Integrated mineralogical and typological study of Axe-God pendants from the Jade and Pre-Columbian Culture Museum in Costa Rica

Camila Hernández-Murillo[a, b]*, Sergio García[c], Patricia Fernández[d, e], Matthieu Ménager[e, f] & Mavis L. Montero[a, b]

[a]University of Costa Rica (UCR), School of Chemistry, San Jose, Costa Rica
[b]University of Costa Rica (UCR), Materials Science and Engineering Research Center (CICIMA, by its acronym in Spanish), San Jose, Costa Rica
[c]Jade and Pre-Columbian Culture Museum, National Insurance Institute (INS, by its acronym in Spanish), San Jose, Costa Rica
[d]University of Costa Rica (UCR), School of Anthropology, San Jose, Costa Rica
[e]University of Costa Rica (UCR), Center for Anthropological Research (CIAN, by its acronym in Spanish), San Jose, Costa Rica
[f]IMBE- Avignon University/ CNRS/ IRD/ Aix-Marseille University, Restoration Engineering of Natural and Cultural Heritage, Faculty of Sciences, Avignon, France
*Contact author: camila.hernandezmurillo@ucr.ac.cr

Abstract: The mineralogical composition and typological classification of a group of 226 Axe-God pendants from the Jade and pre-Columbian Culture Museum (from the Instituto Nacional de Seguros) in San José (Costa Rica) was studied, using a non-invasive characterization technique and a novel stylistic classification scheme. Possible composition-design correlations were examined through descriptive and functional statistical analysis. This study constitutes an initial step towards the comprehensive analysis of this distinctive pendant design.
Keywords: Jade; greenstone; axe-god pendant; non-invasive characterization; Lower Central America.

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Estudio mineralógico y tipológico de colgantes hachoides del Museo del Jade y de la Cultura Precolombina
Resumen: Se realizó un análisis de la composición mineralógica y clasificación tipológica de 226 colgantes hachoides ("Dios-Hacha") de la colección del Museo del Jade y de la Cultura Precolombina (Instituto Nacional de Seguros) en San José, Costa Rica. El estudio integró los resultados de caracterización mediante técnicas no-invasivas y un reciente sistema de clasificación estilística. Posibles correlaciones entre material y diseño fueron examinadas a través de estadística descriptiva y funcional. Esta investigación significa el inicio de un análisis exahustivo de este distintivo diseño de colgante.
Palabras clave: Jade; piedras verdes; Dios-hacha; colgantes hachoide; caracterización no invasiva; baja América Central.

Introduction

In modern-day Costa Rica, near the border between the Mesoamerican and the Intermediate region, took place one of the largest jade and greenstone workshop of Lower Central America. Here, thousands of artifacts were produced, starting around 800-500 BCE until the decline and end of this lapidary tradition estimated around 700-900 CE (Mora-Marín et al., 2013; Snarskis, 2003; Guerrero, 1999). Among the several designs and types of ornaments carved in jade and green-stone, there's a specific style that is representative of Costa Rica's green-stones lapidary tradition: The Axe-God pendants. This distinct design displays an animal or human figure on its upper section (referring to the head or crest), an axe-like lower section, as well as transversally drilled perforations that allowed its suspension (Fig. 1), most likely to be worn as pendants (Kuboyama, 2019; Mora-Marín, 2016; Snarskis, 2003).

In Mesoamerica and Lower Central America, jade and greenstones were highly valued materials with great symbolic meaning, its association with concepts such as fertility, water and agriculture has been identified since the Middle Formative period in the Olmec region (Taube, 2005). These materials were often used to craft ritual objects and as markers of social and political distinction (Guerrero, 1999; Hoopes, 2005). Nonetheless, several authors have highlighted that the pre-Columbian societies in this region used raw materials with a broad mineralogical diversity, that included, but was not limited to jadeite and its associated minerals (Hauff, 1993; Jaime-Riverón, 2010; Snarskis, 2003).

The aim of this study is to explore, through non-invasive physicochemical techniques, if the Axe-God pendants present any correlation between their design and the material employed in their making, an approach that hasn't been used yet to study this distinctive artifact design.

The sample of 226 pendants have been selected out of the vast collection of the Jade and pre-Columbian Culture Museum in San José (Costa Rica), this collection includes more than 2500 jade artifacts (Soto, 1999). It should be noted that these artifacts were not recovered through scientific methodologies and therefore are not associated to a well-defined archaeological context. Fortunately, this lack of information does not restrict the scope of this research. In this instance, the collection of the Jade and pre-Columbian Culture Museum represents an ideal opportunity to study the typological and mineralogical diversity of this particular pendant design.

