Assessing Systematic Bias in Museum Collections

A Case Study of Spindle Whorls

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ABSTRACT

Archaeologists often overlook museum collections for research purposes due to concerns about the representativeness of the artifacts in the collection. Such concerns can be addressed by comparing non-scientifically produced collections to collections of known standing, such as those from more modern projects, using the same exploratory data analysis and basic statistical methods that archaeologists use to compare sets of artifacts in other situations. As a case study, this article compares spindle whorls recovered during the 2007 excavations at the Aztec site of Calixtlahuaca with two museum collections of whorls attributed to the site. A variety of metric and non-metric traits were recorded for each item in the three collections and were compared using Kolmogrov-Smirnov, Chi-square, and Fisher's exact tests. Both museum collections show a bias toward more elaborately decorated pieces, but with varying side effects on other attributes of analytical interest.

Muchas veces, los arqueólogos evitan usar las colecciones de museos porque dudan que los artefactos de la colección sean una muestra representativa. Estas dudas se pueden por medio de comparaciones entre las colecciones de museo y las mejor documentadas, usualmente de excavaciones más modernas. Se pueden aplicar los mismos métodos de comparación que los arqueólogos usan para comparar grupos de artefactos en otras situaciones—las exploraciones preliminares de información y las pruebas estadísticas. Como un caso ejemplar, comparo los malacates (husos de volar) recuperados en las excavaciones del sito azteca de Calixtlahuaca en 2007 con dos colecciones de museo atribuidas al sitio. Anoté una variedad de características métricas y no-métricas para cada pieza en las tres colecciones y las comparé por medio de los pruebas Kolmogrov-Smirnov, Chi-cuadrado, and prueba de Fisher's. Ambas colecciones de museo tienen piezas más decoradas, pero los efectos secundarios en la distribución de otros atributos varían entre las colecciones.

Dirt archaeologists have a love-hate relationship with museum collections. On one hand, they offer us an embarrassment of riches—whole vessels, unique items, and large comparative sets of uncommon artifact types. On the other hand, many of these collections result from non-scientific collections practices, ranging from the common archaeological practices of prior eras to outright looting. They have entered museum contexts as private donations, piecemeal acquisitions, or exchanges with other institutions. Since entering the museum context, portions of collections may have been culled and deaccessioned, exchanged or loaned to other institutions, or lost to the ravages of time. The frequent lack of background information for these artifacts leaves archaeologists contemplating what to do with them.

An archaeologist's primary research goal is to understand past patterns of behavior. In field research contexts, this involves taking into account formation processes, post-depositional processes, and the limits of the sampling strategy used. Archaeologists do this with varying degrees of success, but the conversation about bias in field contexts is well acknowledged. The analysis of museum collections adds at least one, if not more, levels of human behavior to the patterning of material culture. As a result, the use of museum collections to investigate ancient human behavior requires an additional level of consideration of the effects of much more recent human actions. Unfortunately, the archaeologist's reaction is often one of two extremes—either to ignore the possibility of collection bias, or to ignore the collection because of the possibility of bias.

https://doi.org/10.7183/2326-3768.1.2.77 Published online by Cambridge University Press

This article provides a method to address the issues created by the often unknown specific source contexts and recovery conditions of museum collections through the comparison of collections to identify systematic biases. This discussion pertains primarily to cases where museum collections are likely to have large quantities of a single artifact class, such as projectile points or figurines. Such artifact classes usually encompass enough variation that they are more useful analytically to archaeologists as sets, where the range and distribution of variation can be established.

ARCHAEOLOGISTS AND MUSEUMS

Archaeologists and other anthropologists have a long history of working for and with museum institutions, with many of the founders of the profession working for museums (Rothschild and Cantwell 1981). The study of material culture, in the form of artifacts collected for and curated in museums, has historically provided a unifying force between archaeology and cultural anthropology (Miller 1994). Museums remain one of the primary repositories of archaeological artifacts. This longstanding relationship is enshrined in the Society for American Archaeology Principles of Archaeological Ethics—specifically, in the principles of Stewardship and Records and Preservation—which advocate the use of museum collections in archaeological research (Society for American Archaeology Ethics in Archaeology Committee 1996). More broadly, some scholars have begun to question whether continued excavation is ethical in cases where there are existing unanalyzed or under-analyzed collections that could be used to address the same research questions (Barker 2003). At the same time, the use of museum collections may need to be tempered by concerns about working with looted artifacts, or publishing data on artifacts that may result in increased looting (Wylie 1995, 1996).

During the last century, however, the primary locus of archaeological research has shifted from museums to academia (Barker 2010). This shift was accompanied by a reduction of museum collections-based research in modern archaeology. In 2011 and 2012, only 4 of 54 articles and reports in *Latin American Antiquity* (Castiñeira et al. 2011; Ostapkowicz and Newsom 2012; Scott 2011; Tarkanian and Hosler 2011) and 1 of 68 articles (not including replies) in *American Antiquity* (Taylor and Creel 2012) used museum collections as one of their primary datasets. It is possible that some additional articles may be based on the products of more recent excavations where the entire excavated collection is currently housed in a museum facility, but such cases were not identifiable from the articles themselves. All of the identified museum-based articles featured analyses of unique or uncommon artifacts. The majority of these articles featured archaeometric analyses. The focus on rare artifact classes masks the variability of museum collections and the focus on archaeometric techniques obscures the range of research opportunities in such collections.

Types of Collections and Types of Analysis

People create collections for a variety of reasons, tempered by cultural conventions and personal preferences (Pearce 1995). A collection, archaeological or otherwise, may have multiple meanings to different groups, both in the past and the present (Pearce 1994b). Even what is considered an artifact may change over time (Pearce 1994a). As a result, museum collections of archaeological materials are highly variable, and Pearce (1997) offers a useful classificatory scheme:

> [There are] six distinct kinds of objects comprising archaeological collections in museums: (a) chance finds, usually received as single pieces or small groups and generally lacking meaningful documentation; (b) private collections amassed by individuals, with or without accompanying documentation; (c) material from museum-based excavation projects, usually accompanied by complete documentation; (d) material from excavations by other bodies or institutions, with the level of accompanying documentation varying by age and quality of excavation; (e) materials accepted from fieldwork or cultural resources management (CRM) projects, often through curation agreements, which should in general be accompanied by levels of documentation specified in the curation agreement; and (f) material from metal detectorists, a category more commonly separable in British museums than elsewhere (Barker 2010:299).

Collections can also be organized by the type of research that they allow. Archaeological museum collections tend to be used in three ways: (1) as a source of artifacts for new methods of technical analysis, (2) as examples of rare or unique items, and (3) for assemblage or collection-level studies of the same classes of variables studied in field project contexts.

The first category is a natural match for museum collections. Studies involving archaeometric techniques, such as neutron activation analysis (NAA), thin-section petrography, or particle-induced X-ray emission (PIXE) usually feature a relatively small number of items from relatively wide temporal or spatial spans. As a result, even site or regional level proveniences are analytically sufficient for many such analyses. The artifacts featured in this category often fall into the second category as well, featuring relatively rare artifact classes perceived as valuable, such as metal, shell, or precious stones.

