types of artifacts. Therefore, samples and methods within this study were of a preliminary nature and will serve for future sampling strategies.

The geochemical analyses were initiated in 2016 by the Center for Archaeological and Anthropological Research at

Figure 1. Iron-ore beads found as an offering associated with Burial 13 in Structure 13R-10 from La Corona. Photos by Carías.

the Universidad del Valle de Guatemala (CIAA-UVG), with direct collaboration from the Center for Research and Development at Cementos Progreso (CI + D/CETEC), the Institute of Earth Sciences, Academia Sinica in Taiwan (Iizuka et al. 2020), and University of Bradford, UK. This cooperation allowed the use of specialized equipment for different objectives: analysis of crystalline solids through XRD, determination of elemental composition through SEM with an EDS detector and energy-dispersive X-ray fluorescence (EDXRF), and identification of chemical compounds with Raman spectroscopy. Recently, this project has joined the Red Reflejos, a collaboration network for the study of pyrite mirrors in Mesoamerica and Central America, led by Matthieu Ménager and Silvia Salgado, from the Universidad de Costa Rica.

X-Ray diffraction for crystalline solids

Loose powder X-ray diffraction (PXRD) was run in a PANalytical Empyrean diffractometer, using a low background sample holder (due to the low sample amount). The angle (2θ) was configured between 5° and 90°. Rietveld refinement was used to semi-quantify the crystalline phase abundance. Mineral identification was based on matching the experimental diffractogram with those available at the Inorganic Crystal Structure Database (ICSD).

EDXRF for bulk chemistry

An energy-dispersive X-ray fluorescence spectrometer (EDXRF: JEOL JSX-1000S) was used to study the bulk chemistry from the specimen surface. The samples were operated under low-vacuum conditions (100Pa) and the primary X-ray (Ph target) irradiated for 100s with 2.0 or 0.9 mm in diameter.

SEM-EDS for mineral chemistry

The microtextures and mineral chemistries were studied non-invasively using SEM. Identification of mineral phases

Figure 2. Offering associated with Burial 18 from La Corona. It shows two calcified iron-ore beads (tubular and spherical), combined with jade beads and shell fragments. Photo by Carías.

Figure 3. Geochemically analyzed iron-ore artifacts from La Corona, El Achiotal, and Cancuen. Photos by Carías.

was made by an energy-dispersive spectrometer detector. Samples were directly loaded into the specimen chamber without sample polish and any coating of conductive material such as carbon or gold. Due to the work requiring collaboration between several different laboratories, SEM-EDS was carried out with different equipment and in different working conditions: one field emission scanning electron microscope (JEOL JSM-7100F, with EDS: Oxford Instruments Ltd, X-max 80 operated by INCA-350, low-vacuum conditions (50Pa) were used with purged nitrogen gas); one scanning electron microscope with EDS detector under low-vacuum conditions (JEOL, JSM-IT500, detector model X-Max); and one scanning electron microscope with EDS detector under high-vacuum conditions (Oxford Instruments Xplore 30, 30 mm cross-sectional detector area, software: Aztec lite 4.4).

Figure 4. Raw material from Cancuen (sample CAN-2). Note the cubic crystal habit, and the luster and color exposed in the polished facet. Photos by Carías.

Raman spectroscopy for chemical compounds

Raman spectroscopy was run in a Renishaw inVia Raman microscope, with a 785-diode laser. The measurements were conducted with a 20× lens, 5%–50% laser power and 1 accumulation. The spectrum was obtained from 200 to 1400 cm^{-1}.

Results of geochemical analyses

The first approach was to identify the crystalline phases of this material by analyzing three samples (CAN-2, CR-10, CR-11) through non-destructive XRD analysis, as the surface of these artifacts is flat (Table 1). This method was combined with a Rietveld refinement and the results suggested that, contrary to the preliminary visual identification, the raw material was not pyrite. However, the diffractograms did not present the expected quality, as the non-destructive approach did not allow well-defined peaks, so we took this as a starting point to continue doing further analysis.

In the second phase, bulk elemental analysis was performed in the external surface of samples CR-8, CR-9, CR-10, CR-11, and CR-12 using EDXRF. Additionally, SEM-EDS was used for the same purpose on all sample surfaces except CR-6, CR-7, and CAN-2, in order to identify secondary minerals within the raw material matrix (Table 1).

Table 1. Results of geochemical analyses.

				SEM-EDS						EDXRF				Result	
				av % Fe			av % S			av % Fe	av % S	Raman spectroscopy	XRD		
Sample number	Sample ID	Site	Type	△	x	●	△	x	●	x	x	●	△	Matrix	Special minerals
CR-1	CR21A-3-2	La Corona	Tessera	62.3			ND							Iron oxide	
CR-2	CR164E-6-4-4	La Corona	Tessera	25.2			ND							Iron oxide	
CR-3	CR164E-5-1-1	La Corona	Other	46.5			ND							Iron oxide	
CR-4	ACH99B-12-2	El Achiotal	Raw material	20.6			ND							Iron oxide	
CR-5	CR153D-1-1-1	La Corona	Other	60.8			ND							Iron oxide	
CR-6	CR16C-24A-13-33	La Corona	Raw material										Goethite/ quartz	Goethite	Quartz
CR-7	ACH99B-12-2	El Achiotal	Raw material										Hematite/ hauerite	Hematite	Hauerite (MnS_2)
CR-8	CR16C-34-11-12 (CRN-24)	La Corona	Bead		86.0			3.1		91.7	0.6			Iron oxide	Barite ($BaSO_4$)
CR-9	CR16C-34-11-12 (CRN-25A)	La Corona	Bead fragments		82.0			ND		87.8	0.8			Iron oxide	Xenotime, monazite, zircon, calcium carbonate (in the white line)
CR-9	CR16C-34-11-12 (CRN-25B)	La Corona								89.6	0.5			Iron oxide	
CR-9	CR16C-34-11-12 (CRN-25C)	La Corona								80.8	0.8			Iron oxide	
CR-10	CR16A-32-7-10 (CRN-26)	La Corona	Tessera		83.7	62.2		1.8	0.9	88.7	0.8	Hematite	Hematite(?)	Hematite	Cinnabar (HgS) on the surface
CR-11	CR16A-45-8-15 (CRN-27)	La Corona	Tessera		91.1			ND		93.0	0.7		Hematite(?)	Hematite (?)	Cinnabar (HgS) on the surface
CR-12	CR15A-1-17 (CRN-49)	La Corona	Raw material		71.1	32.5		ND	ND	77.8	ND	Hematite		Hematite	
CAN-1	CAN24-253-1-1	Cancuen	Tessera			50.5			1.2			Hematite		Hematite	
CAN-2	CAN58-2-1-1	Cancuen	Raw material										Goethite(?)	Goethite (?)	

ND = not detected; ● Bradford, UK; x Ac. Sinica, Taiwan; △ Cempro-CIAA, Guatemala

Special attention was given to the abundance of iron and sulfur, as pyrite (FeS_2) was the most commonly identified mineral from preliminary visual assessments made in the field. For the SEM-EDS analysis, the iron composition on the surfaces of the artifacts was between 20.6 wt% and 91.1 wt%, whereas the sulfur content was either undetected (for 9 of the 13 analyses; this happens when the sample value is lower than the methodology's detection limit) or lower than 3.1 wt%. EDXRF results indicate that the iron content on the artifacts surfaces was between 77.8 wt% and 93.0 wt%, and that the sulfur content was between 0.5 wt% and 0.8 wt%. (Table 1) Both techniques not only showed a low sulfur content, but also that the relative proportions of iron to sulfur were different to those associated with pyrite, in which the sulfur content is higher than the iron (pyrite has an iron content of 47% and sulfur content of 53%). Thus, the results demonstrate that the mineral matrix of all samples surfaces analyzed by SEM-EDS and EDXRF were of an iron oxide, but not iron sulfide.

