Frances F. Berdan

The Technology of Ancient Mesoamerican Mosaics: An Experimental Investigation of Alternative Super Glues

Traducido del Inglés por Alex Lomónaco

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Table of Contents

Abstract

The overarching goal of this project is to advance scientific understanding of the technology involved in the production of ancient Mesoamerican mosaics. Central to this investigation is the role of proper adhesives and their uses in bonding different types of materials (such as feathers to paper or stone to wood). This experimental study focusing on the adhesives (from orchid gums to copal, pine resin and beeswax) resulted in a refined assessment of technical qualities such as relative adhesive strengths, ease of production, transparency/opaqueness and length of “set-up” time. Furthermore, an understanding of these qualities leads to broader issues regarding labor arrangements in mosaic production, trade and exchange, and ecological considerations.

Resumen

La meta que se pretende alcanzar con este proyecto consiste en dar un paso adelante en la comprensión científica de la tecnología involucrada en la producción de los antiguos mosaicos mesoamericanos. Punto central de esta investigación es el papel que juegan los adhesivos apropiados y sus usos para unir tipos diferentes de materiales (por ejemplo, plumas y papel, o la piedra a la madera). Este estudio experimental centrado en los adhesivos (que incluye gomas de orquídea y copal, resina de pino y cera de abejas) tuvo como resultado una evaluación ajustada de calidades técnicas, incluyendo las fuerzas adhesivas relativas, la sencillez de su producción, su transparencia/opacidad, y la cantidad de tiempo necesario para solidificar. Además, la comprensión de estas cualidades lleva a asuntos más amplios con respecto la organización del trabajo en la producción de mosaicos, al comercio y al intercambio, y a consideraciones de tipo ecológicas.

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Frances F. Berdan
Department of Anthropology
California State University San Bernardino
San Bernardino, CA 92407
fberdan@csusb.edu

Introduction

This report presents the results of research activities designed to elucidate the production processes of ancient Mesoamerican mosaics. More specifically, this research has involved experiments testing the efficacy of different natural adhesives on different materials, building on evidence from Mesoamerican historical documents, archaeological specimens, and chemical analyses.

Figure 1. Bletia purpurea, a terrestrial orchid.

Figure 2. Laelia autumnalis, an epiphytic orchid.

Background

The ancient Aztecs (more properly Mexica) and their neighbors manufactured essential adhesives from a variety of natural vegetal substances. Copal, pine resin, beeswax, and orchids figured prominently among the gums used for adhesive purposes. The first stage of this research involved the identification of these natural materials from ethnohistoric sources, ethnographic usages, and extant sixteenth-century artifacts. A second stage involved the testing of these adhesives to assess their differential effectiveness as adhesives. Ethnohistoric documents, chemical analyses of existing mosaics, and ethnographic information suggest that several orchid species (Figure 1 and Figure 2, shown above), two copal genera (Figure 3, shown below), pine resin, and native beeswax (Figure 4) all served as Aztec super gums.

Figure 3. Copal in the Tepoztlan market.

Figure 4. Native beeswax.

The initial point of entry into understanding the types of adhesives used by these Mesoamerican peoples is the abundance of ethnohistoric documentation. These sources provide pictorial depictions and textual descriptions of adhesives and their varied uses. Particularly enigmatic in the ethnohistoric record is a gum derived from the roots and pseudobulbs of a plant called *tzacuhtli*, an orchid that reportedly produced a gum of extraordinary quality. The precise botanical identification of this plant has not been firmly established, nor is it clear whether this term referred to a single plant specie or to a class of related plants with glutinous qualities. The four most significant primary references to this elusive gum-plant in early colonial Mexican documents are Francisco Hernández's *Historia Natural de la Nueva España* (1959), Bernardino de Sahagún's *Florentine Codex* (1950-82), the pictorial *Códice de Xicotepec* (Stresser Pean 1995), and an early seventeenth-century visitation report by Alonso de la Mota y Escobar (1939-40). These documents all speak of or illustrate one or more types of *tzacuhtli* (detailed in a longer work by Berdan, Maynard, and Stark n.d.). In the final analysis, there are several very different descriptions and depictions of this plant, all called *tzacuhtli*. Pictorial depictions in Hernández, the *Códice de Xicotepec,* and two variations in Sahagún all suggest different types of plants, though all qualify as orchids. While different scribal conventions were at work, it is likely that several specific plants all qualified as *tzacuhlti*, or a plant that yields a gum. This convention of a generalized term based on its use was not uncommon in Aztec nomenclature. In Nahuatl, the term *tzacuhtli* was generalized much in the way that in English a tissue has become a "Kleenex" and a soft drink a "Coke" (see Molina 1970: 151-152).

