The Mesoamerican codex re-entangled : production, use, and re-use of precolonial documents

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1. Materials for Writing

For many works of art, modern photographic and digital reproductions have artificially separated the image from its physical original. One of the clearest examples of this can be found in the works of painter Pieter Mondrian. Many people will have seen pictures of his most famous works which are composed of vertical and horizontal lines forming red, yellow, blue, black, or white squares and rectangles. What is completely lost in such a picture, however, is the three-dimensional nature of his work, so clearly illustrated by his last and unfinished work: Victory Boogie Woogie. This "painting" was made by applying layers of painted self-adhesive tape onto a canvas. And the Victory Boogie Woogie seems to have been one large experiment with working with this newly invented material. Photographic reproduction has done a similar thing to the precolonial Mesoamerican codices. It is now possible to study photographs of the originals and come to a new interpretation of what the texts mean without considering these codices as unique three-dimensional objects. In the first two chapters of this work, the material aspect of these codices is brought back to the centre of attention. The first chapter focusses on the materials that have been identified as ingredients for the codices, using scientific methods. The difficulty here is that, due to the rarity and fragility of the codices, their caretakers have adopted an understandably protective conservation policy. As such, all modern investigation needs to be fully non-invasive. This means that no samples can be taken and that all investigation is done with different forms of electromagnetic spectroscopy (see Charola & Koestler, 2006, pp. 14-19; Pollard, Batt, Stern, & Young, 2007, pp. 45-137). These techniques at present have difficulty securely identifying organic materials. Their similar chemical composition, being mostly a specific arrangement of carbon and hydrogen molecules, makes it impossible to distinguish between them. To come a step closer to identification, a second source of information needs to be consulted: the early colonial Spanish sources describing the use of plants and animals in the Americas. Combining these two types of information yields a list of certain and likely ingredients. This in turn forms the basis for the second chapter, which focusses on the actual technical process of working with these materials. It was decided to divide the materials used into different categories of ingredients needed for making a codex. These categories are: the writing surface, composed of the support and the white covering layer; the covers, of which multiple types can be identified; the paints, subcategorized by colour; and the different glues used in and between each of the previous ingredients. Each of these categories will be considered in turn.

1.1 THE WRITING SURFACE

The surface on which the Mesoamerican books are written comes in two types, both of which seem to be rather unique combinations of materials within world literature. In Medieval Europe, books were made of parchment, which was created by drying and stretching animal skins, while in China the art of making paper has been perfected for centuries. From the few remaining examples in existence today it is clear that in Mesoamerica both a type of paper and animal skins were in use for the creation of a writing surface. The main difference between these book-making traditions and those in practice in Europe and Asia is that these surfaces were not written on directly. All precolonial Mesoamerican documents have a surface that was covered with a white layer before it was deemed fit to write upon. In general, a book consisted of a long strip of this skin or paper covered on both sides with a white layer, which was folded to form a so-called screenfold book. This combination of materials formed the blank book which was then filled with writing either on one, or on both, sides of the support. The materials that were used to make these supports have been relatively well identified.

Figure 1.1 top left: Detail of Paris Codex showing structure of amate paper (from gallica.bnf.fr accessed 04-01-2016); bottom left: modern day amate paper showing same structure; right: amate tree in ethno-botanical garden of Oaxaca City (courtesy of A. Rojas).

The surface of the Mesoamerican books is a strong, yet flexible material. As stated above, the material of choice was either paper or animal skin. The nature of precolonial Mesoamerican paper is well understood, as in the early 20th century Rudolf Schwede (1912) studied and identified the paper of the three remaining Maya codices. These three are all made from the bark fibres of the amate tree (Ficus spp.) (see figure 1.1). Though this identification is over a hundred years old, the bark paper used for these books is still on occasion erroneously called Agave paper. This may be related to the fact that in one of the first semi-scientific descriptions of these manuscripts, that by Alexander von Humboldt, can be read as stating that [some are painted]:

"*..sur des peaux de cerfs, les autres sur des toiles de coton, ou sur du papier de maguey*". (Humboldt, 1989, p. 66)

Unlike the work by Von Humboldt, which quickly attained fame around the world, the article by Schwede was never translated from the original German. Von Hagen (1944) first brought this discussion to the attention of the Anglophone world, but to this day some confusion still remains. The first chroniclers such as Mártir de Anglería (1964, p. 425) were very clear in their descriptions: "paper is made from the bark of a tree". According to von Hagen (1944, p. 42), Motolinía (1969, p. 199)[5] is the first

5. It must be noted however that Motolinía does continue to talk about a different tree that is called Amatl, so he is not

to cloud the discussion with his statement that "good paper is made of metl". This "metl", the Nahuatl word for agave, is probably used erroneously instead of the word amatl, the word used for both paper and for the fig tree from which the paper is made. The statement "paper is made from agave" cannot possibly be true as it is virtually impossible to make high quality paper of agave, due in the most part to the coarse nature of its fibres. Agave is very suitable for the creation of strong ropes, but for the creation of paper the wooden material would have to be cut up into very fine pieces and joined together in a mould akin to the modern way of papermaking (von Hagen, 1944, pp. 43-44). This technique was not available in precolonial Mesoamerica.

Schwede (1912, pp. 28-33) tested a number of Central Mexican documents, which were thought to be made from agave. Not only were these proven to be made from the bark of the Ficus genus, the actual species used could be correlated with the climate of the region from whence the documents came. This showed that the creation of amate paper was not only widespread but also a more or less local affair. To this day, paper is made from the bark of the Ficus tree also known as Jonote in Nahuatl. The term Jonote seems to refer to a range of fibrous trees from which paper can be made, including, but not limited, to the Ficus spp. As such, any identification of the specific species of tree from which amate paper is made would require detailed analysis of the fibres possibly including an invasive DNA analysis.

Although it is clear from later colonial documents and from present day traditions that paper was – and still is – being made and used in Central Mexico and Oaxaca, the surviving precolonial codices from this region were made on a material that was taken from an animal source. It has been referred to variously as: (deer) hide; skin; leather; and even parchment. Except for the term skin, all these designations imply a specific processing method of the product to keep it from degradation, each resulting in very different final materials. As these treatments have effects upon the structure of the skin, a short explanation of this structure is in order. Skin is composed of multiple layers. The outside of the skin is the epidermis: a layer of dead skin cells, which during life are shed and constantly renewed. Below the epidermis is the grain. This is a mass of small collagen fibres, hair follicles, and sweat glands, criss-crossed by arteries and veins. Further down into the skin the fibres start to become thicker. This is termed the corium layer. In this layer, depending on the thickness of the skin of the animal, the fibres can run from perpendicular to the body to parallel along the body. In the deepest part of the skin all fibres run along the body, forming a more or less smooth surface over the fat and flesh. The main structural components of skin are the collagen fibres. This collagen is composed of about twenty different amino acids, combining to form long helical chains or polypeptides.[6] Three of these chains combine to form a right-twisting coil, or triple helix, which is the collagen molecule. These three strands are held together by hydrogen bonds between the NH and the CO groups of two adjacent chains (see Haines, 2006a, p. 6). The strength of skin, its ability to stretch, and its resistance to tearing comes from these molecular chains and coils, which in turn twist together to form fibrils, which again twist together to form fibres and fibre bundles. These coils of coils interweave to give strength in any direction (Haines, 2006b, p. 11). When processing skin, the bonds between these coils need to be strengthened or at the least protected from degradation.

The term hide usually refers to nothing more than the skin of a larger animal. However in some cases, especially with the term rawhide, some measures may have been taken to allow the skin to be temporarily preserved. It may, for example, have been salted to dehydrate the skin, thus temporarily preventing bacterial growth (see Lockwood, 1912, pp. 22-26). However, none of these techniques provide a long-term solution. Besides that, the introduction of massive amounts of salt into a codex' substrate would have major ramifications for the end result, such as leaching of the salt and formation of salt crystals on and beneath the surface. These salt crystals would have caused major damage in a manner similar to the

completely to blame for the confusion.