The bulk chemical analysis cannot give a specific iron oxide identification, as it is not possible to determine the proportion of oxygen and hydrogen attached to the iron atoms. To identify the specific chemical compound present in the matrix, Raman spectroscopy was used for amorphous and crystalline solids, and XRD was used to identify crystalline phases present in the raw material. Two nodules of raw material from La Corona and El Achiotal (CR-6 and CR-7) were analyzed by PXRD with Rietveld refinement, identifying goethite and quartz in sample CR6, and hematite and hauerite in sample CR7. Raman spectroscopy showed hematite as the best match for the experimental spectrums from the surface of a raw material nodule (CR-12) and two mosaic tesserae, one from La Corona (CR-10) and one from Cancuen (CAN-1). Secondary minerals were identified by SEM-EDS, in which the presence of cinnabar, barite, xenotime, monazite, zircon, and calcium carbonate were identified in samples CR-6 to CR-11 (Table 1 and Figure 5).

In summary, the relative iron and sulfur content within the materials from La Corona, El Achiotal, and Cancuen does not match the proportions expected of pyrite. The high abundance of iron suggests that the matrix of these materials is an iron oxide, possibly hematite and/or goethite. Although it is important to highlight that the analyses were conducted on the surface of well-preserved artifacts, for further studies, with appropriate sample alterations, it will be possible to conduct similar analysis on the inner material.

Geographical and chronological patterns of pre-Columbian Maya reflective objects

Pre-Columbian reflective artifacts have been reported in almost all Mesoamerican regions, including the Olmec zone, the Maya area, Oaxaca, and the Valley of Mexico, as well as the Mexican states of Michoacan, Puebla, Chiapas, and Veracruz (Blainey 2007:42–49; Carlson 1991; Young-Sánchez 1990:328, 341). In the Mesoamerican southern periphery, mirrors have been found in northern Honduras, Nicaragua, and Costa Rica, and some examples have been reported further south, in Panama, Ecuador, and Peru (Blainey 2007:49–51; Dennett and Blainey 2016).

Previous studies on mirrors have documented 29 sites in the Maya region where mirrors or tesserae have been identified visually as made of pyrite: Actun Tunichil Muknal, Aguateca, Altar de Sacrificios, Barton Ramie, Bonampak, Cancuen, Caracol, Chama, Chichen Itza, Chihuatal, Chipal, Copan, Cozumel, Hatzcap Ceel, Holmul, Kendal, Kixpek, Labna, Lamanai, Los Encuentros, Mayapan, Nebaj, Pusilha, Ratinlixul, Río Amarillo, Río Azul, San Agustín Acasaguastlan, Tenam Puente, and Zaculeu (Blainey 2007:55–104; Kidder et al. 1946:132–133; Kovacevich 2016:84; Melgar et al. 2014; Zamora 2002:31–41). Another 14 sites have reports of both pyrite and iron oxide artifacts (visually identified): Baking Pot, Ceibal, Coba, Cueva de Río Murciélago (Dos Pilas), Jaina,

	Wt%	σ
Fe	62.2	0.2
O	26.4	0.2
Si	4.5	0.1
Hg	3.3	0.2
Al	1.4	0.1
Ca	1.1	0.1
S	0.9	0.1
P	0.2	0.0

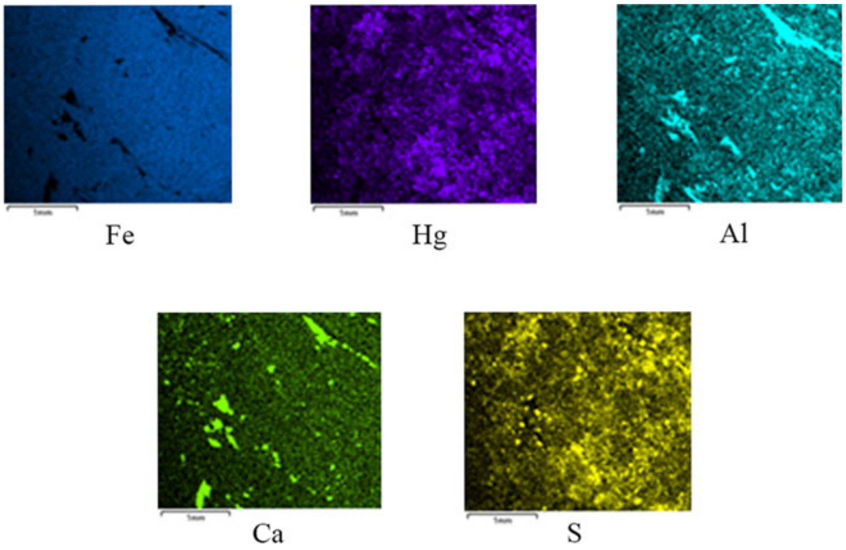

Figure 5. Identified minerals through SEM-EDS from sample CR-10.

Kaminaljuyu, La Lagunita, Lubaantun, Pacbitun, Palenque, Piedras Negras, Quirigua, San José, and Tikal (Blainey 2007:59–101), and six sites where only hematite mirrors have been identified visually: Altun Ha, Buenavista del Cayo, Cerros, Dos Hombres, Dzibilchaltun, and Minanha (Blainey 2007:60–85; Zamora 2002:35, 40; and Figure 6).

In addition to the sites already included from these previous surveys, the consultation of other archaeological reports added a further 18 sites where pyrite mirrors or tesserae have been visually identified: Bejucal (Garrison and Beltrán 2011:303), Bilbao (Mata 2003:833), Calakmul (González 2018:219), Cauinal (Ichon et al. 1980:34–36), Chirramos (Ichon and Grignon 1983:86); El Jocote (Ichon and Grignon 1981:29, 67, 93–94), El Paraíso (Shook 1947), El Perú/Waka' (Pérez et al. 2015:18), El Zotz (Gillot 2008:127; Piedrasanta 2018:43; Piedrasanta et al. 2014:947), Izapa (Clark and Lee 2018:270–275), Machaquila (Ciudad-Ruiz et al. 2011:162), Motul de San José (Hart and Gauger 2013:115); San Clemente (Fialko 2013:277), San Juan Las Vegas (Ichon and Grignon 1983:22, 44), Serchil (Roldán 1998:608), Topoxte (Fialko 2000), Uayma (Thomson 1962), and Xultun (Romero 2010:97). Pyrite together with hematite fragments were also reported at the site of Chitomax (Ichon and Grignon 1983:107, 128; Ichon et al. 1988:72, 77, 115; and Figure 6).