In the following table, we propose botanical identifications of orchid-gum plants, based on studies by La Llave and Lexarza (1881), Urbina (1903), Linares and Bye (2006), and our own research.

Proposed Botanical Identifications of *Tzacuhtli* Plants
[t = terrestrial orchid, e = epiphytic orchid]

Hernández (1570s)	La Llave & Lexarza (1881)	Urbina (1903) additions	Berdan *et al.* (n.d.)
acatzacuhtli	Cranichis tubularis (t)		
amatzacuhtli	Encyclia pastoris (e)	Encyclia pastoris (e)	Laelia speciosa (e) or Encyclia concolor
atzacuhtli	Cranichis speciosa (t)		
chichiltictepetzacuxochitl	Laelia autumnalis (e)	Laelia autumnalis (e)	Laelia autumnalis (e) or Laelia speciosa (e)

coatzontecoxochitl	----	Stanhopea tigrina (e)	Stanhopea tigrina (e) or Stanhopea hernandezii (e)
cozticcoatzontecoxochitl	Encyclia citrina (e)		
coztictepetzacuxochitl	Govenia superba (t)		
cozticzacatzacuxochitl	Govenia lilliacea (t)		
iztactepetzacuxochitl	Govenia lilliacea (t)		
tzacuhtli	Encyclia pastoris (e)	Encyclia pastoris	Bletia or Govenia (t); Oncidium cebolleta
tzacuxilotl	Arpophyllum spicatum		
tzacuxochitl (first)	Bletia campanulata (t)		
tzacuxochitl (second)	Bletia coccinea (t) or Epidendrum (Encyclia) vitellinum (e)		(epiphyte)

As can be seen from the table, a major discrepancy is the identification of *tzacuhtli* itself. We suggest that this is not an epiphytic (as Encyclia pastoris) but rather a terrestrial orchid, most likely a Govenia or Bletia (see Figure 1, above). Indeed, ethnographically, orchid gums used in parts of Mesoamerica, particularly in the manufacture of fine wooden musical instruments, involve Govenias and Bletias, terrestrial orchids (Wyndham 2004, Yetman 2002, Breedlove and Laughlin 1993). Additionally, chemical research on a colonial Mexican feather mosaic suggests the use of a Bletia orchid as the mosaic's adhesive (González Tirado 1996).

Figure 5. Bursera (copal) tree in the Jardín Etnobotánico, Cuernavaca.

Tree resins provided an additional class of adhesives. In Mesoamerica, the most important of these were copal and pine resins. Copal falls under two main genera: the central Mexican Bursera (Figure 5) and the Mayan-area Protium. There are at least a hundred species of Bursera in México, and Hernández (1959) described 16 of these, noting the uses of their resins. Recent chemical analyses (McEwan *et al.* 2006, Victoria Lona 2004) clearly identify the use of one or more of these resins on Aztec artifacts.

Additionally, beeswax appears as an adhesive on stone mosaics (e.g., on the British Museum's "animal head" and on Pakal's funerary mask from Palenque). These uses suggest the application of beeswax as a repair material. Its repair qualities are discussed below. In all, these identifications provide the basis for the second stage of research: testing and experimentation.