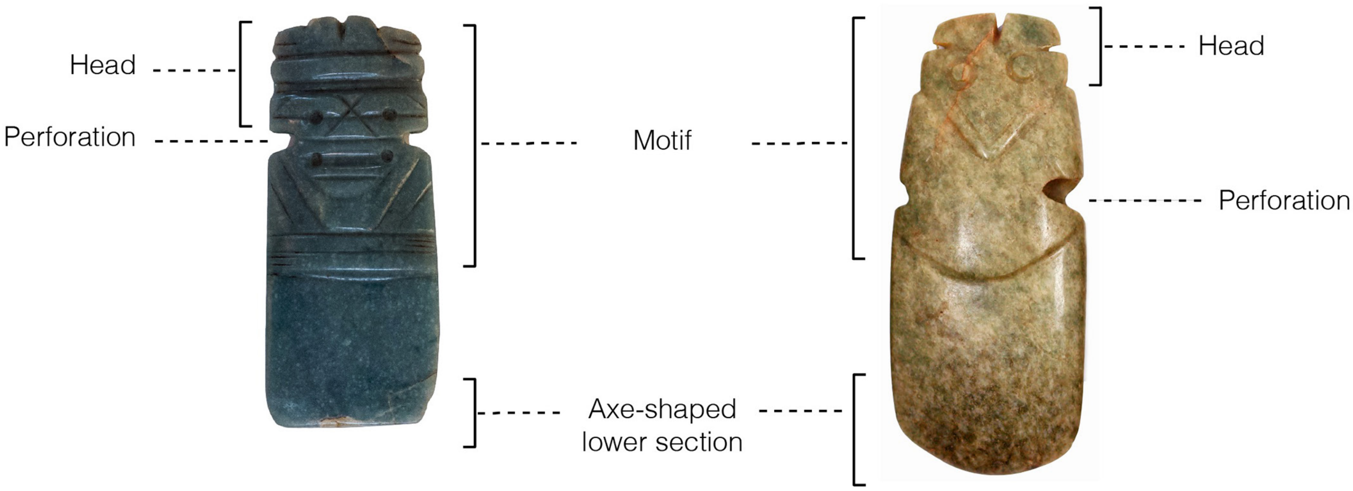

Figure 1: Photographs of two Axe-God pendant and their characteristic features: artifact 4451 (left) and artifact 6483 (right).

In this instance, the artifact's design will be examined based on a recently published research that proposes a typological classification scheme for the Axe-God pendants that takes into account design features of the head or crest of the pendants (Kuboyama, 2019).

Moreover, the non-invasive mineralogical characterization of the pendants will be centered mainly in Fourier Transform Infrared Spectroscopy (FTIR). FTIR has been reported as an ideal technique to identify the main mineral(s) present in Mesoamerican jadeite and greenstone artifacts (Manrique-Ortega et al., 2019; Delgado Robles et al., 2015; Mitrani Viggiano et al., 2016) and has also been found suitable to characterize the mineralogical composition of Axe-God pendants, despite their particular surface topography characteristics (Hernández-Murillo et al., 2021).

Methodology

Samples

A group of 226 axe-God pendants were selected from the vast collection of the Jade and pre-Columbian Culture Museum in San José, Costa Rica. The artifacts were chosen based on the mineralogical information provided by the museum. The objects selected have reported mineral compositions of either jadeite, associated minerals or other greenstones common in the collection. Photographs of some samples can be seen in the Supplementary Material section. Subsequently the pendants were classified into their corresponding motif category, according to the most recent Axe-God pendant typological categorization (Kuboyama, 2019).

Methods

Portable Fourier transform infrared spectroscopy (FTIR)

To study the vibrational properties of the samples, a portable FTIR spectrometer Bruker Optics Alpha with the external reflection module was used for the measurements, the spectrometer belongs to the Material Science and Engineering Research Center (CICIMA, Universidad de Costa Rica). For each spot 35 scans were carried out in order to improve signal-to-noise ratio, focusing in the spectral region between 400-4000 cm-1. The spot size has a 3 mm diameter. Ten spectra were obtained for each sample all of which were taken exclusively on the front face of the pendants. The spectra were viewed with the software OPUS 7 and compared with reference spectra from the RRUFF project database (Lafuente et al., 2016) and reported elsewhere (Ostrooumov, 2009; Delgado Robles et al., 2015). Taking into account the mineral and geochemical heterogeneity of the objects, for each sample several spots were included in the analysis. In every case, the spots were distributed throughout the object, selecting only flat surfaces with an appropriate location on which both techniques could be performed.

Spectral pre-processing

A series of pre-processing procedures were applied to the spectroscopic data: i) cropping (the range of the FTIR spectra was cropped to 400-2000 cm-1), ii) baseline correction (polynomial fitting) and iii) filter based on minimal intensity (the spectrum maximum intensity should be at least 0.01 a.u.). The preprocessing was done using the free software R.

Statistical analysis

The statistical treatment of spectroscopic data was achieved using functional data analysis (FDA) techniques. Firstly, a function was constructed starting from the discrete observations of each spectrum, B-splines basis functions were used. Subsequently, functional principal component analysis (FPCA) was used as a dimension reduction technique, it performs a dimensionality reduction analogous to the multivariate principal component analysis (Burfield et al., 2015). Lastly, k-means clustering was carried out. The statistical analysis was done using the free software R.

Results and discussion

Mineralogical analysis

It has been stated that the rocks employed in Costa Rica's lapidary tradition display a high mineralogical diversity (Alvarado and García-Casco, 2019). Several authors have highlighted that the possible list of raw materials is not limited to jadeite (which is one of the two mineral species classified as jade) and its associated minerals, such as omphacite, hedenbergite, augite and albite. In fact, previous investigations in Costa Rica, the Maya area and the Caribbean indicate that other minerals and rocks with a broader range of colors and textures were used as raw materials as well, including a great variety of igneous, sedimentary and metamorphic rocks, including quartz, serpentinite, dolomite, jasper, siltstone, gabbro, and andesite; all of which are generally referred to as greenstones or as social jade (Alvarado and García-Casco, 2019; Kovacevich and Callaghan, 2019; Powis et al., 2016; Knight, 2020).

It has been argued that the analysis of the chemical and mineralogical composition of these materials is essential for a detailed comprehension of their exchange and distribution by pre-Columbian societies (Tremain, 2014). Unfortunately, in the region this information is limited and research on this topic has been greatly affected by the scarce access to accurate identification techniques.

Moreover, in the case of Costa Rica, the current information available about the diversity of raw materials used as part of this lapidary tradition was gathered using techniques that are no longer considered ideal by today's standards; either because they employed destructive techniques (Lange, Bishop & Lambert, 1981) or because they relied on microscopic or gemological examination (Fischer, 1882; Laguna & Kussmaul, 1987; Reynoard, 1993) that do not always provide an accurate identification of the mineral components. Recently, spectroscopic techniques have been proposed as an alternative to these methods with valuable benefits such as in situ characterization and non-invasive and non-destructive analysis (Manrique-Ortega et al., 2019).