It is also important to note the presence of other reflective objects besides mirrors. Pyrite or iron beads have been reported at 10 sites: Aguateca (Zamora 2002:115), Balam Na (Brady et al. 2003:147), Cancuen, Caracol (Chase and Chase 2006:50), Holmul (Cormier 2018:303), La Corona, Lamanai

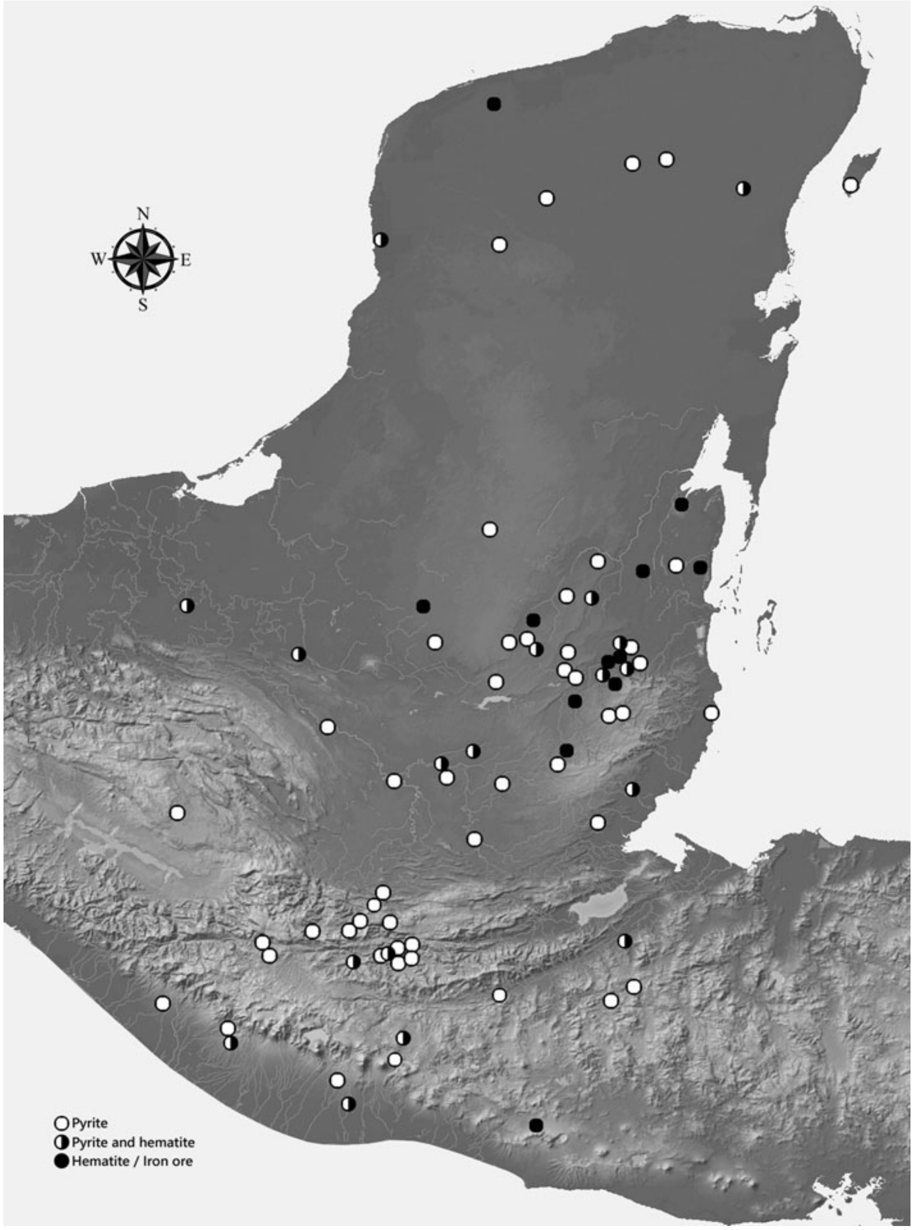

Figure 6. Map of archaeological sites with reported artifacts made of pyrite, hematite, or both minerals. Map by Barrientos Q.

(Blainey 2007:84), Nakum (Zralka et al. 2014:105), Pacbitun (Blainey 2007:93), and Uaxactun (Zamora 2002:115). Pectorals and headdress mosaics are reported from Aguateca (Aoyama 2007), La Corona, Tak'alik Ab'aj (Schieber 2003), and Tikal (Blainey 2007:73; Kovacevich 2016:83). Dental inlays have been found at Baking Pot (Blainey 2007:75), Cancuen (Kovacevich 2016:90), Chalchuapa (Fowler 1984:616), Holmul (Cormier 2018:241, 260, 316), Jaina (Fastlicht 1962:398), Piedras Negras (Satterthwaite 1952 in Weeks et al. 2005:350), Reynosa (Sandoval et al. 2020), Ucanal (Miller 2019:213), and various sites in Southeastern Peten (Ramírez et al. 2018). A possible ear flare or button has been found at La Corona, and a possible figurine fragment has been reported from Aguateca (Zamora 2002:128). The use of these minerals in objects other than mirrors highlights the symbolic importance of their reflective quality. If "mirrors" were shamanic tools (Blainey 2016) or mystical devices (Healy and Blainey 2011) and were carried as part of ritual and military paraphernalia (García-Des Lauriers 2017; Taube 1992), then it is possible that these special properties were also perceived as transferred to individuals through the use of decorative objects such as necklaces, pectorals, or dental inlays.

The list of sites with known presence of reflective artifacts made of pyrite, hematite, and other iron oxides, totals 79. Although this list is by no means exhaustive, it at least indicates how widely spread these artifacts were throughout the Maya region, and that they were present at the majority of main centers (Figure 6). They have been found in particularly high numbers in the North Quiche and Verapaz regions, with notable quantities at sites such as Nebaj, Kaminaljuyu, and Aguateca. Of the 79 sites where reflective artifacts have been found, 52 (67%) are located in the Maya Lowlands, 23 (29%) in the Maya Highlands, and four (5%) on the Pacific Coast. Forty-nine sites (63%) reputedly have only pyrite objects, while 18 (23%) have both pyrite and hematite/iron oxide artifacts, and 12 (15%) have artifacts identified as made of hematite. However, if we take into account that many documented instances of pyrite may be misidentified, it is possible that pyrite and hematite may be more evenly distributed than was previously thought.

Understanding the mineral composition of the materials used for mirrors and other reflective artifacts reveals interesting patterns in the geographical distribution of these goods and materials that would otherwise not be noticed. Unfortunately, a pre-Hispanic pyrite or iron-ore quarry has yet to be identified. This may be because the minerals used for these goods are widely distributed across the region in small quantities, mixed with other minerals (Blainey 2007:171–174; Gallaga M. 2014:296, 2016b:39; Kovacevich 2016:74). The main geological concentrations of iron ores have been identified in eastern Guatemala (Chiquimula, Izabal, and Zacapa) and the Maya Mountains in Belize (Abramiuk and Meuer 2006:339, 345; Gallaga M. 2014:296; Graham 1987:754). Other minor outcrops in Guatemala have been reported in Huehuetenango, Aguacatan, Jalapa, Quetzaltenango, Chinautla, and the Chixoy-Polochic zone. Some deposits have also been reported around Copan (Honduras), San Sebastian in El Salvador, and along the Pacific Coast (Blainey 2007:172; Gallaga M. 2016b:39; Kovacevich 2016:74). Outside the Maya region, iron ores and pyrite are found in the Mexican states of Baja California, Chihuahua, Coahuila, Durango, Guerrero, Jalisco, Michoacan, Oaxaca, Sinaloa, Sonora, Tamaulipas, Veracruz, and Zacatecas (Blainey 2007:175; Melgar et al. 2014:44). Although the geographically wide distribution of iron ore and pyrite deposits across this region makes it very difficult to trace the raw materials used for manufacturing reflective objects, the application of more advanced geochemical techniques could detect small chemical composition variations that may allow the raw material source of different artifacts to be traced.