Methodology

Production of orchid gums

Fortunately, the sixteenth-century documents provide us with "recipes" for the production of some of these adhesives. Hernández (1959, vol. I: 118-119) tells us that the roots (or pseudobulbs, perhaps) are cut into small pieces, dried in the sun, ground up into a powder, and "prepared." Sahagún (1950-82, Book 10: 87; 1956: 150) provides two recipe variations: the plant (roots or pseudobulbs) is trimmed, pulverized with a stone and sold uncooked. Alternatively, the roots were cleaned, soaked, pounded, dried in the sun, and then finely ground up after they are dry. It is possible that these different procedures were applied to different types of orchids.

Figure 6. Cutting Bletia orchid bulbs with obsidian knife.

Figure 7. Cut orchid pseudobulbs.

We selected 15 of the most likely orchid candidates for testing, and replicated these recipes as far as the documentation led us, although as with any recipe, some gaps appeared. We sliced the psuedobulbs (epiphytic orchids) and roots (terrestrials) with obsidian blades (Figure 6 and Figure 7, shown above), laid them out on screens (admittedly our adaptation), and dried them in the sun (Figure 8, shown below).

Figure 8. Orchid pieces drying in the sun.

Figure 9. Jeff Sahagún pulverizing dried bulbs in a *molcajete*.

We then pulverized the dried pieces in a stone *molcajete* (Figure 9, shown above and Figure 10) and sieved this material through a screen (our adaptation again) to yield a relatively fine powder (Figure 11). We mixed this powder with water to yield a clear gum (Figure 12). The recipes do not tell us how long to dry the pieces in the sun (we averaged 45 hours, in Southern California), how much water to add to the powder (we averaged 4 parts water to 1 part powder), nor how to reduce or sieve the material to a truly fine powder. This last matter persists as a problem. To produce a sufficiently fine powder (and eliminate the fibrous material from the epiphytic orchids), we sieved the pounded orchids through a fine metal sieve (250 micro) and through a tightly woven, hand-loomed textile.

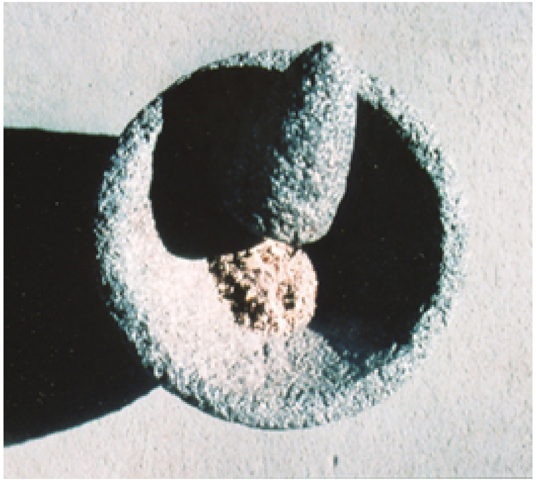

Figure 10. Ground pseudobulbs.

Both of these yielded fine powders, but not fine enough for the work of master artisans. Molina (1970: 152r) mentions sieving with the use of straw, but we have not succeeded in operationalizing a workable procedure using straw. Nonetheless, feathers attached readily to *amatl* paper in most cases (Figure 13).

Figure 11. Ed Stark sieves orchid powder while Jeff Sahagún records data.

Figure 12. Bill Duncan producing orchid gum from powders.

Figure 13. Feathers attached to *amatl* with Stanhopea hernandezii gum.

Along the way, quantities of all materials were measured and weighed (Figure 14, shown below). Gums were produced from several of these different kinds of orchids. Since the most common use of these gums was in feather mosaics, we then adhered feathers to *amatl* paper and tested these with a Mecmesin force gauge to assess relative adhesive strength.