The spectroscopic results presented here, in agreement with previous findings (Alvarado and García-Casco, 2019), indicate that Axe-God pendants were carved in jade and in other materials classified as social jade (for example quartz and serpentine). Altogether, four minerals or mineral mixtures were identified in more than 85% of the artifacts (Figure 2A), the most predominant minerals are: Jadeite, omphacite, quartz and albite. More precisely, jadeite was the most abundant mineral in the sample, this mineral was identified in 165 artifacts (around 74% of the artifacts).

Moreover, jadeite was identified as the sole major mineral component in approximately 49% of the objects. Nonetheless, in this instance, the high percentage of precious gemstones, such as jade, might be a consequence of the selection process that was carried out during the purchase of this museum's collection. Additionally, several other major and minor minerals were identified in a lesser amount, as shown in Figure 2A-B. These minerals include actinolite-tremolite, quartz, albite, diopside, zoisite, serpentine, augite, hedenbergite and plagioclase.

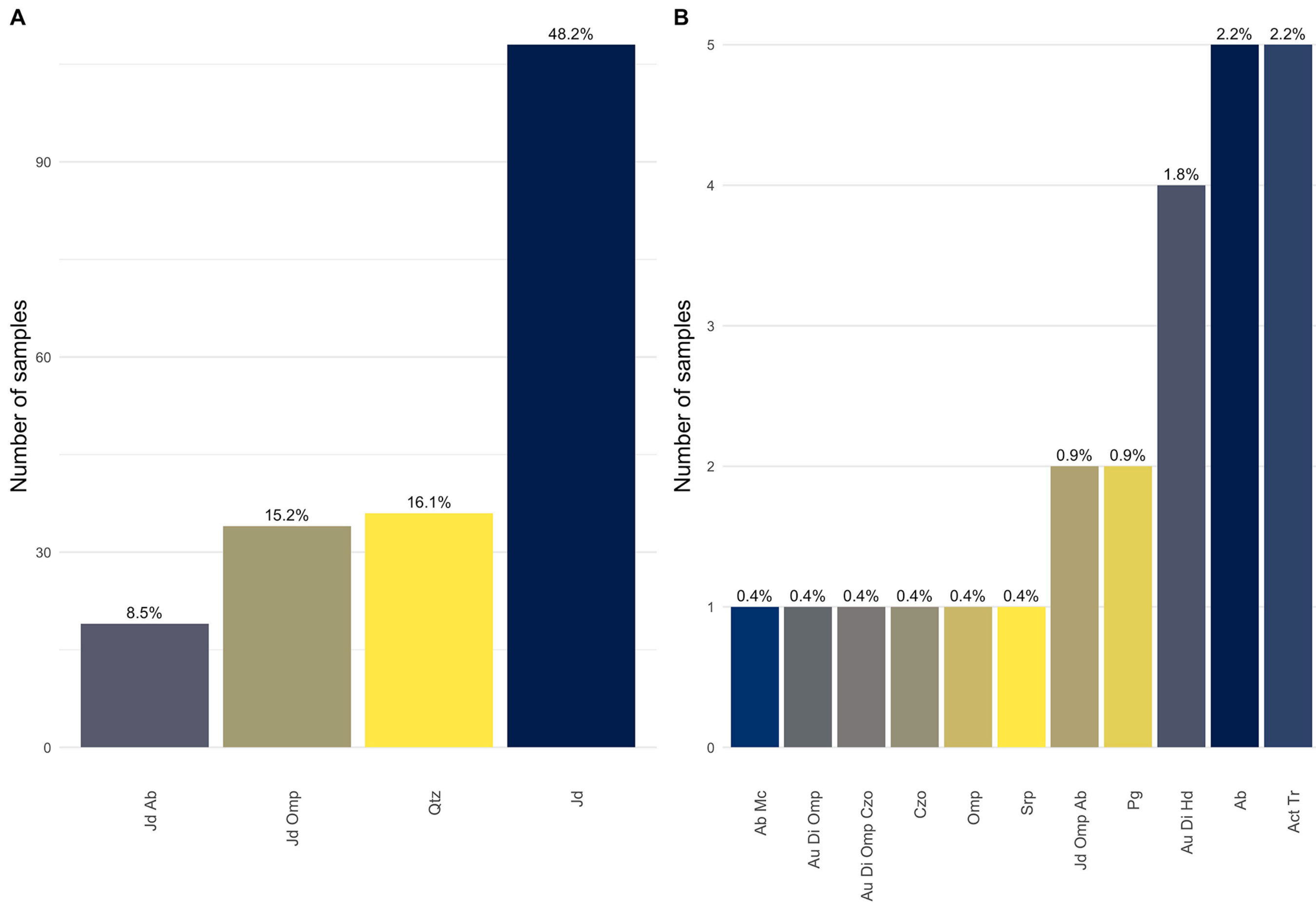

Figure 2: Number and percentage of pendants per type of mineral, divided according to frequency: A) Most abundant minerals and B) Least abundant minerals.

An important question associated to the mineral composition of archaeological artifacts is the source of raw materials. Even though that is not the aim of this study, these results can enrich the discussion of this subject. For instance, jadeite and its associated minerals are of a foreign origin, whereas other minerals, commonly referred to as social jade, might have a local origin, such as quartz and serpentine. In particular, quartz appears to have been an intensively used material in the region (Figure 2); here it was found to be the major mineral in almost 16% of the samples. In fact, several outcrops of quartz in Costa Rica have been suggested as possible sources of this variety of social jade although none has been confirmed yet (Alvarado and García-Casco, 2019).