The second category is rare or unique items. These can be useful archaeologically both because they provide examples of material culture that may not otherwise survive in the archaeological record and because the descriptive publication of such items allows for the identification of otherwise mysterious artifact fragments in the field (Smith 2004). Publication in this category is divided between museum catalogs and descriptive analyses (e.g. Ostapkowicz and Newsom 2012). While publications in this category are rare relative to the amount of potential material, they do occur on a regular basis.

The third category is the analysis of some larger set of artifacts held in a museum collection as a cohesive unit. These types of analyses rarely occur, often due to concerns about the representativeness of the collection as a sample. This should not be an automatic reaction, as collections falling into Pearce's categories (c), (e), and sometimes (d) may have enough documentation to establish the representativeness of the collection without further analysis. Collections falling into category (b) and older examples of (d) are likely to require some demonstration that the collec-

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tion in question is not highly biased in some manner, but if a lack of significant bias can be established, even these types of collections may be useful as collective units.

The most productive artifact classes for this type of evaluation of bias and subsequent analysis will be those that are both more analytically useful in large numbers and likely to occur in collections in the requisite quantities. For many artifact classes, the range and distribution of variation—such as projectile point length or bowl rim diameter—is more important than the characteristics of any single artifact. In many cases, museum collections are more likely to preserve large numbers of specimens with measureable attributes of interest, due to their focus on whole or otherwise well preserved examples. This becomes of particular value for artifact classes that are less than common in modern excavated contexts, as many modern excavations will be too small to recover an adequate sample size to establish patterns of variation.

Examples of Comparisons

In the limited number of established case studies, the most common method for establishing the relative lack of bias in a museum collection is via comparison with a collection of known standing, usually from more recent fieldwork. This is a useful method for identifying potential biases introduced both before museum acquisition (such as the preferences of a private collector) and after museum acquisition (such as the loss of particular portions of a collection).

Comparisons can take place at a number of levels, including classes of artifacts within a collection, types within an artifact class, and particular attributes within a type. In the analysis of a poorly documented salvage excavation of the San Jose Market Street Chinatown, Voss (2012) compared the surviving collection with both the types and frequencies of classes of artifacts found in the excavations of other Chinatowns in the Bay Area. The presence of all major classes of artifacts in broadly similar proportions to similar sites allowed research on the San Jose collection to proceed under the assumption that the assemblage had not been heavily affected by the recovery techniques used.

Straddling the line between vessel form and type, Smith et al. (2003) compare the frequency of major functional vessel categories in multiple collections produced by the 1937 excavations of the Aztec Volador deposit with vessel form frequencies from known domestic and imperial ritual contexts. They determined that the Volador ceramics were not consistent with previous interpretations that the deposit resulted from the New Fire ceremony.

More specifically, Kintigh (1981) uses the frequency of ceramic types as his unit of comparision in evaluating bias accumulated during a collection's museum history. He calculated the current frequency of particular ceramic types in Spier's 1916 southwestern surface collections (Spier 1917). He then compared the results with both modern surface collections from a subset of the same sites, and with historic classifications of the museum collections. Both comparisons demonstrate that the historic collections owed their apparent paucity of decorated material to the conservation of plainware sherds in the collections, rather than the systematic loss of decorated sherds.

Goetze and Mills (1991) compare the Babbitt Collection, a turn of the century private collection of southwestern ceramic vessels now held by the Northern Arizona State Museum, with more recent excavated assemblages from similar regional and temporal contexts. They examine both the frequencies of types and the distribution of rim diameters within specific types. They find that the Babbitt collection can be considered a reasonable sample of bowl types, but that the size distributions of some types does not appear to be representative, as compared to excavated collections.

In all four examples, the museum and control cases were compared using the same basic methods—exploratory data analysis, such as stem-and-leaf plots, and basic statistical tests, such as Fisher's exact or Kolmogrov-Smirnov tests—that archaeologists use to compare sets of artifacts in other situations. These cases demonstrate that the evaluation of bias in museum collections does not require specialized analytical methods, and it should not be seen as a barrier to the use of such collections in archaeological research.

CASE STUDY

Mesoamerican spindle whorls, small clay weights used for hand-spinning thread (Figure 1), fall precisely into the class of medium-to-low frequency artifacts likely to benefit from the study of museum collections. Spindle whorls are more informative in large quantities. There will be a range of sizes, shapes, and ornamentation among the whorls from any given archaeological site, making any individual whorl of limited utility in addressing archaeological questions. In contrast, both the range and distribution of variables among a group of whorls provides significantly more information on local technologies, craft production, and trade. Whorls have been used to investigate a wide range of topics, including the organization of craft production (Ardren et al. 2010; Nichols et al. 2000; Otis Charlton et al. 1993), the effects of political change (Fauman-Fichman 1999; Levine 2011), and gender identity and ideology (Brumfiel 2001; Lugo Ramírez and Hernández Rivero 2008; McCafferty and McCafferty 1994). Whorl size, shape, decoration, and excavated frequency have all been subject to study. Whorls are relatively uncommon items in excavations, occurring at frequencies of 1–3 whorls per 1,000 ceramic sherds in Postclassic Central Mexico (King 2011), requiring a fairly large archaeological project to recover an analytically useful sample (approximately greater than 40). This issue of adequate sample size is further aggravated by the fact that excavated whorls are often fragmented or eroded, and thus not all attributes of interest can be recorded for all pieces. At the same time, large collections of spindle whorls are not uncommon in museum collections. This is likely because they are frequently decorated, generally found as whole pieces, and appear exotic to modern observers because they do not have an obvious function. Because of their larger than average sample size and the good condition of the artifacts, museum collections have the potential to provide large comparative datasets if the provenience and representativeness of a collection can be established. The over-representation of whorls relative to many other artifact types is not limited to museum collections. When I am shown local families' collections of artifacts in the Mexican villages where I work, whorls are the single most common type of artifact featured. Despite this ubiquity of spindle whorls in

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FIGURE 1. Examples of spindle whorls used for spinning maguey (back two rows) and cotton (front left) (photograph by Calixtlahuaca Archaeological Project).

museum collections, Mesoamerican archaeological analyses of the artifacts draw almost exclusively on assemblages produced by survey or excavation projects.

Mesoamerican Textiles

Textiles have a long history in Mesoamerica, with spun cotton thread dating back to at least 1200 B.C. (MacNeish et al. 1967). The technology involved in textile production remained stable over time, with hand-held spindles used to spin thread, which was then woven into cloth on a backstrap loom (Brumfiel 2006). Woven cloth might then be embroidered, dyed, or stamped with designs. Because the majority of the items used in textile production were made of organic materials, the most common surviving archaeological indicators of textile production are spindle whorls. While ceramic spindle whorls do not become widespread until the beginning of the Postclassic period around A.D. 900, murals, figurines, and the occasional preserved piece of cloth attest to cloth production long before this period, probably using whorls made of organic materials (Brumfiel 2006; Follensbee 2008; Stark et al. 1998). Cloth production was both ideologically and economically significant. Spinning and weaving were linked to both status and female gender identity. Lengths of cloth were also used as a standardized medium of exchange, both for the payment of taxes and in marketplace exchange (Brumfiel 1997).