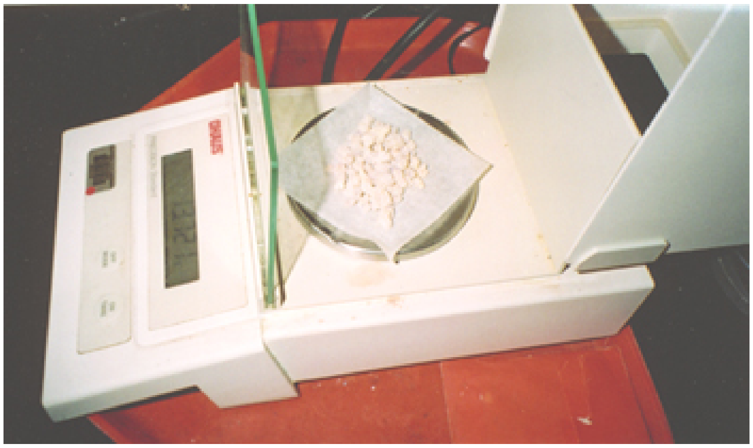

Figure 14. Orchids were weighed at every stage in the process.

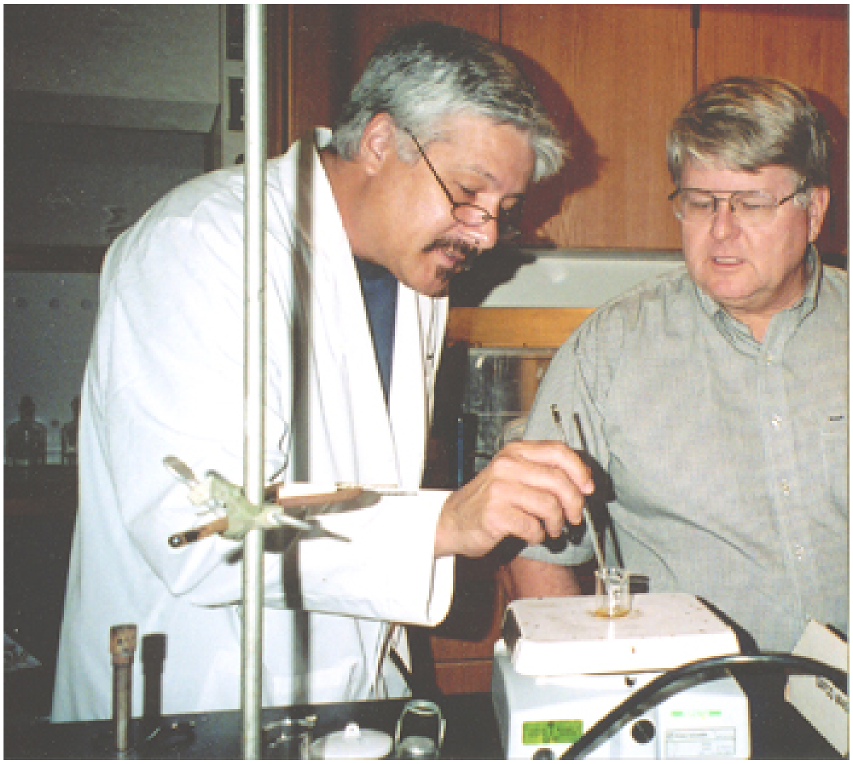

Figure 15. Jeff Sahagun and David Maynard cook up copal into a strong adhesive.

Production of adhesives from copal, pine resin, and beeswax

In Aztec times, copal was paid in tribute in both raw and refined forms, and both types, available today, have been tested for their adhesive qualities. Copal, pine resin, and beeswax were all heated to yield gums of workable consistency (Figure 15, shown above). Archaeological mosaics using these adhesives typically involved the attaching of stones (predominately jadeite or turquoise), shells, or gold to wood (*cedrela odorata* or pine) or to bone (see McEwan *et al.* 2006), and we replicated these situations (Figure 16). As with the orchid experiments, we measured, weighed, and performed strength tests on all preparations.

Figure 16. Jadeite affixed to *Cedrela odorata* wood with a copal-beeswax adhesive.

Experimental Results

In working with these different adhesive substances, it is clear that they display significantly different qualities, qualities that may well affect the decision by the artisan to select one or another substance as an adhesive for the production of a particular object. Some of these qualities, strength, texture, color, transparency, ease of production, and set-up time have been assessed experimentally.