Temporal variability in the presence of iron ore and pyrite minerals at archaeological sites within the Maya region has allowed a general interpretation of their use and production over time (Blainey 2007:56–97; Gallaga M. 2016a:16–18). Although concave single-piece hematite, magnetite, and ilmenite mirrors are known from the Oaxaca and the Olmec regions during the Early and Middle Preclassic, through sites such as San Lorenzo, La Venta, and San José Mogote, no early Preclassic reflective artifacts are known from the Maya region (Heizer and Gulberg 1981:114; Pires-Ferreira 1975:65). The only artifacts dated to the Middle Preclassic are the dental inlays from Reynosa (Sandoval et al. 2020; Suzuki et al. 2018), and a slate disk from Cahal Pech (Awe 1992, in Blainey 2007:56). This is evidence of an incipient industry of reflective objects, probably importing knowledge and techniques from other Mesoamerican regions. The production of reflective artifacts continued developing during the Late Preclassic, though still in modest numbers (Blainey 2007:58–60). However, it is in this period that the first evidence of mosaic mirrors appears in the Maya region, with hematite the predominant raw material for reflective objects throughout Mesoamerica at this time (Gallaga M. 2016b:30).

The Early Classic period is when mirror production increased significantly. This increase was also marked by technological improvements, including the manufacture of "composite" mirrors, greater diversity in mirror size and shapes, and a notable preference for the use of pyrite (Gallaga M. 2014:280, 2016a:17). These changes are widely attributed to the broad exchange networks associated with the economic and ideological influence of Teotihuacan (Blainey 2007:29; Gallaga M. 2016a:17; Taube 1992), meaning that the manufacture of mirrors and other reflective objects became one of the most relevant industries in Mesoamerica during the Early Classic, or at least in central Mexico and the Maya Highlands, reaching as far afield as Costa Rica (Blainey 2007:50–51; Dennett and Blainey 2016; Stone and Balser 1965:310). It has also been proposed that the mirrors found in the Maya region during the Early Classic could have been direct imports from Teotihuacan or imitations of those produced there (Gallaga M. 2014:281, 2016a:17; Gazzola et al. 2016; Mata 2003:832; Moholy-Nagy 1997:308; Pereira 2008:124–126; Taube 1992; Young-Sánchez 1990:326, 342). Certainly, the high frequency of Teotihuacan-related iconographic motifs in mirror bases points to a close relationship between mirror production and the Valley of Mexico, especially at sites like Nebaj and Kaminaljuyu. This pattern suggests that the Maya Highlands could have been the most important area for production and/or use of pyrite mirrors in the Maya region during the Early Classic.

During the Late Classic, the distribution of reflective objects across the Maya region changed considerably. Reflective artifacts from this period are mostly concentrated within the Maya Lowlands, possibly as a result of the collapse of Teotihuacan and its political and economic influence. Based on the revision of archaeological reports presented above, and the preliminary results of geochemical analyses, it is possible to consider that the use of hematite could have increased at this time in the Lowlands. By the end of the eighth century, sites like Aguateca, Cancuen, and La Corona show a considerable amount and diversity of types among reflective objects, including some evidence of manufacturing. It is interesting that during the same period, Cancuen and La Corona also present similarities in greenstone artifact production techniques (Melgar and Andrieu 2016), thus suggesting a new pattern of commercial routes (at least in the western part of Peten), which could have had its origins in the exchange system promoted by previous hegemonic polities like Kaanu'l (Calakmul; Canuto and Barrientos Q. 2013).

Finally, changes observed during the Postclassic period relate to an increase in the size of mirror bases and the incorporation of new materials in pyrite mirrors, such as turquoise and metals like gold and copper. Obsidian mirrors were also added to the inventory of reflective objects from this period (Gallaga M. 2014:281, 2016b:30; Pereira 2008:132). Nevertheless, the propagation of gold objects seems to have gradually replaced pyrite as the preferred reflective mineral for many artifacts. Pyrite and iron ores became primarily restricted in use during this period for objects such as inlays for sculptures and other effigies, such as the eyes of decorated human skulls (Melgar et al. 2014:49). At this moment, mosaic mirrors were also exported to other regions outside Mesoamerica, such as northern Mexico and the southwestern United States, especially in Hohokam sites (McGuire and Valdo Howard 1987:129).

Discussion: Differentiating iron oxides and sulfides through geochemical analyses

The ability to reliably differentiate between the pyrite and hematite raw materials used in reflective artifacts would significantly improve the spatial and temporal resolution of the production and distribution networks of these goods throughout the Maya region. In order to address this problem, the relative abundance of sulfur and iron within artefacts, compared to their naturally occurring abundance within pyrite, may be used to differentiate the materials. This makes it possible to distinguish between a matrix of pyrite or iron oxide, as the latter does not have sulfur in its elemental composition. Results given by SEM-EDS and EDXRF were used to determine the mineral composition of the artifacts. Secondary minerals were identified by SEM-EDS making single spot analysis within the areas of interest or by obtaining a map of the elemental distribution along the sample. Unfortunately, these techniques do have limitations, as distinguishing between iron oxides using the relative proportions of iron, oxygen, and hydrogen is not currently possible. Here, Raman spectroscopy proved a good alternative for identifying the iron oxide, and has the added benefit of being a non-destructive analysis for both crystalline and amorphous solids, whereas XRD is specific to crystalline solids and requires the sample to be ground. The results carried out on the surface of 14 selected samples from La Corona-El Achiotal (12) and Cancuen (2) were congruent in recognizing a low sulfur abundance compared to the iron content. This means the materials sampled were not pyrite (or indeed any other similar iron sulfide), contrary to their classification based upon visual identification. This misidentification suggests that the quantity of mirrors and reflective objects manufactured with hematite or another iron ore could be larger than previously thought, at least during the Late Classic period. Nevertheless, it is difficult for some geochemical methods to identify the specific iron ore with a non-destructive approach. For this, we propose to use Raman spectroscopy, along with magnetic susceptibility measurements. Mass magnetic susceptibility can be used to identify magnetic minerals from a sample by its magnetic properties (Hunt et al. 1995).

The absence of sulfur in the chemical composition of mirrors and other reflective artifacts has been explained as a consequence of oxidation and other transformation processes typical of pyrite and iron ores. This explanation might account for some highly degraded samples that have dulled, but many mirrors retain brightness or are found in relatively stable conditions, indicating that they have not undergone significant chemical change. In the absence of evidence for degradation or dulling, the absence of sulfur may more likely indicate that the raw material used was an iron oxide, or pseudomorphic pyrite. Further studies may have to verify this criteria, by analyzing the inner material of samples with a well-preserved surface. Cases where both pyrite and iron oxides are identified in different samples from the same site may indicate a variety of reflective raw materials; it is possible that the ancient Maya lapidary artisans could have combined different types of reflective minerals within the same object.

As mentioned above, no specific source from which these minerals have been mined has yet been identified, and it may be that they have been extracted from small sources located throughout the whole Maya region. Nevertheless, the accurate identification of these raw materials could help to determine whether they were extracted from an area close to the sites at which they were found, or if they were imported from a distant source, thus establishing patterns of consumption and exchange. For example, the identification of significant pyrite or hematite deposits in the Northern Highlands of Guatemala might explain the large number of mirrors excavated in Nebaj and its surrounding areas. In the same way, we may question whether the mirrors from Kaminaljuyu and other Early Classic sites were manufactured with local pyrite or imported from the Central Highlands of Mexico. Lastly, we hope to confirm whether the production of hematite objects increased during the Late Classic period, and if that relates to the emergence of new trade routes under the authority of polities like Cancuen, which controlled the economy of minerals such as obsidian, jade, and, possibly, pyrite or hematite, at the end of the eighth century A.D. (Demarest et al. 2014; Forné et al. 2014).