From the beginning of the Middle Postclassic period until the Spanish conquest (A.D. 1100–1521), Central Mexico consisted of a mosaic of city-states. Over the course of the period, the city-states were increasingly consolidated into a series of progressively larger confederations, states, and mini-empires. This process of centralization culminated in A.D. 1328, with the beginning of the Aztec Empire. Within a hundred years, the empire controlled most of the central highlands and had begun expanding across the remainder of Mesoamerica. The entire period is characterized by the presence of strong local and regional market systems, which the Aztec Empire continued to promote in an effort to increase tax revenue. Textiles, in a variety of designs, circulated widely through the market system.

There are certain technical constraints in the design of whorls. Their size, or more specifically their weight, is closely related to the length of the fiber being spun and how tight of a twist it requires (Tiedemann and Jakes 2006). In particular, there is a strong bimodal weight distribution in Mesoamerican archaeological whorls, which has been ethnographically demonstrated to correspond to the type of fiber being spun (Figure 1). Whorls used for cotton, a short fiber, weigh less than 12 g, while those used for agave, a long fiber, usually weigh 20–60 g (Huster 2008; McCafferty and McCafferty 2000; Parsons 1972). After the Spanish introduction of sheep, the larger whorls were also used to spin wool, which is also a long fiber. Within the whorl weight range for any given fiber, the lighter whorls will produce finer thread (Parsons and Parsons 1990:316). On the other hand, the shape and decoration of a whorl appear to have no effect on its function, and whorl shape and the method, placement, and elaborateness of decoration vary geographically across Mesoamerica.

Field Site

This article features artifacts from the site of Calixtlahuaca, a large city-state capital conquered by the Aztec Empire in the

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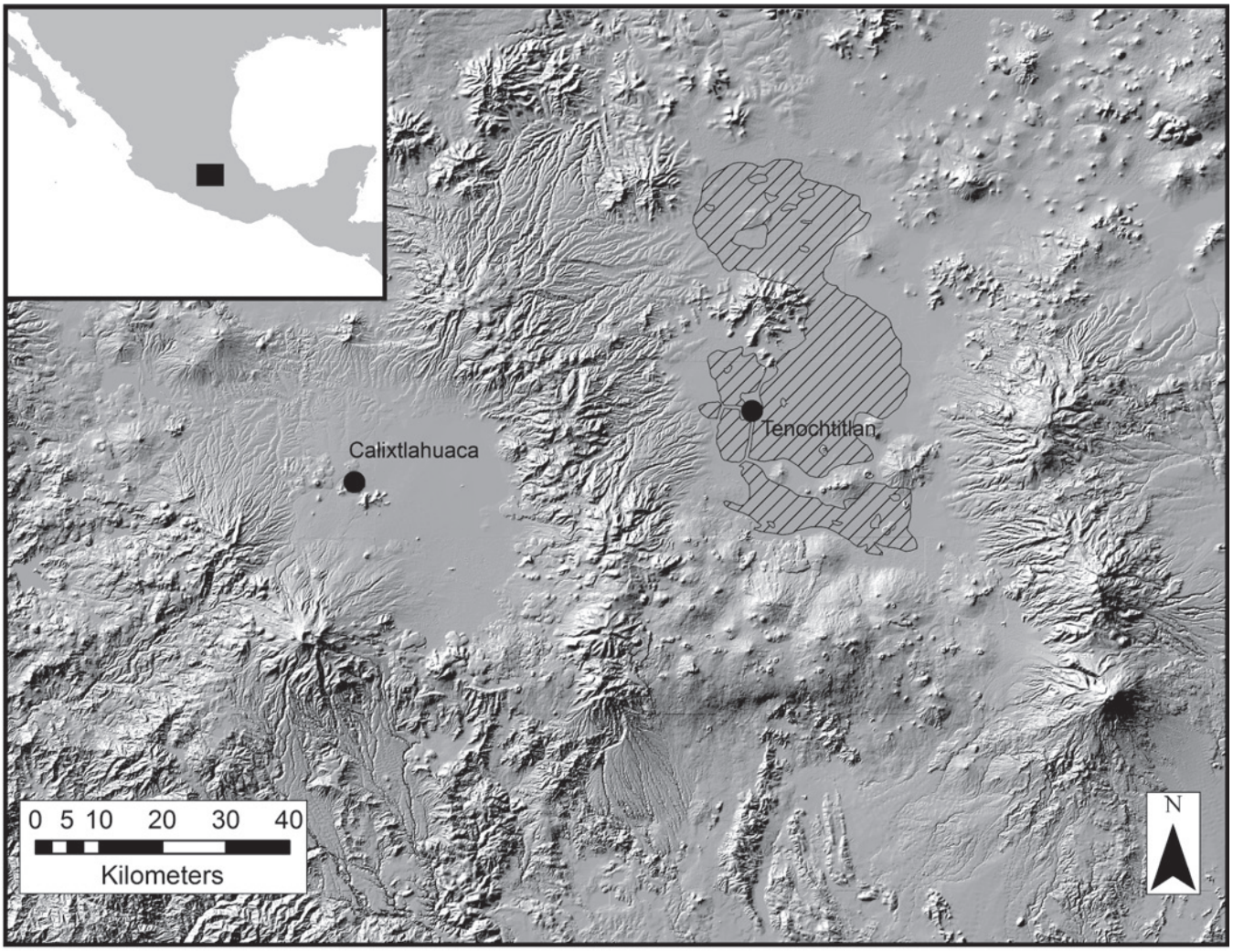


FIGURE 2. Location of Calixtlahuaca within Mesoamerica.

late 1470s (Figures 2, 3). The site is located about an hour west of modern Mexico City. It was continuously occupied from approximately A.D. 1100 to A.D. 1530 and covered around 264 ha at its maximum extent (Smith et al. 2013). Early Spanish documentation clearly identifies the site as the dominant city-state within the Toluca Valley prior to the region's conquest by the Aztec Empire (Tomaszewski and Smith 2011). Reconstructions of linguistic distributions suggest that the site was located in an area of overlap between Otomi, Mazahua, and Matlatzinca speakers (García Castro 1999). Following the Aztec conquest, local ethnic groups were joined by Nahua-speaking immigrants from the heart of the Aztec Empire, adding further diversity to an already multiethnic city.