Additionally, the FTIR analysis offers valuable evidence for the use of nephrite (actinolite-tremolite) in Costa Rica. We acknowledge that there have been considerable discussions in the past among researchers as to the extent of its use in Lower Central America, the Caribbean and Mesoamerica, because of the lack

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of known exploitable sources for nephrite-bearing rocks in the region. However, our findings are in line with recent studies that have reported the use nephrite in the Mayan site Palenque (Delgado Robles et al, 2015), in Teotihuacan (Manrique-Ortega et al., 2020) and in some Caribbean islands (Guzzo Falci et al., 2020; Queffelec et al., 2018).

Typological classification

Recently Kuboyama (2019) published a classification scheme that focuses specifically in Axe-God pendants, the author stablished different categories for variables such as size, profile shape, motif and design details in the upper section of the pendants. For the typological categorization of the pendants, Kuboyama identified five major motif categories, each of which can be further subdivided based on the decorative elements on the head of the figure represented in the pendant. Some examples of every category are shown in Supporting Information (Figure S1). The principal motif categories are:

-Anthropomorphous: representation of a human figure, mostly its head and occasionally its upper torso.

-Avian shaped: representation of a bird figure, with a clear depiction of its beak.

-Feline: Figure with animal-like features that resembles a feline.

-Simple: Contains either stylized and simple geometric designs or no decoration at all.

-Chimera: Multiple figures are depicted in the same pendant, including combinations of anthropomorphic and zoomorphic motifs.

The 226 artifacts presented in this study were classified accordingly, overall the sample includes pendants of the 5 major motifs and of the thirteen head features categories defined by Kuboyama (2019).

It is worth noting that, in this sample, the pendants' designs are not equally distributed among the five motif categories, as detailed in Figure 3. Nonetheless, the number of artifacts in each motif category is representative of the distribution of the pendants' design in the museum's collection.

For instance, the anthropomorphous motif is the most common design among the pendants in this sample, approximately one third of the artifacts (35%) were classified in this category. On the contrary, the feline motif was the least frequent, only 12 pendants presented this design (5%).

Mineralogical-Typological correlation

Afterwards, the correlation between the mineral composition and their stylistic features of these artifacts was examined (Table 1). These results are displayed in Figure 4.

Overall, the present findings show that jadeite is the most abundant mineral, regardless of the design characteristics and classification. Additionally, the results suggest that anthropomorphous is the category which displays a greater variety of minerals, in this case only jadeite, albite and quartz were identified. However, these observations might be affected by the number of artifacts in each category.

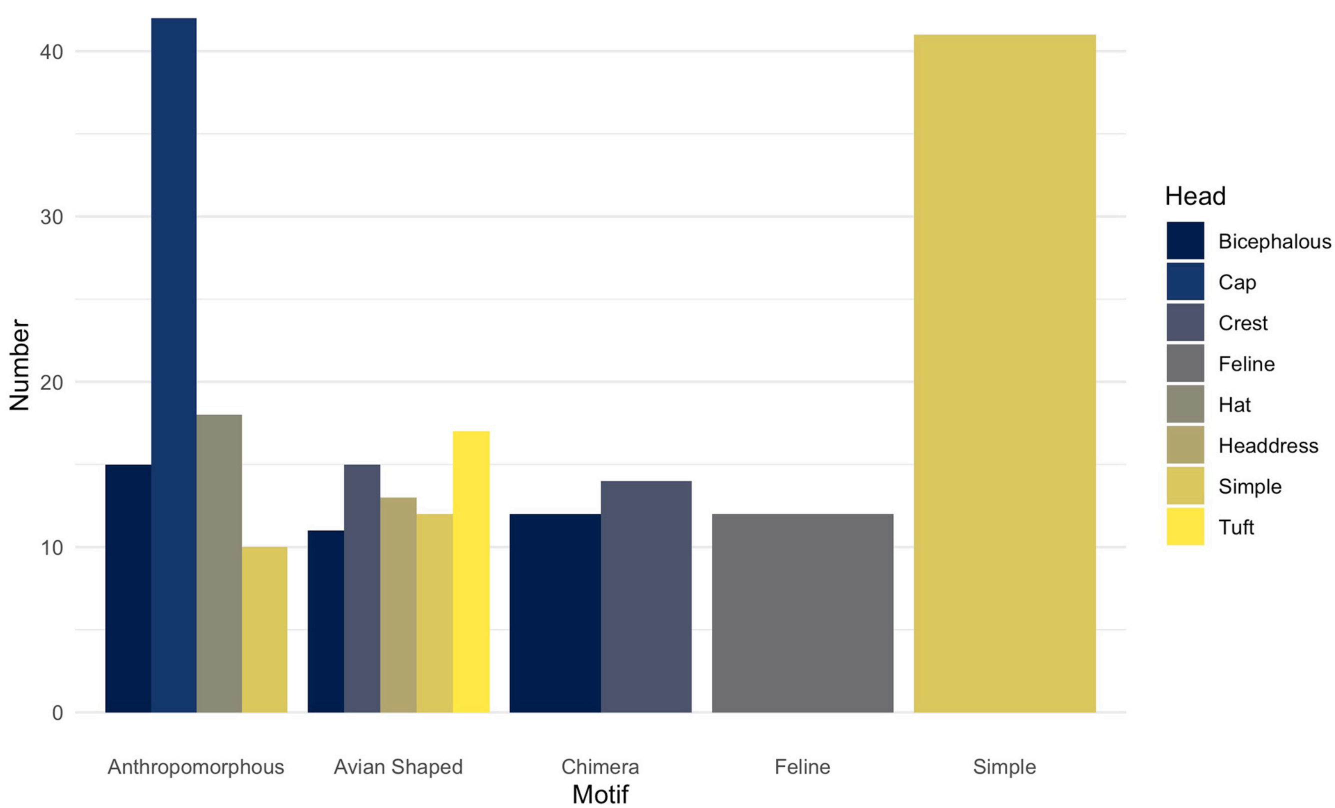

Figure 3. Number of pendants per type of stylistic features in the upper section of the artifact (head), divided according to motif categories.