Conclusions and future research recommendations

Review of previous publications about reflective objects used by the ancient Maya has shown that these kinds of artifacts had a wide geographic distribution, especially during the Early and Late Classic periods. Although mosaic mirrors figure as the most common, other reflective objects, such as necklaces and dental inlays, were also produced, suggesting that the symbolic value of these minerals could be conveyed as personal ornaments.

Most of the raw materials used for manufacturing reflective artifacts have been identified as pyrite through visual inspection. However, there is an increasing consensus that some of these identifications may be unreliable, potentially undermining the typically assumed predominance of pyrite over other reflective minerals. Geochemical analyses performed on the external surfaces of an initial sample of 14 artifacts from the sites of La Corona and Cancuen determined negligible quantities of sulfur in their chemical composition, thus suggesting that they were hematite or some other type of iron oxide, and that these materials might have been more important than previously thought. Previous discussions about pyrite and iron-ore preservation in archaeological contexts indicate that due to the instability of these kinds of minerals, they oxidize, degrade, and transform into other minerals, thus making it difficult to identify the original raw material. Although this argument is valid for many of the more poorly preserved objects, some mirrors and other reflective objects have preserved their original brightness, and others have been found in relatively stable contexts. Therefore, we suggest the continued identification of raw materials through geochemical analyses on well-preserved reflective surfaces, but also for interior sections that have been exposed by breaks in the objects, and fragments of unworked raw materials. In addition, applying the same analyses to oxidized, calcified, or degraded surfaces will contribute to the understanding of the transformation and pseudomorphic processes that alter iron oxides and sulfides recovered in archaeological contexts in the Maya region. Measuring magnetic susceptibility will be a good complement to address the specific iron oxide identification.

Given the constraints and limitations of these types of analyses, we hope that with the collaboration of other colleagues, especially from the Reflejos network, we can come up with a reliable and accessible methodology for assessing a precise identification of iron-ore materials in Mayan archaeological contexts, especially the difference between sulfur and oxides. In addition, it will be important to soon start sampling the different iron-ore and pyrite deposits in Guatemala, in order to build a reference database similar to that which has been made for clay deposits, obsidian sources, and stable isotopic mapping. Although the data presented correspond to preliminary investigations from the initial stages of a larger research project, they constitute an important reference for future related studies, and demonstrate the potential of multidisciplinary archaeometry research in Maya archaeology. These preliminary results have also helped to formulate new research questions related to spatial and temporal patterns on the reflective objects used by the ancient Maya, which can contribute to improving economic models already defined for the Maya region.

Acknowledgments. The authors would like to express our sincere gratitude to James Walker, Marcello A. Canuto, Ben Stern and Catherine Batt for their invaluable help in revising and improving the English translation and general editing of this article. There were a number of specialists who generously contributed their expertise, especially Luis Velásquez from Cementos Progreso and Stuart Fox and Alex Surtees from the University of Bradford. We also wish to thank Paola Torres and Chloé Andrieu for providing us with information related to iron ore artifacts from Cancuen and for facilitating the sampling of two artifacts. Also, we thank Marissa López and all the PRALC laboratory staff for making the La Corona and El Achiotal samples available for analysis.

References

Abramiuk, Marc, and William Meurer
2006 A Preliminary Geoarchaeological Investigation of Ground Stone Tools in and around the Maya Mountains, Toledo District, Belize. *Latin American Antiquity* 17:335–354.

Aoyama, Kazuo
2007 Elite Artists and Craft Producers in Classic Maya Society: Lithic Evidence from Aguateca, Guatemala. *Latin American Antiquity* 18:3–26.

Arrouvela, Corinne, and Jean-Guillaume Eon
2019 Understanding the Surfaces and Crystal Growth of Pyrite FeS_2. *Materials Research* 22(1):e20171140.

Awe, Jaime
1992 *Dawn in the Land Between the Rivers: Formative Occupation at Cahal Pech, Belize and its Implications for Preclassic Development in the Maya Lowlands.* Ph.D. dissertation, Institute of Archaeology, University of London.

Babcock, Barbara, and Nancy Parezo
1988 *Daughters of the Desert: Women Anthropologists and the Native American Southwest, 1880–1980.* University of New Mexico Press, Santa Fe.

Barrientos, Tomás, Brigitte Kovacevich, Michael Callaghan, and Lucía Morán
2001 Investigaciones en el área residencial sur y suroeste de Cancuén. In *Proyecto Arqueológico Cancuén: Informe temporada 2000*, edited by Arthur Demarest and Tomás Barrientos, pp. 99–160. Report submitted to the Dirección General del Patrimonio Cultural y Natural, Guatemala.

Barrientos, Tomás, Andrea Sandoval, Yoshiyuki Iizuka, Shintaro Suzuki, and Pablo Estrada
2020 Más allá del jade y la pirita: Diversidad de materias primas minerales utilizadas en la época prehispánica. In *XXXIII Simposio de Investigaciones Arqueológicas en Guatemala, Tomo II*, edited by Bárbara Arroyo, Luis Méndez, and Gloria Ajú, pp. 1021–1036. Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Guatemala.

Beovide, Laura, Maira Malán, Elena Vallvé, Alejandro Trujillo, Mirian Mejía, Helena Pardo, Ricardo Faccio, Alvaro Mombrú, and Mariela Pistón
2015 Contenedores, instrumentos y pigmentos: Una aproximación arqueométrica a los procesos de producción y uso en las

sociedades del holoceno tardío en los Humedales del Santa Lucía, Uruguay. *Revista de Antropología Chilena* 47:1–9.

Blainey, Marc

2007 *Surfaces and Beyond: The Political, Ideological, and Economic Significance of Ancient Maya Iron-Ore Mirrors*. MA thesis, Faculty of Arts and Sciences, Trent University, Canada.

2016 Techniques of Luminosity: Iron-Ore Mirrors and Entheogenic Shamanism among the Ancient Maya. In *Manufactured Light: Mirrors in the Mesoamerican Realm*, edited by Emiliano Gallaga M. and Marc G. Blainey, pp. 179–206. University Press of Colorado, Boulder.

Brady, James, Allan Cobb, Sergio Garza, and Robert Burnett

2003 Balam Na: Reporte preliminar de la investigación de una cueva asociada al Río Poxte, Poptun. In *Reporte 17: Atlas Arqueológico de Guatemala*, edited by Juan Pedro Laporte, pp. 145–172. Instituto de Antropología e Historia, Guatemala.

Canuto, Marcello, and Tomás Barrientos Q.

2013 The Importance of La Corona. *La Corona Notes* 1(1):1–5. Electronic document, www.mesoweb.com/LaCorona/LaCoronaNotes01.pdf, accessed March 31, 2021.

Carlson, John

1991 The Olmec Concave Iron-Ore Mirrors: The Aesthetics of a Lithic Technology and the Lord of the Mirror. In *The Olmec and their Neighbors: Essays in Memory of Matthew W. Stirling*, edited by Elizabeth P. Benson, pp. 117–147. Dumbarton Oaks, Washington, DC.