The site was abandoned within a decade of the 1520s Spanish conquest of the area, probably due the Spanish policy of consolidating native communities that had been decimated by disease. This abandonment meant that the elaborate terrace system covering much of the site collapsed, triggering large-scale erosion. In 1561, the modern village of San Francisco Calixtlahuaca was (re)founded by decree of the Viceroy, with the new community located immediately adjacent to the remains of the archaeological city. Likely due to land pressure from surrounding haciendas (Spanish-descendent controlled estates), villagers re-terraced much of the hill during the 1800s. The process of erosion and re-terracing likely brought large quantities of artifacts to the surface, and by the late 1800s, the site was a regular destination on the antiquities-collecting circuit.

Formal archaeological work at the site began in the 1930s. Jose García Payón, a noted Mexican archaeologist, excavated the site's palace (which he mistakenly identified as a *calmecac*, or a school for male nobility), a round pyramid, and several other groups of monumental architecture. The plazas in front of these groups included large numbers of burials. Unfortunately, while García Payón published a first volume of general background on the region (García Payón 1936) and several articles (García Payón 1941a, 1941b, 1956/1957), he never published a full report of his excavations. During the 1970s, his notes were used to publish one additional volume (García Payón 1979), but the third volume with accompanying illustrations was abandoned after the project editor's death. Recent attempts to locate the original excavation notes and the third volume manuscript in various Mexican local, state, and federal archives have been unsuccessful (Smith 2003).

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FIGURE 3. The archaeological site of Calixtlahuaca, viewed from the east (photograph by Calixtlahuaca Archaeological Project).

Starting in 2006, the Calixtlahuaca Archaeological Project began modern archaeological investigations at the site. The project surveyed the site to determine the extent and intensity of occupation. Survey was followed by six months of excavation of terraces and commoners' houses across the site, providing a large sample of artifacts from well-documented domestic contexts spanning the occupation of the site (Smith et al. 2013; Smith et al. 2009). In the process of analyzing the fiber-processing artifacts produced by the excavations, I began looking for comparative collections. The lack of other modern archaeological work on contemporaneous sites in the region led me to two museum collections of whorls from Calixtlahuaca.

The Collections

The histories of the three sets of spindle whorls used in this study mirror the history of interest in the site itself. The recent Calixtlahuaca Archaeological Project excavations of domestic contexts at the site provide the first sample. This sample consists of 176 spindle whorls. The proveniences and contexts for these whorls are known, and the screening of excavated soil insured that whorls were recovered regardless of size. However, as a result of being recovered from midden and terrace fill contexts, the artifacts are generally fragmented and in eroded condition, making a detailed descriptive analysis difficult.

The second collection is held at the Museo de Antropología e Historia in Toluca, Mexico. It consists of 185 whorls, most of which have only minor chipping and all of which have at least two-thirds of the original piece. Based on the records available, this collection consists primarily of the materials excavated at Calixtlahuaca by Jose García Payón in the 1930s. However, no provenience information below the site level is available and, as noted above, efforts to locate García Payón's excavation notes have been unsuccessful (Smith 2003). If the whorls are from the earlier excavation at the site, they likely come from ritual and elite contexts, given that García Payón excavated the palace, a possible elite residence, and several temple groups. Based on the number of burials that he excavated, and the grave goods characteristic of other sites in the Toluca Valley (Reinhold 1981; Tommasi de Magrelli 1978), it is also very probable that a high percentage of the whorls in the museum collection came from mortuary contexts.

The third collection is located at the Yale Peabody Museum of Natural History. It was part of a larger donation of small Mesoamerican artifacts to the museum in 1946 by Mr. and Mrs. Ledyard Cogswell, who identified the pieces as having been collected and previously owned by Mr. Benjamin Walworth Arnold. Mr. Arnold was a prominent New York industrialist who died in 1932, so the collection must predate this. The spindle whorls I examined were identified as being from Calixtlahuaca at the time of donation, but no more detailed provenience information was available. Given this collection's provenance, it is likely a product of antiquities collecting at Calixtlahuaca during the late 1800s or early 1900s. This collection consists of 310 whorls, most of which show only minor chipping around the edges.

Hypotheses

The goal of this case study is to determine what aspects of the museum collections can reasonably be used to draw conclusions about the behavior of the ancient occupants of Calixtlahuaca, and which are more likely to provide information about more modern collecting behaviors. The excavated collection is presumed to be a near-representative sample of the pattern produced by ancient behavior, while the two museum collections may have been subject to other selection processes. I hypothesize two potential causes of bias in the museum collections. First, the whorls, particularly in the modern excavated collection and the Centro Cultural Mexiquense collection, may have been recovered from different types of contexts within the site. As a result, a certain amount of variation in collections may be due to differences in the source populations of the samples, such as an elite preference for non-local styles of whorls. If this is the case, I expect the most variation to occur between the modern excavated and Centro Cultural Mexiquense collections, with the Yale Peabody results representing an intermediate mixture of contexts.

Second, non-scientific artifact collecting practices, particularly in the Yale Peabody collection, may be biased toward larger, more ornately decorated pieces. There is a pronounced size difference between cotton and maguey spindle whorls, which means that the latter are more likely to be (a) seen at all and (b) ornately decorated and thus sold to collectors. I address the issue of size-related recovery rates by analyzing cotton and maguey whorls

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TABLE 1. Whorl Variables Analyzed.

	Category	Description
Shape	Non-metric	The general cross section of the whorl. For cotton, described as Truncated Conical, Flat Disk, Flattened Hemisphere, Hemisphere, Cone, Composite, or Unknown. For Maguey, described as Hemispherical, Conical, Truncated Conical, Disk, or Other.
Type of decoration	Non-metric	The general method of decoration. Described as (0) Eroded, (1) Plain, (2) Simple Hand-decorated, (3) Simple Molded, (4) Complex Hand-decorated, (5) Complex Molded, (6) Punctate, (7) Stamped, (8) High-relief Molded, and (9) Other
Height/ diameter ratio	Metric	The maximum original height of the whorl divided by the maximum original diameter of the whorl. This provides a metric approximation of whorl shape, particularly for cotton whorls.
Calibrated weight	Metric	The original weight of the whorl, if necessary reconstructed from the observed weight and percent of the whorl present.

separately. I address the issue of aesthetic bias by collectors by independently comparing weight, height/diameter ratio, shape, and elaborateness of decoration. Of these four variables, the decoration and shape are likely to be subject to aesthetic bias in selection, while the weight and height/diameter ratio are less likely to be subject to collecting biases. If an aesthetic bias is present I expect the distribution of the latter traits to be similar to the distribution in the excavated material, while those traits with a clear visual component differ more dramatically.

METHODS

For each whorl in the three collections, I produced four attributes for analysis: calibrated weight (observed weight/percentage of whorl present), height/diameter ratio, profile shape, and method of decoration. (See Table 1 for variable lists and Figures 4 and 5 for illustrations of the more common non-metric variables.) The first two attributes are referred to as metric traits, and the latter two as non-metric traits in the following discussion. Height, diameter, hole diameter, and decorative motif were also recorded, but are not analyzed here due to their high correlations with one or more of the previous variables. For the excavated whorls, typically one or more attributes could not be recorded due to the condition of the artifacts.