The possible material-design correlation can be further examined with a functional principal component analysis (FPCA). The graph displayed in figure 5, resulting from this type of statistical analysis, show similar FTIR spectra as two symbols located very close together. For example, samples identified as jadeite, augite, diopside and omphacite (which are minerals with great similarities in their chemical composition and therefore in their FTIR spectra) have, for the most part, very similar scores in the calculated principal components. While other minerals, such as quartz and serpentine, can be seen further apart in figure 5, because of the differences in their chemical composition and spectroscopic results. Additionally, figure 5 includes a representation of the samples' motif, denoted as the different symbols included in the diagram.

Altogether, no significant correlation was observed between the Axe-God pendants' design and the mineralogical composition of the rocks they were carved in. Nonetheless, the are certain interesting observations that could be examined in future studies; for example, the reduced mineralogical diversity found among the Feline and Simple Axe categories, as opposed to the greater material variation found in the more common anthropomorphous motif.

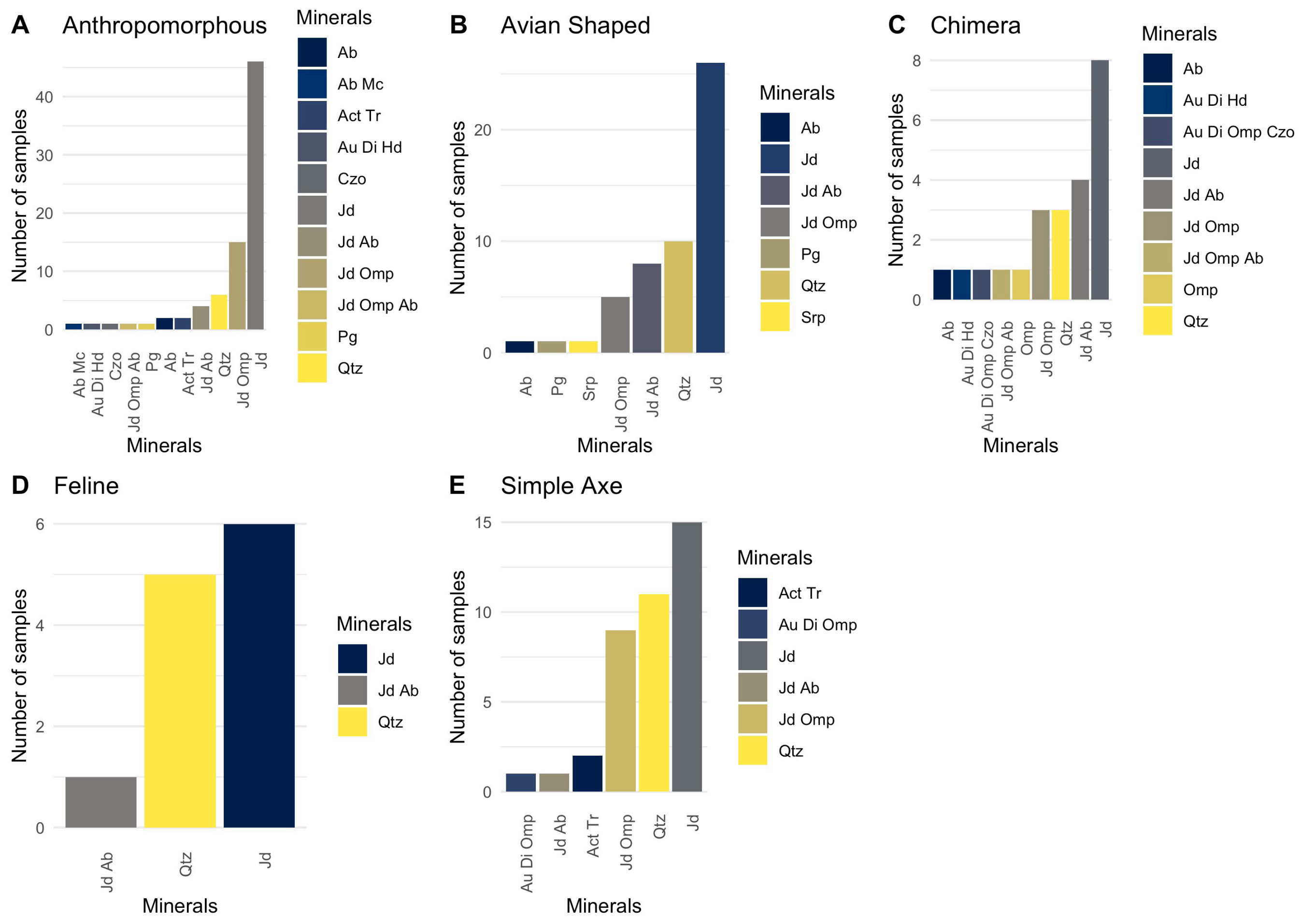

Figure 4: Number of pendants per type of mineral, divided according to motifs: A) Anthropomorphous, B) Avian Shaped, C) Chimera, D) Feline, E) Simple Axe.

Given that these findings are based on artifacts that lack contextual information, the results from such analyses should thus be interpreted with particular caution. For that reason, this study focuses only on the correlation between material and design, two variables that can be determined without information about the archaeological context of the objects.