Orchids

The orchids differ considerably among themselves in terms of texture, color, and strength, and even Hernández observes that some yielded better gums than others. The terrestrial orchids (Govenias and Bletias) have a smoother texture, are easier to pound, and exhibit considerably greater adhesive strength than the epiphytic ones (which tend to be fibrous and grainy, and also require more sieving to gain a smooth gum). In addition, the orchids vary considerably in terms of workability: terrestrial bulbs and young pseudobulbs (especially those with flower stalks) require considerably less pounding time and effort (average 4 minutes) than an equivalent quantity of older pseudobulbs (average 8-12 minutes). The former also yielded more powder and less fiber than comparable quantities of older bulbs; that is, the yield of adhesive was greater, and of higher quality from the roots and young pseudobulbs. Transparency was an essential quality for the manufacture of feather mosaics, since feathers themselves are delicate, and in one stage of manufacture the feathers are completely dipped into the adhesive and then laid upon the surfacing material. In our experiments we found that the feathers retain their color and brightness after being totally immersed in Govenia and Bletia adhesives. Gums produced from pseudobulbs tended, on the whole, to be more grainy, and this may be due to our continuing need to more finely sieve this fibrous material. On another dimension, whether roots or pseudobulbs, these gums dried relatively slowly, allowing considerable time to assemble and adjust the feathers Furthermore, in one strength test (Figure 17), the Govenia orchid samples fared better than even the hearty copal and pine resins (Figure 18, shown below).

Figure 17. Jeremy Coltman preparing the Mecmesin force gauge.

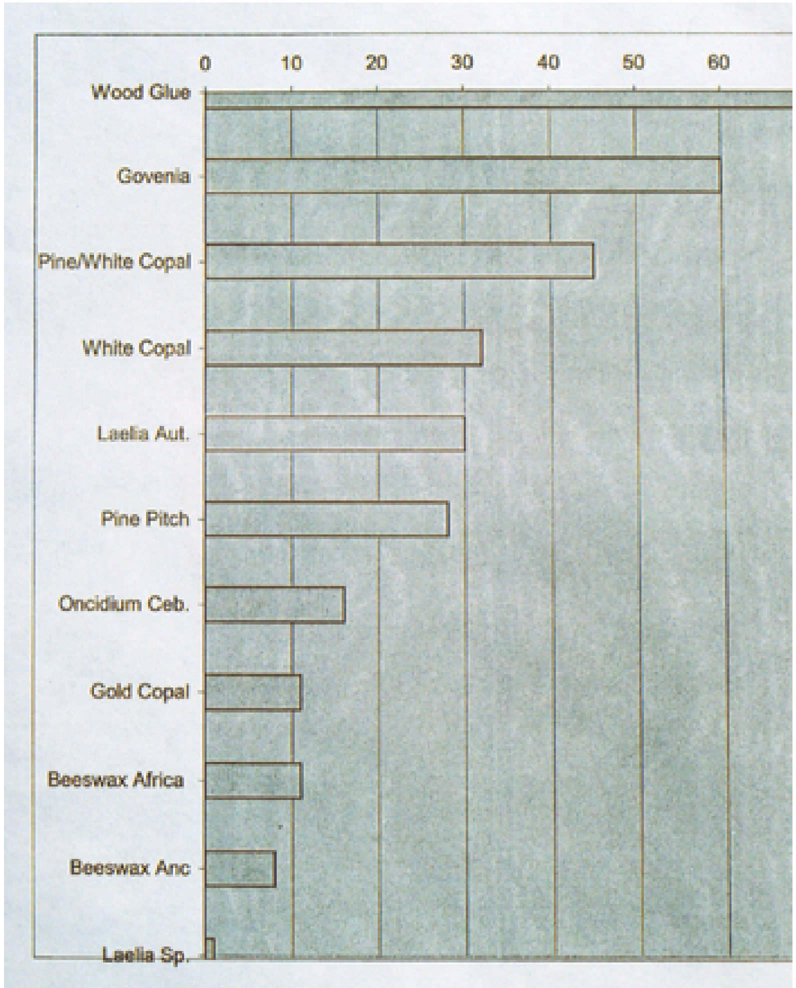

Figure 18. Relative strengths of orchid gums, resins, and beeswax.