The first step of analysis consisted of basic exploratory data analysis. For metric variables, I generated histograms and box plots showing the distribution of each variable in each collection. For non-metric variables, I generated graphs showing the frequency of each potential attribute state. Due to the number of variables, only a selection of the resulting figures is included in the analysis sections below.

I next compared the distribution of these attributes of the whorls within each of the assemblages using Kolmogorov-Smirnov, Chi-square, and Fisher's exact tests to establish the degree of similarity between the collections. Within archaeology, tests of independence are usually used to measure the probability of a given set of similarities occurring due to random chance, most commonly with a significance level of .05. In such cases, archaeologists are usually seeking a very low *p*-value, indicating that the data sets being compared are distinct enough that it is unlikely that the observed differences are due to chance. However, *p*-values can also be looked at the other way around, as measures of the similarity between two collections. From this perspective, higher *p*-values indicate more similar collections. While any specific *p* value may or may not indicate an emic perception of difference, they do provide a measure of relative degree of similarity. Chi-square and Fisher's exact tests are based on the standard deviation from the expected values and can be used with categorical data, while the Kolmogorov-Smirnov test is based on the sum difference of two distributions and is limited to metric data. All analyses were run using MYSTAT software. The Chi-square and Fisher's exact test values were calculated pair-by-pair, while the Kolmogorov-Smirnov algorithm allows for multiple simultaneous comparisons.

Analysis of Cotton Whorls

Analysis of the cotton whorls (< 12 g) consists of two stages, an initial round of exploratory data analysis to identify general trends, followed by more rigorous statistical testing of the observed trends. Exploratory data analysis of the cotton whorls in the three collections suggests that the metric attributes of the three collections are reasonably similar (Figure 6A). The weight distributions for all three collections show a single peak, with the means and medians of the three collections both falling within 1.25 g of each other. Given that the scale used measured only to the nearest gram, this is within an expected level of error. If there is a bias, it is that the museum collections favor slightly larger cotton whorls.

In contrast, when examining types of decoration, the Peabody collection diverges sharply from the other two collections, with a much lower frequency of plain (undecorated) whorls (Figure 6B). As 43 percent of the Peabody cotton whorls are decorated, as opposed to 17 percent of the excavated whorls and 24 percent of the Toluca whorls, this suggests that the Peabody cotton whorls are biased in favor of decorated items.

When these initial observations are tested using various statistical measures, the whorls in the three collections show a relatively low degree of similarity across all attributes, both metric and non-metric (Table 2). Five of the original 12 pairwise comparisons have *p* values less than .05, and an additional two have *p* values less than .10, suggesting that in many aspects, the collections are significantly different. The values showing significant differences are scattered between variables and pairs of collections, showing a complex pattern of similarity and difference rather than consistent patterning across multiple variables.

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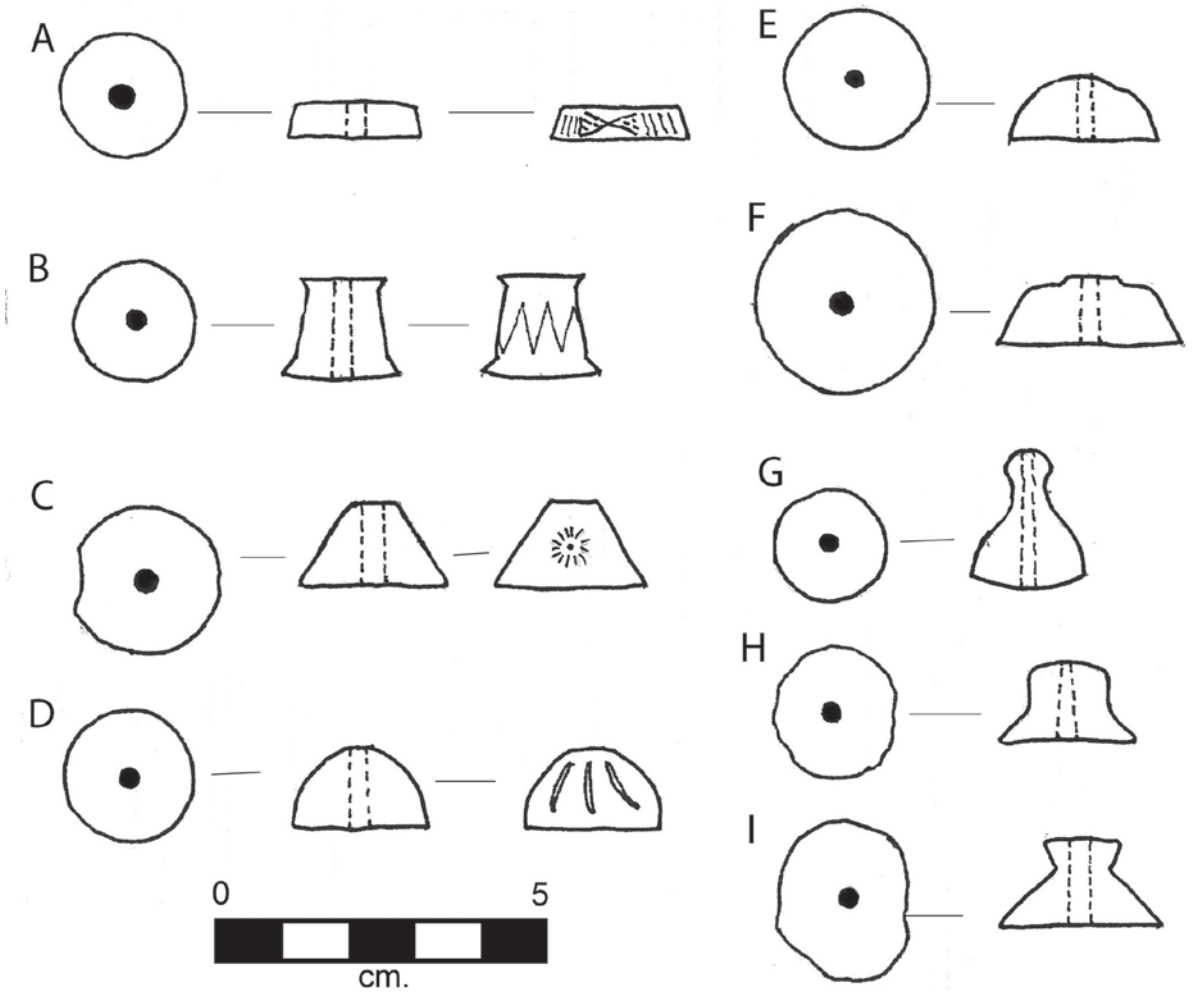


FIGURE 4. Cotton whorls from the Calixtlahuaca Archaeological Project excavations showing variation in decoration and shape. Decoration: (a-d) decorated; (e-i) plain/eroded. Shapes: (a) disk; (c) cone; (d, e) hemisphere; (f) truncated cone; (g-i) composite.