Chase, Arlen, and Diane Chase

2006 Before the Boom: Caracol's Preclassic Era. In *Archaeological Investigations in the Eastern Maya Lowlands: Papers of the 2005 Belize Archaeology Symposium*, edited by John Morris, Sherilyne Jones, Jaime Awe, and Christophe Helmke, pp. 41–57. Institute of Archaeology, National Institute of Culture and History, Belmopan.

Ciudad-Ruiz, Andrés, María J. Iglesias, Jesús Adánez, and Alfonso Lacadena

2011 Excavaciones arqueológicas en Machaquila, Petén, Guatemala. *Revista Española de Antropología Americana* 41:143–173.

Clark, John, and Thomas Lee

2018 A Touch of Teotihuacan at Izapa: The Contents of Two Burials from Group F. *Ancient Mesoamerica* 29:265–288.

Cormier, Aviva Ann

2018 *Maya Osteobiographies of the Holmul Region, Guatemala: Curating Life Histories through Bioarchaeology and Stable Isotope Analysis*. Ph.D. dissertation, Graduate School of Arts and Sciences, Boston University, Boston.

Demarest, Arthur, Chloé Andrieu, Paola Torres, Mélanie Forné, Tomás Barrientos, and Marc Wolf

2014 Economy, Exchange, and Power: New Evidence from the Late Classic Maya Port City of Cancuen. *Ancient Mesoamerica* 25:187–219.

Dennett, Carrie, and Marc Blainey

2016 Reflecting on Exchange: Ancient Maya Mirrors Beyond the Southeast Periphery. In *Manufactured Light: Mirrors in the Mesoamerican Realm*, edited by Emiliano Gallaga M. and Marc G. Blainey, pp. 229–253. University Press of Colorado, Boulder.

Dieseldorff, Erwin

1893 Ausgrabungen in Coban. Zeit. *Fur Ethnologie* 25:374–380.

Fastlicht, Samuel

1962 Dental Inlays and Fillings among the Ancient Mayas. *Journal of the History of Medicine and Allied Sciences* 17(3):393–401.

Fialko, Vilma

2000 El espejo del Entierro 49; morfología y texto jeroglífico. In *El sitio maya de Topoxté. Investigaciones en una isla del lago Yaxhá, Petén, Guatemala*, edited by Wolfgang Wurster, pp. 144–149. Verlag, Mainz am Rhein.

2013 El proceso de desarrollo político del estado maya de Yaxha: Un caso de competencia de élites y readecuación dentro de un marco de circunscripción territorial. In *Millenary Maya Societies: Past Crises and Resilience*, edited by Marie-Charlotte Arnauld and Alain Breton, pp. 265–283. Electronic document, www.mesoweb.com/publications/MMS/17_Fialko.pdf accessed March 31, 2021.

Forné, Mélanie, Chloé Andrieu, and Arthur Demarest

2014 Las actividades económicas como parte de una estrategia política: El caso de Cancuén, una ciudad entre tierras altas y tierras bajas en el clásico tardío. In *Socio-Political Strategies among the Maya from the Classic Period to the Present*, edited by Verónica Vazquez, Rogelio Valencia, and Eugenia Gutiérrez, pp. 33–50. British Archaeological Reports. Archaeopress, Oxford.

Fowler, William

1984 Late Preclassic Mortuary Patterns and Evidence for Human Sacrifice at Chalchuapa, El Salvador. *American Antiquity* 49:603–618.

Freidel, David, Linda Schele, and Joy Parker

1993 *Maya Cosmos: Three Thousand Years on the Shaman's Path*. Harper Collins, New York.

Gallaga M., Emiliano

2014 La manufactura de los espejos de pirita: Una experiencia. In *Estudios de la lítica arqueológica en Mesoamérica*, edited by Lorena Mirambell and Leticia González, pp. 273–308. Instituto Nacional de Antropología e Historia, Mexico City.

2016a Introduction. In *Manufactured Light: Mirrors in the Mesoamerican Realm*, edited by Emiliano Gallaga M. and Marc G. Blainey, pp. 3–24. University Press of Colorado, Boulder.

2016b How to Make a Pyrite Mirror. In *Manufactured Light: Mirrors in the Mesoamerican Realm*, edited by Emiliano Gallaga M. and Marc G. Blainey, pp. 25–50. University Press of Colorado, Boulder.

Gallaga M., Emiliano, and Marc G. Blainey (editors)

2016 *Manufactured Light: Mirrors in the Mesoamerican Realm*. University Press of Colorado, Boulder.

Gann, Thomas

1918 *The Maya Indians of Southern Yucatan and Northern British Honduras*. Bureau of American Ethnology, Bulletin No. 64. Smithsonian Institution, Washington, DC.

Garber, James

1989 *The Artifacts: Archaeology at Cerros, Belize, Central America, Vol. 2*. Southern Methodist University Press, Dallas.

García-Des Lauriers, Claudia

2017 The Regalia of Sacred War: Costume and Militarism at Teotihuacan. *Americae* 2:83–98.

Garrison, Thomas, and Fernando Beltrán

2011 Investigaciones en Bejucal (Operación 1). In *Proyecto Arqueológico "El Zotz": Informe no. 5, temporada 2010*, edited by José Luis Garrido, Stephen Houston, and Edwin Román, pp. 293–319. Report submitted to the Instituto de Antropología e Historia, Guatemala.

Gazzola, Julie, Sergio Gómez, and Thomas Calligaro

2016 Identification and Use of Pyrite and Hematite in Teotihuacan. In *Manufactured Light: Mirrors in the Mesoamerican Realm*, edited by Emiliano Gallaga M. and Marc G. Blainey, pp. 107–124. University Press of Colorado, Boulder.

Gillot, Alejandro

2008 Grupo El Diablo (Operación 5). In *Proyecto Arqueológico "El Zotz": Informe no. 1, temporada de campo 2008*, edited by Ernesto Arredondo and Stephen Houston, pp. 115–134. Report submitted to the Instituto de Antropología e Historia, Guatemala.

González, Liliana

2018 *El arte funerario en el período clásico tardío maya: Una interpretación del destino de las entidades anímicas después de la muerte*. Tesis doctoral, Departamento de Arte y Musicología, Universidad Autónoma de Barcelona, Barcelona.

Goodall, Rosemary

2007 *Spectroscopic Studies of Maya Pigments*. Ph.D. dissertation, School of Physical and Chemical Science, Queensland University of Technology, Brisbane.

Graham, Elizabeth

1987 Resource Diversity in Belize and its Implications for Models of Lowland Trade. *American Antiquity* 52:753–767.

Hart, Betsy, and Kelsey Gauger

2013 Operación KTL-13: Exploración del lado suroeste de la Plaza 2. In *Sitio arqueológico Kante't'u'ul/Finca Obando, San Andrés, Petén: Proyecto Arqueológico Periferia de Motul de San José, Petén, Guatemala*, edited by Antonia Foias, Jeanette Castellanos, and Carlos Cruz, pp. 112–120. Report submitted to the Instituto de Antropología e Historia, Guatemala.

Healy, Paul, and Marc Blainey

2011 Ancient Maya Mosaic Mirrors: Function, Symbolism, and Meaning. *Ancient Mesoamerica* 22:229–244.

Heizer, Robert, and Jonas Gullberg

1981 Concave Mirrors from the Site of La Venta, Tabasco: Their Occurrence, Mineralogy, Optical Description, and Function. In *The Olmec and their Neighbors: Essays in Memory of Matthew W. Stirling*, edited by Elizabeth P. Benson, pp. 109–116. Dumbarton Oaks, Washington, DC.