Although there's no evidence, reports or studies that suggest that some artifacts from the Jade and Pre-Columbian Culture Museum might be replicas, it should be mentioned as a plausible scenario. However, it should be noted that, the development of a robust characterization methodology and a thorough statistical analysis as the ones presented here, could have only been possible with a sample as numerous

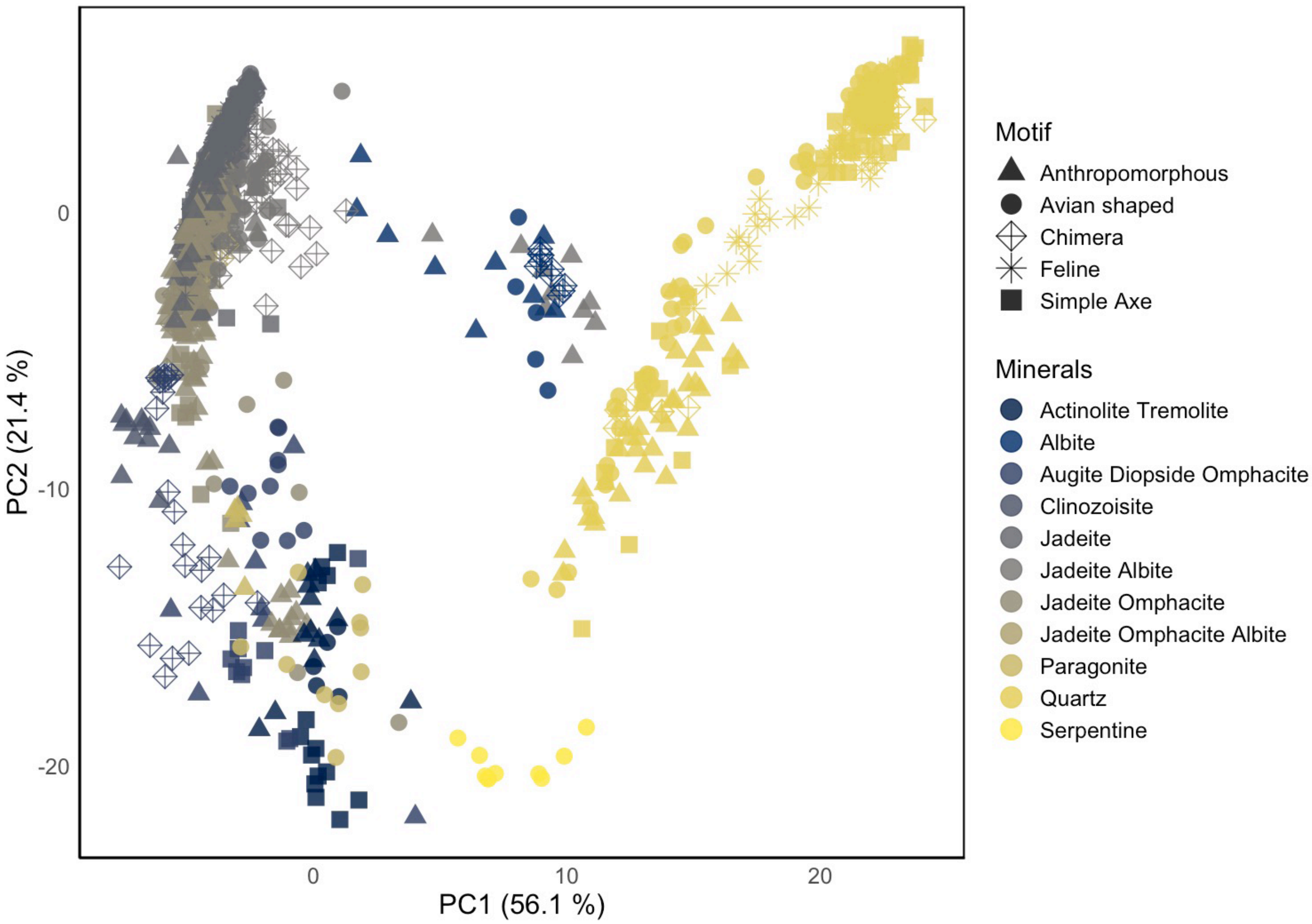

Figure 5: Scores of the first two functional principal components for the pre-treated FT-IR spectra of the 226 Axe-God pendants from the Jade and Precolumbian Culture Museum.

and as diverse as that of the Jade and Pre-Columbian Culture Museum. Taking this study and its methodology as the basis, future work will focus on collections from other museums, to be able to analyze artifacts with a known archaeological context. Interdisciplinary studies of this kind could provide accurate and new information about exchange routes, manufacturing techniques, raw material exploitation and distribution, among others. All of which could be used to reevaluate local and long-distance dynamics linked to jade, greenstones and social jade.

Table I: Summary of spectroscopic results and typological classIfication of the Axe-God pendants.