The form ratio (metric) and shape (non-metric) variables show the same pattern, though the overall degree of similarity between collections is much stronger for the form ratio. For these two variables, the excavated and Peabody collections are the most similar, while all other pairs of collections are significantly different. These two variables are related, as particular shapes of cotton whorls tend to have form ratios within set ranges. As a result, the similarity in results between the two variables is not unexpected, even though it does break down the distinction between metric and non-metric traits established in the hypotheses.

The Kolmogrov-Smirnov tests of the remaining metric trait, weight, show a distinctly different pattern. The excavated and Peabody collections are significantly different, while the Toluca collection is not significantly different from either of the other collections. This suggests that the Toluca collection is intermediate between the excavated and Peabody collections, sharing some aspects of its weight distribution with each.

For decoration, statistical testing supports the pattern observed during exploratory data analysis. Based on a Fisher's Exact Test, the frequency of decorated whorls in the Peabody collection is significantly different from either of the other two collections. In contrast, the frequency of decorated whorls in the Toluca collection is quite similar to the excavated material (p = .45). This pattern is weaker in the Chi-square tests of the occurrences of particular types of decoration, though the excavated and Peabody collections remain the most dissimilar.

In summary, the cotton whorls in the museum collections show a bias toward decorated items and slightly larger pieces. These trends are more pronounced in the Peabody collection. This bias did not produce consistent results with the other two variables.

Analysis of Maguey Whorls

The maguey whorls (> 20 g) show a more similar pattern of variation between the collections as the cotton whorls. The initial look at the maguey whorls suggests that there are distinct patterns of difference in weight distribution and decorative types between the collections (Figure 7A). Each of the three collections has a different peak in its weight distribution, with the excavated whorls having the highest peak, followed by the

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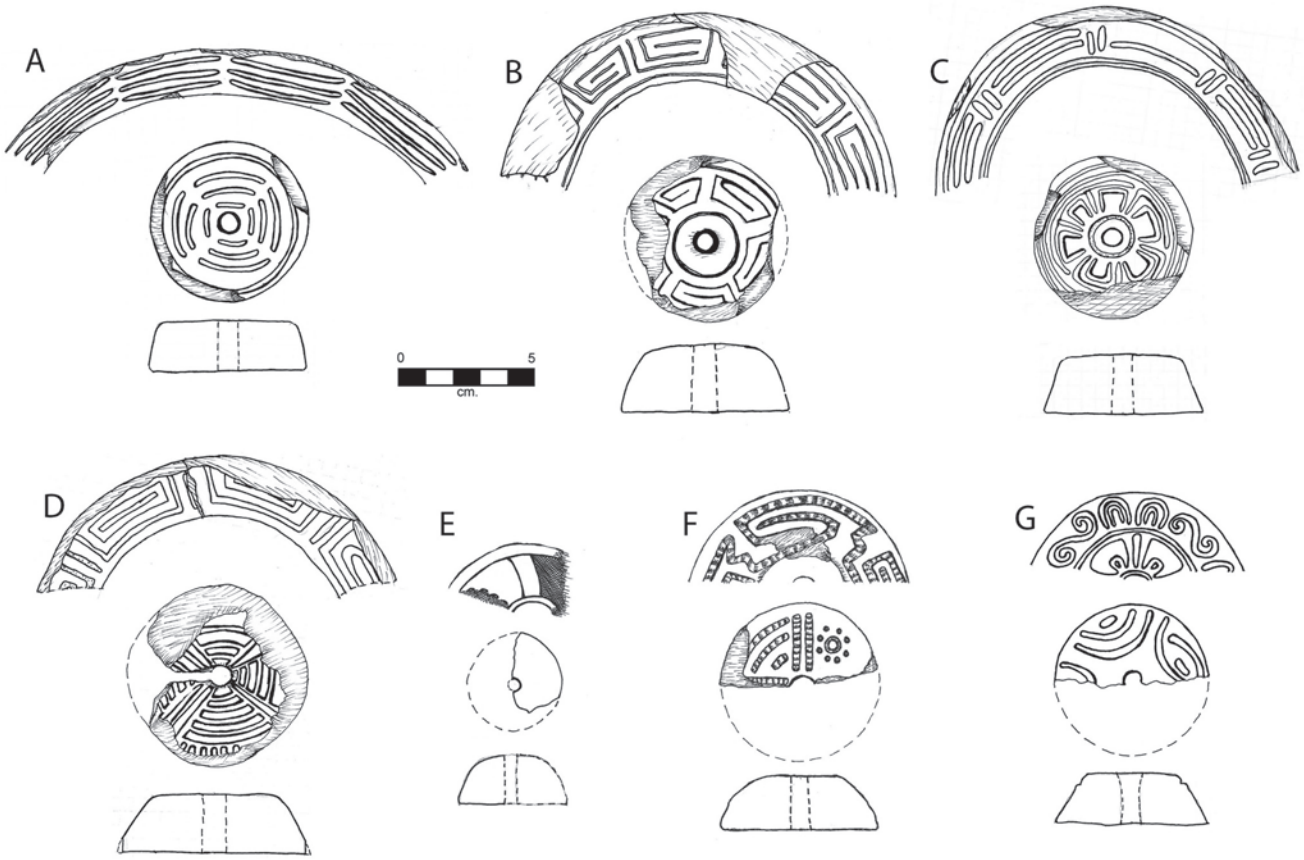


FIGURE 5. Maguey whorls from the Calixtlahuaca Archaeological Project showing variation in shape and decoration. Shapes: (a-d, g) truncated cone; (e, f) hemisphere. Decoration: (a) simple hand-incised; (b) complex hand-incised; (c, d) simple molded; (e) stamped; (f) punctate; (g) high-relief molded.

Peabody and then the Toluca museum collections. The shape of the Peabody collection weight distribution, with a secondary peak at very low weights, is, however, distinct from either of the other collections.

In terms of decoration, there are pronounced frequency differences between the collections for several types, but the overall pattern is one in which the two museum collections look more similar to each other than either does to the excavated material (Figure 7B). Of the ten possible types of decoration, the two museum cases are distinctly more similar to each other in four cases (Types 0, 5, 8, and 9), while the excavated and Toluca collections are more similar in a single case (Type 2), and the excavated and Peabody collections are more similar in one case (Type 7). For examples of the more common decorative types and shapes, see Figure 5.

When assessed statistically, the overall degree of similarity between the collections is similar to the cotton whorls, with five of twelve pairwise comparisons being significantly different at the .05 level and one additional comparison differing at the .10 level.

For the non-metric traits of shape and decoration, which are more likely to be influenced by collection bias, the excavated collection is significantly different from both museum collections. For both variables, the degree of difference is more extreme for the Toluca collection. The two museum collections are not significantly different from each other for either variable. The higher overall degree of similarity for shape is likely due to the relatively low number of possible categories (5) as compared to decoration (10).

There is likely some degree of correlation between shape and decoration in this case, as the primary differences between the excavated and museum collections are probably due to the same subset of artifacts for both variables. While the assessment of decoration as "cruder" or "finer" is culturally subjective, the decorative types overrepresented in the two museum collections (complex molded and high relief molded) do feature more delicate, elaborate, and symmetrical decoration than most of the other decorative types. These traits make these particular whorls aesthetically appealing to the modern western observer, and may have been selected for at some point in the museum collections' history.