Hunt, Christopher, Bruce Moskowitz, and Subir Banerjee

1995 Magnetic Properties of Rocks and Minerals. In *Rock Physics and Phase Relations: A Handbook of Physical Constants*, edited by Thomas J. Ahrens, pp. 189–204. American Geophysical Union, Washington, DC.

Ichon, Alain, and Rita Grignon

1981 *Archéologie de sauvetage dans la vallée du Río Chixoy: El Jocote*. Editorial Piedra Santa, Guatemala.

1983 *Archéologie de sauvetage: Les sites classiques de la vallée moyenne du Chixoy*. Editorial Piedra Santa, Guatemala.

Ichon, Alain, Marie F. Fauvet-Berthelot, Robert Hill II, Christine Plocieniak, Rebecca Gonzalez Lauck, and Marco A. Bailey

1980 *Archéologie de sauvetage dans la vallée du Río Chixoy: Cauinal*. Editorial Piedra Santa, Guatemala.

Ichon, Alain, Denise Douzant-Rosenfeld, and Pierre Usselmann

1988 *La vallée moyenne du Río Chixoy (Guatemala): Occupation préhispanique et problèmes actuels*. Editorial Piedra Santa, Guatemala.

Iizuka, Yoshiyuki, Shintaro Suzuki, and Tomás Barrientos

2020 Non-Invasive Chemical Investigation on Stone Artifacts from Guatemalan Maya Sites. *Kodai Amerika* 23:29–50.

Inomata, Takeshi, Daniela Triadan, Erick Ponciano, Estela Pinto, Richard Terry, and Markus Eberl

2002 Domestic and Political Lives of Classic Maya Elites: The Excavation of Rapidly Abandoned Structures at Aguateca, Guatemala. *Latin American Antiquity* 13:305–330.

Ixer, Robert

1990 *Atlas of Opaque and Ore Minerals in their Associations*. Van Nostrand Reinhold, New York.

Johnson, Neil, Sidney Pollack, Elizabeth Frommell, and Patricia Eldredge

1995 Powder Diffraction Analysis of an Interstratified Marcasite/Pyrite Structure. *Powder Diffraction* 10(3):198–203.

Kidder, Alfred

1947 *The Artifacts of Uaxactun, Guatemala*. Carnegie Institution of Washington Publication No. 576. Carnegie Institution of Washington, Washington, DC.

Kidder, Alfred, Jesse Jennings, and Edwin Shook

1946 *Excavations at Kaminaljuyu, Guatemala*. Carnegie Institution of Washington Publication No. 561. Carnegie Institution of Washington, Washington, DC.

Kirchhoff, Paul

1960 *Mesoamérica: Sus límites geográficos, composición étnica y caracteres culturales*. Suplemento de la revista Tlatoani No. 3. Escuela Nacional de Antropología e Historia, Mexico City.

Kovacevich, Brigitte

2016 Domestic Production of Pyrite Mirrors at Cancuen, Guatemala. In *Manufactured Light: Mirrors in the Mesoamerican Realm*, edited by Emiliano Gallaga M. and Marc G. Blainey, pp. 73–106. University Press of Colorado, Boulder.

Kovacevich, Brigitte, Duncan Cook, and Timothy Beach

2004 Áreas de actividad doméstica en Cancuen: Perspectivas basadas en datos líticos y geoquímicos. In *XVII Simposio de Investigaciones Arqueológicas en Guatemala, 2003*, edited by Juan Pedro Laporte, Bárbara Arroyo, Héctor Escobedo, and Héctor Mejía, pp. 876–891. Museo Nacional de Arqueología y Etnología, Guatemala.

Mason, Alden

1927 Mirrors of Ancient America. *The Museum Journal* 18:201–209.

Mata, Guillermo

2003 Espejo de pirita y pizarra de Amatitlán. En *XVI Simposio de Investigaciones Arqueológicas en Guatemala 2002*, edited by Juan Pedro Laporte, Bárbara Arroyo, and Héctor Escobedo, pp. 831–839. Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Guatemala.

McGuire, Randall, and Ann Valdo Howard

1987 The Structure and Organization of Hohokam Shell Exchange. *Kiva* 52:113–146.

Melgar, Emiliano, and Chloé Andrieu

2016 El intercambio del jade en las tierras bajas mayas, desde una perspectiva tecnológica. In *XXIX Simposio de Investigaciones Arqueológicas en Guatemala, 2015*, edited by Bárbara Arroyo, Luis Méndez, and Gloria Ajú, pp. 1065–1076. Museo Nacional de Arqueología y Etnología, Guatemala.

Melgar, Emiliano, Emiliano Gallaga M., and Reyna Solís Ciriaco

2014 La pirita y su manufactura: Análisis de cuatro contextos mesoamericanos. *Estudios de Cultura Maya* 43:43–68.

Miller, Katherine

2019 Excavación de Entierro 4-1B y análisis en laboratorio de restos óseos de 2016 y 2017. In *Proyecto Arqueológico Ucanal 2018*, edited by Cristina Halperin and José Luis Garrido, pp. 197–220. Report submitted to the Dirección General del Patrimonio Cultural y Natural, Guatemala.

Moholy-Nagy, Hattula

1997 Middens, Construction Fill, and Offerings: Evidence for the Organization of Classic Period Craft Production at Tikal, Guatemala. *Journal of Field Archaeology* 24:292–313.

Nelson, Zachary, Barry Scheetz, Guillermo Mata, and Antonio Prado

2005 Composite Mirrors of the Ancient Maya: Ostentatious Production and Precolumbian Fraud. *PARI Journal* 9(4):1–7.

Nesse, William

2000 *Introduction to Mineralogy*. Oxford University Press, Oxford.

Pereira, Grégory

2008 La materia de las visiones: Consideraciones acerca de los espejos de pirita prehispánicos. *Diario de Campo*, suplemento 48:123–135.

Pérez, Juan Carlos, Griselda Pérez, David Freidel, and Olivia Navarro-Farr

2015 Waka', el reino del ciempiés: La reina K'abel y su historia recién descubierta. *Anales del Museo de América* 23:7–31.

Piedrasanta, Rony

2018 Investigaciones en la Estructura M7-1 (Operación 21). In *Proyecto Arqueológico El Zotz: Informe final, 12va temporada de campo*, edited by Yeny Gutiérrez, José Luis Garrido, Thomas Garrison, Stephen Houston, and Edwin Román, pp. 41–56. Report submitted to the Instituto de Antropología e Historia, Guatemala.

Piedrasanta, Rony, Thomas Garrison, Edwin Román, and Stephen Houston

2014 Investigaciones recientes en el Grupo El Tejón, El Zotz, Petén, Guatemala. In *XXVII Simposio de Investigaciones Arqueológicas en Guatemala, 2013*, edited by Bárbara Arroyo, Luis Méndez, and Andrea Rojas, pp. 945–950. Museo Nacional de Arqueología y Etnología, Guatemala.

Pires-Ferreira, Jane

1975 *Formative Mesoamerican Exchange Networks with Special Reference to the Valley of Oaxaca*. Prehistory and Human Ecology of the Valley of Oaxaca 3, Museum of Anthropology Memoirs 7. University of Michigan, Ann Arbor.