Sample	Minerals [a]	Motif	Head	Sample	Minerals [a]	Motif	Head
1189	Jd, Omp	Avian shaped	Bicephalous	1798	Jd	Avian shaped	Bicephalous
1195	Srp	Avian shaped	Simple	1802	Qtz	Anthropomorphous	Hat
1344	Jd	Simple Axe	Simple	1804	Jd Ab	Avian Shaped	Tuft
1505	Jd Omp	Anthropomorphous	Cap	1805	Qtz	Anthropomorphous	Cap
1508	Act Tr	Simple Axe	Simple	1822	Qtz	Anthropomorphous	Cap
1520	Qtz	Anthropomorphous	Simple	1851	Aug Di Omp	Simple Axe	Simple
1521	Jd Ab	Anthropomorphous	Cap	1856	Jd Ab	Simple Axe	Simple
1525	Act Tr	Avian Shaped	Simple	1873	Jd Omp	Avian shaped	Simple
1526	Jd	Chimera	Crest	1900	Qtz	Simple Axe	Simple
1529	Ab	Anthropomorphous	Bicephalous	1901	Qtz	Simple Axe	Simple
1531	Jd Ab	Anthropomorphous	Cap	1904	Jd	Simple Axe	Simple
1547	Qtz	Avian shaped	Simple	1925	Jd	Avian shaped	Crest
1552	Qtz	Avian shaped	Simple	1936	Jd	Avian shaped	Tuft
1554	Qtz	Feline	Feline	1942	Jd	Anthropomorphous	Bicephalous
1558	Jd	Chimera	Bicephalous	1950	Jd Omp	Anthropomorphous	Bicephalous
1570	Qtz	Chimera	Crest	1953	Aug Di Omp Zo	Chimera	Crest
1575	Jd	Simple Axe	Simple				
1587	Jd Omp	Avian Shaped	Tuft	1963	Jd	Simple Axe	Simple
1588	Jd Omp	Anthropomorphous	Cap	1978	Jd	Simple Axe	Simple
1613	Jd	Avian Shaped	Crest	1989	Jd	Simple Axe	Simple
1631	Jd	Avian Shaped	Tuft	2004	Jd	Feline	Feline
1637	Qtz	Simple Axe	Simple	2011	Jd	Simple Axe	Simple
1705	Jd	Anthropomorphous	Cap	2015	Jd Omp	Avian shaped	Crest
1709	Jd	Chimera	Crest	2018	Jd Omp	Anthropomorphous	Hat
1710	Jd	Avian shaped	Headdress	2024	Jd	Anthropomorphous	Hat
1711	Jd	Avian shaped	Headdress	2025	Jd	Simple Axe	Simple
1722	Qtz	Chimera	Bicephalous	2058	Qtz	Feline	Feline
1730	Jd Omp	Avian Shaped	Tuft	2059	Qtz	Feline	Feline
1733	Jd Ab	Feline	Feline	2061	Jd	Avian Shaped	Simple
1749	Aug Di Hd	Anthropomorphous	Cap	2079	Jd	Simple Axe	Simple
1753	Qt	Avian shaped	Tuft	2087	Jd	Chimera	Crest
1758	Aug Di Hd	Avian Shaped	Tuft	2101	Qtz	Avian shaped	Headdress
1769	Jd	Avian shaped	Tuft	2105	Qtz	Feline	Feline
1772	Jd	Avian Shaped	Tuft	2106	Jd	Feline	Feline
1788	Jd Ab	Avian shaped	Simple	2109	Qtz	Avian shaped	Simple

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Table I: Summary of spectroscopic results and typological classIfication of the Axe-God pendants (Continuation).

Sample	Minerals [a]	Motif	Head	Sample	Minerals [a]	Motif	Head
2112	Jd	Avian Shaped	Crest	4872	Jd Ab	Avian shaped	Headdress
2113	Qtz	Avian shaped	Tuft	4884	Jd Ab	Anthropomorphous	Cap
2143	Jd Omp	Avian shaped	Simple	5862	Jd Omp	Anthropomorphous	Cap
2167	Aug Di Hd	Avian Shaped	Crest	5881	Qtz	Chimera	Bicephalous
2188	Aug Di Hd	Chimera	Crest	Sample	Minerals a	Motif	Head
2192	Qtz	Simple Axe	Simple	5915	Jd	Feline	Feline
2194	Qtz	Simple Axe	Simple	5916	Zo	Anthropomorphous	Cap
2219	Jd Omp Ab	Anthropomorphous	Simple	5921	Jd Omp Ab	Chimera	Bicephalous
2231	Qtz	Simple Axe	Simple	5926	Jd	Chimera	Bicephalous
2233	Qtz	Simple Axe	Simple	5929	Jd Ab	Avian shaped	Crest
2240	Jd Omp	Simple Axe	Simple	5930	Jd	Avian shaped	Crest
2246	Jd Omp	Simple Axe	Simple	5931	Jd	Avian shaped	Crest
2247	Jd Omp	Simple Axe	Simple	5932	Jd Ab	Chimera	Crest
2248	Jd	Avian shaped	Headdress	5945	Jd	Anthropomorphous	Cap
2250	Act Tr	Simple Axe	Simple	6166	Qtz	Avian Shaped	Crest
2263	Qtz	Simple Axe	Simple	6170	Qtz	Avian shaped	Bicephalous
2267	Qtz	Simple Axe	Simple	6174	Ab	Anthropomorphous	Hat
2275	Qtz	Avian shaped	Tuft	6176	Jd Ab	Chimera	Bicephalous
2289	Jd Omp	Simple Axe	Simple	6185	Jd	Avian shaped	Bicephalous
2290	Qtz	Simple Axe	Simple	6198	Jd	Anthropomorphous	Cap
2297	Qtz	Simple Axe	Simple	6201	Jd	Avian Shaped	Crest
2360	Jd Omp	Simple Axe	Simple	6205	Jd	Anthropomorphous	Bicephalous
2367	Jd Omp	Simple Axe	Simple	6220	Jd	Avian shaped	Headdress
3305	Jd	Anthropomorphous	Cap	6222	Jd	Avian shaped	Headdress
4450	Ab Mc	Anthropomorphous	Bicephalous	6226	Qtz	Avian shaped	Headdress
4451	Jd	Anthropomorphous	Bicephalous	6231	Jd	Chimera	Bicephalous
4455	Jd Omp	Chimera	Crest	6233	Jd Ab	Avian shaped	Simple
4457	Jd	Avian shaped	Bicephalous	6236	Qtz	Avian shaped	Simple
4494	Jd Ab	Avian shaped	Tuft	6240	Jd Omp	Simple Axe	Simple
4508	Jd	Anthropomorphous	Hat	6242	Jd	Avian shaped	Crest
4594	Act Tr	Anthropomorphous	Hat	6254	Jd	Simple Axe	Simple

Table I: Summary of spectroscopic results and typological classIfication of the Axe-God pendants (Continuation).