For the metric traits of weight and height/diameter ratio, a different pattern emerges. The excavated and Toluca collections are consistently the most similar, and the excavated and Peabody collections are consistently the most different. However, the degree of difference is very different between the two variables. None of the collections differ significantly for the

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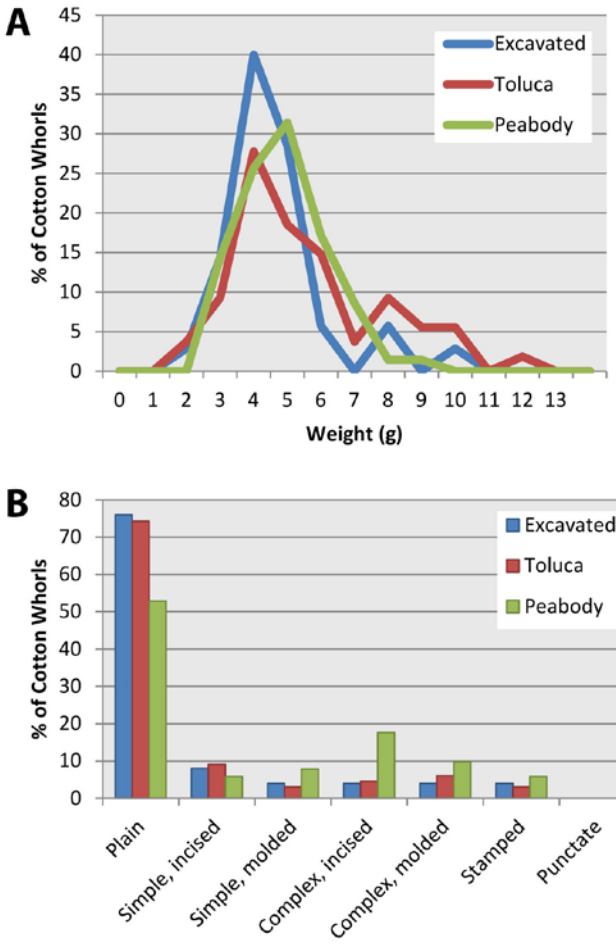


FIGURE 6. Graphs of the distribution of cotton whorl variables by collection: (a) weight distribution; (b) types of decoration.

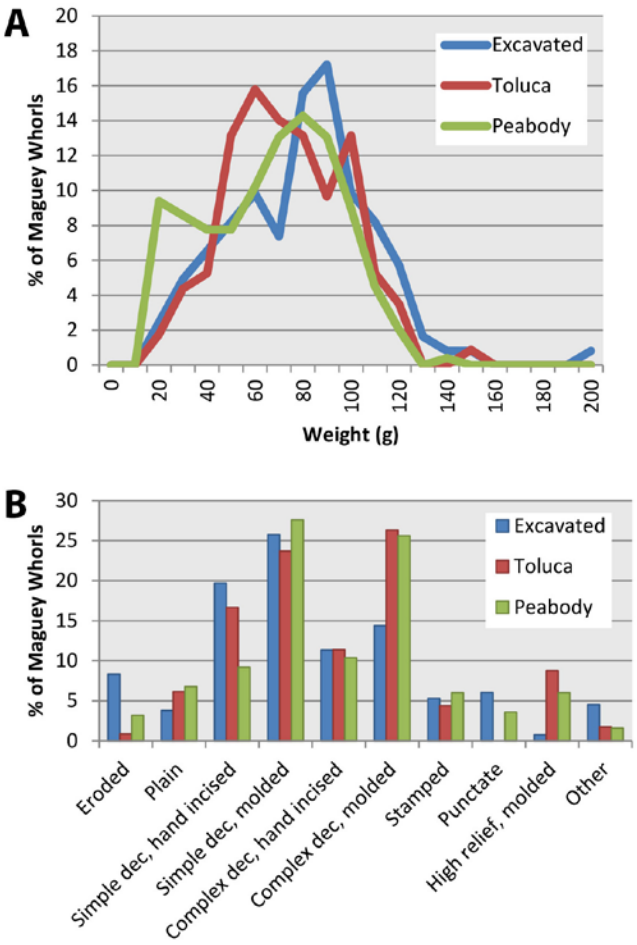


FIGURE 7. Graphs of the distribution of maguey whorl variables by collection: (a) weight distribution; (b) types of decoration.

height/diameter ratio. In contrast, for weight, the differences between the excavated and Peabody collections are significantly different at the .05 level (p = .003), the two museum collections differ at the .10 level (p = .059), and the excavated and Toluca collections are barely above this level (p = .108). The apparent high degree of similarity in height/diameter ratios is likely due to the low degree of possible variation for this trait for maguey whorls in these data sets.

The combination of these two trends suggests that maguey whorls in the two museum collections were consistently selected for their decorative features. However, this selection process produced differing results on the distribution of metric traits among the whorls in a given museum collection. As a result, the Toluca museum collection's metric traits have remained more similar to the excavated sample than the Peabody's.

DISCUSSION

For both cotton and maguey whorls, the range of variation is similar across all three collections for most variables. The metric variables have similar ranges, and any single state for the non-metric variables is generally either uniformly present or uniformly absent in all three collections.

At the same time, the distribution of variation within the range differs between the collections in various ways. The results of the analyses of both cotton and maguey whorls show a trend toward museum collections favoring more visually elaborate pieces. This process is more pronounced among cotton whorls, where there is a clear division between decorated and undecorated whorls, as opposed to maguey whorls, which are contrasted primarily by the degree of decoration. The trend toward decorated pieces is more pronounced in the Peabody collection than in the Toluca museum collection.

Much of the difference between the two museum collections may be due to number of times a given collection was culled prior to entering its current museum collection. The number of whorls in the Toluca museum collection is broadly consistent with the scope of García Payón's excavations, suggesting that the whorls therein have not been heavily culled. However, the inclusion of primarily complete pieces does mean that someone, whether during excavation, at accession, or a time after accession but before comprehensive cataloging, made choices

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TABLE 2. Cotton Whorl *p*-Values.

Variable	Test	Collection	Excavated	Toluca	Peabody
Shape	Chi-square	Excavated	-	-	-
		Toluca	.014	-	-
		Peabody	.074	.006	-
Design	Chi-square	Excavated	-	-	-
		Toluca	.107	-	-
		Peabody	.064	.137	-
Decoration (Y/N)	Fisher's Exact Test	Excavated	-	-	-
		Toluca	.460	-	-
		Peabody	.012	.035	-
Form Ratio	Kolmogrov-Smirnov	Excavated	1.000	-	-
		Toluca	.016	1.000	-
		Peabody	.366	.000	1.000
Calibrated Weight	Kolmogrov-Smirnov	Excavated	1.000	-	-
		Toluca	.111	1.000	-
		Peabody	.013	.209	1.000

TABLE 3. Maguey Whorl *p*-Values.