Postal, William

1935 Qualitative Petrographic Analysis of Potsherds. In *Piedras Negras Archaeology, 1931–1939*, edited by John Weeks, Jane Hill, and Charles Golden, pp. 115–121. University of Pennsylvania, Museum of Archaeology and Anthropology, Philadelphia.

Quintana, Patricia, Vera Tiesler, Mario Conde, Rudy Trejo, Catalina Bolio, Juan J. Alvarado, and Daniel Aguilar

2014 Spectrochemical Characterization of Red Pigments Used in Classic Period Maya Funerary Practices. *Archaeometry* 57:1045–1059.

Ramírez, Marco, Elma Vega, Patricia Quintana, Andrea Cucina, and Vera Tiesler

2018 Pulp Pathosis Associated with Ancient Maya Dental Inlays. *Archives of Oral Biology* 95:202–208.

Roldán, Julio

1998 Hallazgos recientes en el sitio arqueológico Serchil, Huehuetenango. In *XI Simposio de Investigaciones Arqueológicas en Guatemala, 1997*, edited by Juan Pedro Laporte and Héctor Escobedo, pp. 604–615. Museo Nacional de Arqueología y Etnología, Guatemala.

Romero, Luis

2010 Excavaciones en las Estructuras 19 y 21 del Cuadrante K del sitio arqueológico Xultun. In *Informe preliminar de la novena temporada de campo 2010: Proyecto Arqueológico Regional San Bartolo*, edited by Luis Romero and William Saturno, pp. 91–105. Report submitted to the Instituto de Antropología e Historia, Guatemala.

Rosales, Edgar

2017 No todo lo que brilla es oro … ni jade: Las micas especulares mayas. *Temas Antropológicos: Revista Científica de Investigaciones Regionales* 39(2):63–84.

Sahagún, Fray Bernardino

1985 *Historia general de las cosas de la Nueva España*. Editorial Porrúa, Mexico City.

Sandoval, Andrea, Yoshiyuki Iizuka, and Shintaro Suzuki

2020 Preclassic Mesoamerican Dental Inlays: Study of the Raw Materials by SEM-EDS. *Science and Technology of Archaeological Research* 5(2):157–163.

Santamarta, Pedro

1977 *El mundo de los minerales*. Editorial Maves, Bilbao.

Satterthwaite, Linton

1952 The Plazuela of Structure V-1. In *Piedras Negras Archaeology, 1931–1939*, edited by John Weeks, Jane Hill, and Charles Golden, pp. 343–362. University of Pennsylvania, Museum of Archaeology and Anthropology, Philadelphia.

Saunders, Nicholas

1988 Anthropological Reflections on Archaeological Mirrors. In *Recent Studies in Pre-Columbian Archaeology*, edited by Nicholas Saunders and Olivier de Montmollin, pp. 1–39. BAR International Series 421. British Archaeological Reports, Oxford.

2001 A Dark Light: Reflections on Obsidian in Mesoamerica. *World Archaeology* 33:220–236.

Saville, Marshall

1922 *Turquoise Mosaic Art in Ancient Mexico*. Contribution 6. Museum of the American Indian, Heye Foundation, New York.

Schele, Linda, and Peter Mathews

1998 *The Code of Kings: The Language of Seven Sacred Maya Temples and Tombs*. Touchstone, New York.

Schieber de Lavarreda, Christa

2003 Una nueva ofrenda en Tak'alik Ab'aj (antes Abaj Takalik): El Entierro 1. In *XVI Simposio de Investigaciones Arqueológicas en Guatemala, 2002*, edited by Juan Pedro Laporte, Bárbara Arroyo, and Héctor Escobedo, pp. 784–792. Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal, Guatemala.

Seler, Eduard

1904 Antiquities of Guatemala. In *Mexican and Central American Antiquities, Calendar Systems, and History*, Bureau of American Ethnology Bulletin 28, pp. 77–121. Smithsonian Institution, Washington, DC.

Shook, Edwin

1947 Guatemala Highlands. *Carnegie Institution of Washington Year Book* 46:179–184.

Smith, Ledyard, and Alfred Kidder

1951 *Excavations at Nebaj, Guatemala*. Carnegie Institution of Washington, Publication No. 594. Carnegie Institution of Washington, Washington, DC.

Smith, Michael

2014 The Archaeology of Tezcatlipoca. In *Tezcatlipoca: Trickster and Supreme Deity*, edited by Elizabeth Baquedano, pp. 7–40. University Press of Colorado, Boulder.

Stone, Doris, and Carlos Balser

1965 Incised Slate Disks from the Atlantic Watershed of Costa Rica. *American Antiquity* 30:310–329.

Suzuki, Shintaro, Andrea Sandoval, and Héctor Mejía

2018 Enigma de la incrustación dental: Una nueva perspectiva desde Reynosa, Escuintla. In *XXXI Simposio de Investigaciones Arqueológicas en Guatemala 2017, Tomo II*, edited by Bárbara Arroyo, L. Salinas, and Gloria Ajú, pp. 1043–1055. Museo Nacional de Arqueología y Etnología, Guatemala.

Taschek, Jennifer

1994 *The Artifacts of Dzibilchaltun, Yucatan, Mexico: Shell, Polished Stone, Bone, Wood, and Ceramics*. Publication 50. Middle American Research Institute, Tulane University, New Orleans.

Taube, Karl

1992 The Iconography of Mirrors at Teotihuacan. In *Art, Ideology, and the City of Teotihuacan: A Symposium at Dumbarton Oaks, 8th and 9th October 1988*, edited by Janet Berlo, pp. 169–204. Dumbarton Oaks, Washington, DC.

2016 Through a Glass, Brightly: Recent Investigations Concerning Mirrors and Scrying in Ancient and Contemporary Mesoamerica. In *Manufactured Light: Mirrors in the Mesoamerican Realm*, edited by Emiliano Gallaga M. and Marc G. Blainey, pp. 285–314. University Press of Colorado, Boulder.

Thompson, Edward

1897 *The Chultunes of Labna, Yucatan: Report of Explorations of the Museum, 1888–1889 and 1890–91*. Memoirs of the Peabody Museum of Archaeology and Ethnology 3. Harvard University, Cambridge.

Thomson, Raymond

1962 Un espejo de pirita con respaldo tallado de Uayma, Yucatan. *Estudios de Cultura Maya* 2:239–249.

Weeks, John, Jane Hill, and Charles Golden (editors)

2005 *Piedras Negras Archaeology, 1931–1939*. University of Pennsylvania, Museum of Archaeology and Anthropology, Philadelphia.

Woodbury, Richard, and Aubrery Trik

1954 *The Ruins of Zaculeu, Guatemala*. United Fruit Company, New York.

Young-Sánchez, Margaret

1990 Veneration of the Dead: Religious Ritual on a Pre-Columbian Mirror-Back. *Bulletin of the Cleveland Museum of Art* 77(9):326–351.

Zamora, Marcelo

2002 *La industria de la pirita en el sitio de Aguateca durante el período clásico tardío*. Licenciatura thesis, Department of Archaeology, Faculty of Social Sciences, Universidad del Valle de Guatemala, Guatemala.

Zralka, Jarosław, Wiesław Koszkul, Katarzyna Radnicka, Laura Sotelo, and Bernard Hermes

2014 Excavations in Nakum Structure 99: New Data on Protoclassic Rituals and Precolumbian Maya Beekeeping. *Estudios de Cultura Maya* 44:85–117.