Sample	Minerals [a]	Motif	Head	Sample	Minerals [a]	Motif	Head
6263	Jd	Simple Axe	Simple	6611	Jd Omp	Anthropomorphous	Hat
6302	Jd Omp	Simple Axe	Simple	6636	Jd	Avian shaped	Headdress
6315	Jd Omp	Simple Axe	Simple	6640	Jd	Anthropomorphous	Hat
6319	Jd	Simple Axe	Simple	6642	Jd	Anthropomorphous	Bicephalous
6321	Qtz	Feline	Feline	6646	Jd	Anthropomorphous	Cap
6322	Qtz	Anthropomorphous	Cap	6649	Jd	Anthropomorphous	Hat
6363	Jd	Simple Axe	Simple	6650	Jd	Avian Shaped	Tuft
6372	Jd	Anthropomorphous	Cap	6651	Prg	Avian shaped	Headdress
6431	Jd Omp	Anthropomorphous	Cap	6666	Jd	Feline	Feline
6432	Jd	Anthropomorphous	Bicephalous	6667	Jd Omp	Chimera	Bicephalous
6433	Jd Ab	Avian shaped	Bicephalous	6674	Jd Ab	Anthropomorphous	Cap
6436	Jd Ab	Chimera	Crest	6675	Jd Omp	Anthropomorphous	Cap
6443	Jd	Anthropomorphous	Cap	6680	Jd	Anthropomorphous	Cap
6445	Jd	Avian shaped	Crest	6681	Jd	Anthropomorphous	Simple
6449	Jd	Anthropomorphous	Cap	6683	Jd	Anthropomorphous	Cap
6453	Jd Omp	Avian shaped	Bicephalous	6685	Jd	Feline	Feline
6454	Jd	Anthropomorphous	Bicephalous	6686	Jd	Anthropomorphous	Hat
6459	Jd Omp	Anthropomorphous	Cap	6689	Jd	Anthropomorphous	Bicephalous
6468	Jd	Avian shaped	Simple	6690	Jd	Anthropomorphous	Hat
6469	Jd Ab	Chimera	Crest	6695	Jd Omp	Anthropomorphous	Hat
6470	Ab	Avian Shaped	Tuft	6696	Jd Ab	Avian shaped	Crest
6473	Jd	Anthropomorphous	Cap	6698	Jd	Avian shaped	Crest
6480	Jd	Anthropomorphous	Cap	6699	Jd	Avian shaped	Crest
6483	Ab	Avian shaped	Bicephalous	6700	Jd	Chimera	Crest
6484	Jd	Avian shaped	Tuft	6701	Jd	Chimera	Bicephalous
6496	Ab	Chimera	Crest	6703	Omp	Chimera	Bicephalous
6507	Jd	Avian shaped	Headdress	6706	Jd	Anthropomorphous	Cap
6601	Jd	Anthropomorphous	Simple	6708	Jd	Anthropomorphous	Hat
6605	Jd	Anthropomorphous	Bicephalous	6721	Jd	Anthropomorphous	Cap
6607	Jd	Anthropomorphous	Bicephalous	6733	Jd	Simple Axe	Simple
6608	Jd	Anthropomorphous	Simple	6736	Jd	Anthropomorphous	Cap

Table I: Summary of spectroscopic results and typological classIfication of the Axe-God pendants (Continuation).

Sample	Minerals [a]	Motif	Head	Sample	Minerals [a]	Motif	Head
6739	Jd	Feline	Feline	6820	Jd Omp	Chimera	Crest
6747	Jd	Anthropomorphous	Bicephalous	6855	Jd	Anthropomorphous	Hat
6754	Jd	Anthropomorphous	Hat	6856	Jd Omp	Anthropomorphous	Cap
6762	Jd	Avian shaped	Headdress	6857	Jd	Anthropomorphous	Simple
6769	Jd	Anthropomorphous	Simple	6860	Jd Omp	Anthropomorphous	Simple
6777	Jd Omp	Anthropomorphous	Cap	6871	Jd	Anthropomorphous	Cap
6778	Jd	Anthropomorphous	Bicephalous	6873	Jd Omp	Anthropomorphous	Hat
6786	Jd	Avian shaped	Bicephalous	6876	Jd	Avian shaped	Tuft
6788	Jd	Anthropomorphous	Cap	6881	Jd	Anthropomorphous	Cap
6789	Jd	Anthropomorphous	Cap	6882	Jd	Anthropomorphous	Cap
6791	Jd	Avian shaped	Bicephalous	6884	Qtz	Anthropomorphous	Hat
6795	Jd	Avian shaped	Headdress	6907	Jd	Simple Axe	Simple
6801	Jd Ab	Avian shaped	Tuft	6920	Jd	Anthropomorphous	Hat
6803	Jd Omp	Anthropomorphous	Simple	6941	Prg	Anthropomorphous	Cap
6808	Act Tr	Anthropomorphous	Simple				

[a] Act, actinolite; Ab, albite; Aug, augite; Jd, jadeite; Omp, omphacite; Prg, paragonite; Qtz, Quartz; Tr, tremolite; Zo, zoisite.

Conclusions

Overall, 12 different minerals were identified using non-invasive FT-IR spectroscopy. The results show that jadeite and its associated minerals were the most frequent material used for this distinct pendant design, these foreign minerals were present in around 74% of the artifacts. Other geologically more abundant minerals (such as quartz, serpentine and tremolite-actinolite) were identified as well. The artifacts were classified among the five motif categories (anthropomorphous, avian shaped, simple, chimera and feline) previously reported in literature, with the anthropomorphous motif being the most numerous group and feline the least frequent motif. These findings suggest that the Axe-God pendants' design is not directly related to the type of rock used as raw material. Further research will focus on artifacts that were recovered following the scientific method, in order to examine the possible correlation between the archaeological context and raw material employed, researching the use of both local and foreign geomaterials.

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