Operationally, we learned a number of things not offered by the documents. We learned that the smaller we cut the raw pieces, the easier they were to pound when dry. We also learned that young pseudobulbs and roots were considerably easier to work than older ones still attached to a plant. These younger materials were also tactically much more “gluey” than the older ones. Tests with older and younger Encyclia citrine pseudobulbs clearly resulted in a stronger and smoother gum from the younger bulbs. As a whole, the orchids lost an average of 90% of their weight between their raw and powdered states. These latter considerations have important production and ecological implications (see below).

Overall, orchid gums, especially those derived from terrestrial orchids and the young pseudobulbs of epiphytes, were ideally suited for the production of feather mosaics. They are clear, colorless, and delicate, and effectively adhere feathers to each other and to paper backings. They are relatively easy to produce (Sahagún tells us that the children made the glue, at least in its final stage), and the attendant technology was readily accessible (although the matter of sieving remains unresolved).

Resins and Beeswax

Notable qualities of copal, pine resin, and beeswax for the production of mosaics are strength, color, and ease of production. These qualities especially make resins excellent candidates for use on stone mosaics, and that is where they are found artifactually. One set of strength tests (on the Mecmesin force gauge, see Figure 17) underlined the impressive adhesive qualities of these materials when attaching stones to wood. In fact, the gauge was stretched to its maximum force and was unable to dislodge the stones. Alternative strength tests showed white copal slightly stronger than pine resin, and a combination of copal and pine resin stronger than either of its two components alone (see Figure 18). The use of a copal/pine resin combination on two of the objects in the British Museum collection may suggest more than just convenience or happenstance; the artisan may have recognized the practical, enhanced value of combining these adhesives.

Copal (whether white or gold) and pine resins tend to set up more quickly than the orchid gums, suggesting somewhat different procedures for stone mosaics vs. feather mosaics. In fact, they set up so quickly that by the time they are spread on a surface, they have already solidified. This is somewhat ameliorated by adding beeswax to the mixture. It appears that beeswax helps melt and temper the copal and pine resin, but when the combination solidifies, the stronger bonding properties of the resins prevail. The resins solidified so quickly that we barely had time to adhere the stones; one solution to this problem was to heat the stones before applying them. In that case, the stones stuck readily to the applied gums. While undocumented, the artisans may have used this “trick” to allow them time to carefully set their prepared mosaic stones.

Beeswax would have been useful as an additive to resins, but also may have been used primarily as a repair material or for decorative applications (see McEwan 2006). Beeswax is found in a repair on Pakal’s mask, and on an addition to the animal head in the British Museum (McEwan 2006). So while examples are few, they alerted us to the possible preference of this material for repairs. Indeed, beeswax is ideally suited for repairs: it liquefies easily, sets relatively slowly (allowing for placement and adjustment, perhaps by unskilled hands), and is flexible and waterproof. It would also be a readily available and relatively inexpensive material to obtain. We do not know who was responsible for repairs, but beeswax would be an appropriate material for either skilled artisan or unskilled consumer.

Significance of Results

The basic premise of this research is that different adhesives were customarily chosen to bond different types of materials, based on the recognized qualities of the adhesives. In the realm of the orchids, it is clear that different types of orchids yielded different qualities of gums, and that quality varied even within the same orchid depending on the age of the root or pseudobulb. We can assume that the collector recognized these differences and therefore could exercise some choice: make the highest quality gum (and hence destroy the plant) or make a lesser quality gum (and hence preserve the plant). This is an ecologically significant decision. We do know that the gum-producers were not necessarily always high-minded; Sahagún tells us that there were those who doctored their gums with ground up maize, maize stalks, or beans. The ecological impact of the Aztec gum industry is also a worthy consideration. We calculated the surface area covered by a specified amount of orchid gum in terms of the number of bulbs/roots/plants required to cover that area. While these calculations are tentative and preliminary, one suggestion that stands out is that more terrestrial than epiphytic plants were required to produce the same amount of gum. This requires further testing.