Variable	Test	Collection	Excavated	Toluca	Peabody
Shape	Chi-square	Excavated	-	-	-
		Toluca	.015	-	-
		Peabody	.022	.812	-
Design	Chi-square	Excavated	-	-	-
		Toluca	.000	-	-
		Peabody	.001	.246	-
Form Ratio	Kolmogrov-Smirnov	Excavated	1.000	-	-
		Toluca	.621	1.000	-
		Peabody	.194	.498	1.000
Calibrated Weight	Kolmogrov-Smirnov	Excavated	1.000	-	-
		Toluca	.108	1.000	-
		Peabody	.003	.059	1.000

about which whorls to include in the museum collection. In addition, the Toluca museum has served as a source of artifacts for permanent display for other museums in the state system, and such transfers are not always noted in the parent records. In contrast, the Peabody collection may have passed through at least three rounds of culling, at the hands of the individual who originally collected the items in Calixtlahuaca, Mr. Walworth, and the Cogswells, respectively. The pieces currently present at the Peabody match the original accession record, demonstrating that the collection has not been modified since the time of museum accession.

Alternatively, the differences between the excavated and museum collections may be due to the addition of items not actually from Calixtlahuaca to the museum collections. A large component of the maguey whorl differences between the excavated collections and both museum collections is due to the increased frequency of two particular decorated types in the museum collections. Both of these types are more common at sites near the heart of the Aztec Empire than at sites near Calixtlahuaca. The Cogswells' donation to the Peabody also included artifacts from sites other than Calixtlahuaca. The Toluca museum holds collections from the entire state of Mexico, which wraps around three sides of Mexico City, including portions of the Aztec heartland. As a result, it is possible that artifacts from other Central Mexican sites were added to one or both of the museum collections.

Regardless of the source of the differences between the three collections, their existence has implications for the questions

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about past behavior that each collection can answer. Studies of spindle whorls that address questions of thread quality or the intensity of production require a representative distribution of metric variables. In the studied cases, the uncritical application of the Peabody metric data to this type of question might result in an interpretation that two distinct weights of maguey thread were spun, rather than the continuous thread weight distribution indicated by the other two collections. In contrast, studies of iconography can benefit from the use of museum collections, due to the good preservation of the pieces, and the overrepresentation of rare types of decoration. In the studied cases, I would not have been able to understand design symmetry if I had examined only the excavated collection. One example of a paper that balances the potential information and potential limitations of museum collections is Hernández Álvarez and Peniche's (2012) comparison of spindle whorls from across the Yucatan peninsula. The article incorporates data from a combination of museum collections, excavations, and surveys. While it does not explicitly address the potential of collection bias in the museum portion of their sample, the analysis is primarily presence/absence based, which plays to the strengths of museum collections.

CONCLUSION

Museum collections are an underutilized resource for archaeological research, in large part due to archaeologists' concerns about the representativeness of such collections. As a result, most archaeological analyses of museum pieces focus on archaeometric techniques or descriptive work on unique pieces, rather than analyses of entire collections or artifact classes. One method of addressing concerns about the representativeness of a collection is through comparisons with collections of known standing, particularly those produced by modern archaeological projects. The application of exploratory data analysis and basic statistical methods permits the systematic evaluation of museum collections relative to the collection of known standing. The independent analysis of multiple variables in the same sets of artifacts aids in the identification of potential biases. This type of comparison may be used to identify both the range of variation present in a collection and the distribution of that variation.

The results of such evaluation can indicate appropriate uses of particular analyzed collections. A collection may have been highly influenced by the manner in which it was collected and therefore not suitable for the investigation of ancient human behaviors. Alternatively, a collection may be biased in a limited fashion or only in certain aspects and thus usable with appropriate caution, or not particularly biased and appropriate for most analyses. In the cases studied here, both museum collections have a similar overall range of variation to the excavated material. Such cases would be appropriate for descriptive work on the types of variation found in the source region. While this may seem to be of a minimum level of utility, such descriptive works are often urgently needed and should not be overlooked.

The distribution of variation within a collection provides an additional level of comparison, one that is of more concern to many archaeologists. At this level of consideration, the two museum collections used in the case study diverge. The Peabody collection has a sufficiently anomalous distribution of variation that should not be considered representative of the source region, while certain aspects of the Toluca museum collection may be used but others may not. In further applications of this methodology, it may be useful to use an out-group, such as an additional excavated collection from a nearby region or different time period, to establish an outer boundary for acceptable degrees of variations between collections.

Acknowledgments

I wish to thank Dr. Michael Smith and the Calixtlahuaca Archaeological Project (CAP), Victor Osorio, Albina Vazquez and the Instituto Mexiquense de Cultura, and Dr. Rodger Colton and the Yale Peabody Museum for access to their respective whorls. My work on the CAP and Instituto Mexiquense collections was supported by the CAP's National Science Foundation grant for artifact analysis (The Urban Economy of Aztec-Period Calixtlahuaca, Award #0924655), and my examination of the Yale Peabody collection was supported by a grant from the Arizona State University (ASU) chapter of Sigma Xi. I also wish to thank my writing group at ASU and the three anonymous reviewers for their feedback on this paper. Any remaining errors are my own.

Data Availability Statement

The metric and non-metric data for each of the three collections used in this paper are publically available in the Digital Archaeological Repository (www.tdar.org) under tDAR ID: 391587. The whorls from the Calixtlahuaca Archaeological Project are stored in the project's lab in at the Colegio Mexiquense, Zinacantepec, Mexico, for the foreseeable future. Any requests for access to the lab should be directed to Dr. Michael E. Smith (Michael.E.Smith.2@asu.edu). Requests to access the whorls in the Yale Peabody Museum should be directed to Rodger Colton (rodger.colton@yale.edu), or the current curator. Requests to access the Museo de Antropología y Historia (Toluca) collections should be directed to Victor Osorio (victorosoriomah@hotmail.com) or the current director of the museum. The CAP whorls used in this analysis are cataloged as W-001 to W-176 in the project's files. The Yale Peabody whorls are individually numbered from 131576 and 131881, with occasional missing and/or duplicated numbers. The Toluca whorls are cataloged by lots of 5–10 items, under the numbers REG10-104205, REG10-107333, and REG35 PJ 1341 to REG35 PJ 1358.

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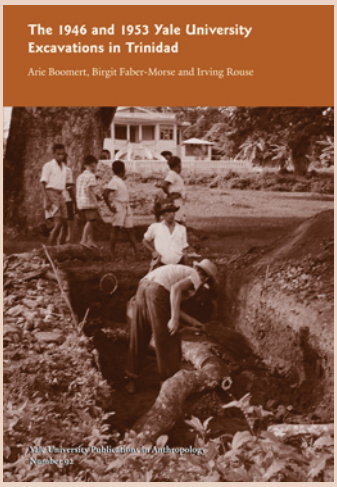
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