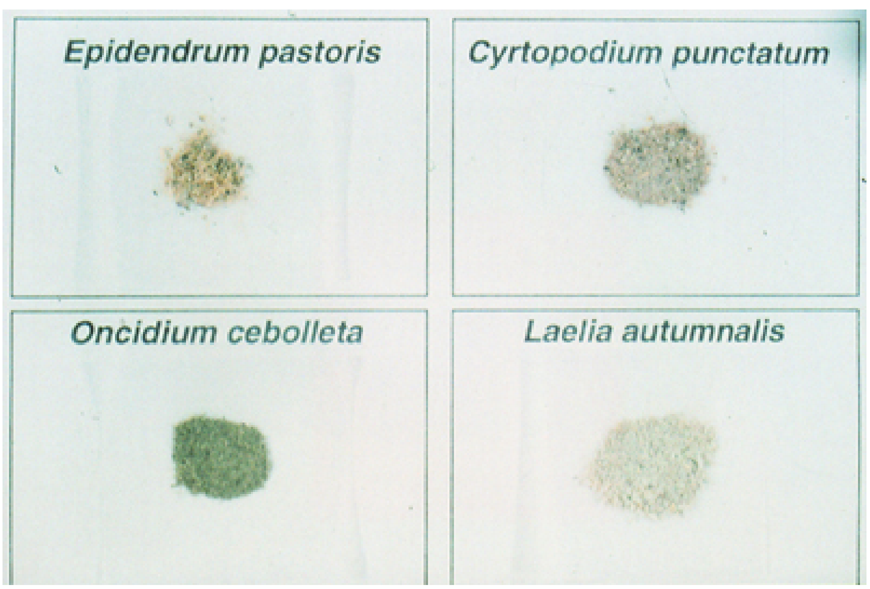

Figure 19. Powders from different gum-producing orchid specie.

The discovery that orchid roots and pseudobulbs lose approximately 90% of their weight when processed into a dry powder (see Figure 19, above) has important implications for understanding the likely production process of this material. We are told by Sahagún (1950-82, Book 10: 87) that *tzacuhtli* was sold in powdered form in the great urban Tlatelolco market. This would make practical economic sense, especially if the sources of the orchids were at some distance from the market and given that all transport was by foot or canoe. This also implies sequential production events, with the initial processing occurring at the sources of the raw material, and the final gum-making provided by the consumer.

The selection of specific types of adhesives, as well as the mixing of different adhesive materials (such as copal and pine resin), provides a window into the artisan's possible decision-making bases and priorities. Additional specific chemical identification of adhesives on extant mosaics is a next important step in understanding the artisan's options, priorities, and range of knowledge and skills.

Figure 20. Mini-feather mosaic, using Stanhopea hernandezii gum.

Concluding Comments

In the course of this research, mini-mosaics were roughly produced (Figure 20). This especially allowed us to gain a sense of timing in the production of these objects. The most time-consuming activities involved the preparation of materials (and designs), with less time required for the actual assembly. The documents emphasize over and over again the meticulousness and care with which these items were approached and produced. We found a fine line between maintaining a perfectionist attitude while working with these exacting materials. This research and experimentation with these materials and processes serves to highlight the society's exceptional level of investment in training, and the extraordinary skills achieved by the mosaic artisans.

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List of Figures

Figure 12. Bill Duncan producing orchid gum from powders.

Figure 13. Feathers attached to *amatl* with Stanhopea hernandezii gum.

Figure 14. Orchids were weighed at every stage in the process.

Figure 15. Jeff Sahagun and David Maynard cook up copal into a strong adhesive.

Figure 16. Jadeite affixed to *Cedrela odorata* wood with a copal-beeswax adhesive.

Figure 17. Jeremy Coltman preparing the Mecmesin force gauge.

Figure 18. Relative strengths of orchid gums, resins, and beeswax.

Figure 19. Powders from different gum-producing orchid specie.

Figure 20. Mini-feather mosaic, using Stanhopea hernandezii gum.

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