6. For an overview of the amino acids in collagen as well as the structures of the most common ones, see Haines (2006a, pp. 4-5).

salt deterioration often found in mural paintings (see Petersen, 2006, pp. 243-244). Parchment implies a very specific procedure of liming, dehydration, and stretching (Woods, 2006, pp. 200-203). This processing changes the collagen structure, opening it up and making it even more susceptible to water (Woods, 2006, p. 206). This makes it a very unsuitable product for a Mesoamerican context, as the climate is often warm and at times especially wet.[7] The application of the white layer, glues, and paints (see below) all involves further introduction of moisture.

Since the codices are made on flexible material that has been able to withstand microbial attack and variations in humidity, the terms skin, hide, and parchment are clearly not applicable to these surfaces. The only candidate left, then, is leather. True leather has undergone a tanning process that causes chemical changes, giving it specific qualities that differ from ordinary skin. There are many process by which tanning can be achieved. The look and feel of the end product is as much dependent on the process used as it is on the type of animal from which the skin is taken. The main characteristic of leather is that it is resistant to microbiological degradation even if kept wet. Thus, the difference between true leather and otherwise preserved skins is to be found in the permanence of the preservation. If skins that have been treated with salt, pickled, or dehydrated become wet, then they quickly lose their protection and will start to degrade. Tanning is a way to reinforce or protect the bonds between collagen coils. It stops them from collapsing or unravelling by introducing more, or other types of, chemical bonds between the collagen coils. The type of bond created between the coils depends on the tanning material used. However, a genuine leather requires a chemical reaction to take place inside the leather, thus strengthening the material with new connections between the collagen strings. This is why tanning with oil, such as brain tanning, which is very common in Native North American processing of hides (Richter & Dettloff, 2002), cannot technically be considered a true tanning technique. While the resultant product is every bit as resistant to microbiological attack, as the individual fibres are insulated in a layer of oil, no new chemical bonds are created. This is important for a second characteristic of leather: an increased resistance to heat. When a skin becomes too warm, the hydrogen bonds between the coils fail and the coils collapse, forming a ball-like mass. The result is a dramatic shrinkage of the leather to about one third of its original size. While true leather has more bonds and is thus better able to withstand the heat, oil tanned leathers are not resistant to heat and will collapse at a temperature of 53-56°C (Thomson, 2006c, p. 2). Secure identification of the tanning agent, therefore, would require further (partially destructive) investigation, and it thus remains unclear whether the codices were made from true leather or if they are merely oil tanned. Considering the properties of the material, however, it must be considered as at least a leather-like material.

The treatment of the skin is only one aspect that determines the look of the leather. The second is the selection of the animal itself. Any vertebrate has a skin that can in principle be turned into leather. The usefulness of the resultant leather is dependent on the intended use, as different animals have skins of different thickness and structure. These skins can be turned into leathers of different suppleness, strength, and aesthetic appeal. Identification of an animal skin can be done based on the differences in fibre structure of the skin or of hairs attached to it; on the basis of follicle patterns on the surface of the skin; or by DNA analysis. The first two methods have as a downside the fact that they require reference collections and are not fully conclusive due to intra-species and intra-individual variations. DNA analysis, on the other hand, is conclusive, though this method requires taking a tissue sample. Though no conclusive evidence has thus far been generated, all research on the codices thus far categorically states that these books are made on deerskin. This attribution is based on the idea that deer was the most widely available source for a skin of that size. Given the lack of domesticates, the number of species available for the production of leather in pre-colonial Mesoamerica was limited. The size of the individual pieces of material that were stuck together to form

7. The highly mountainous Mixtec region, or as it is called in the Mixtec language Ñuu Sau (Land of the Rain), is especially wet during particular seasons.

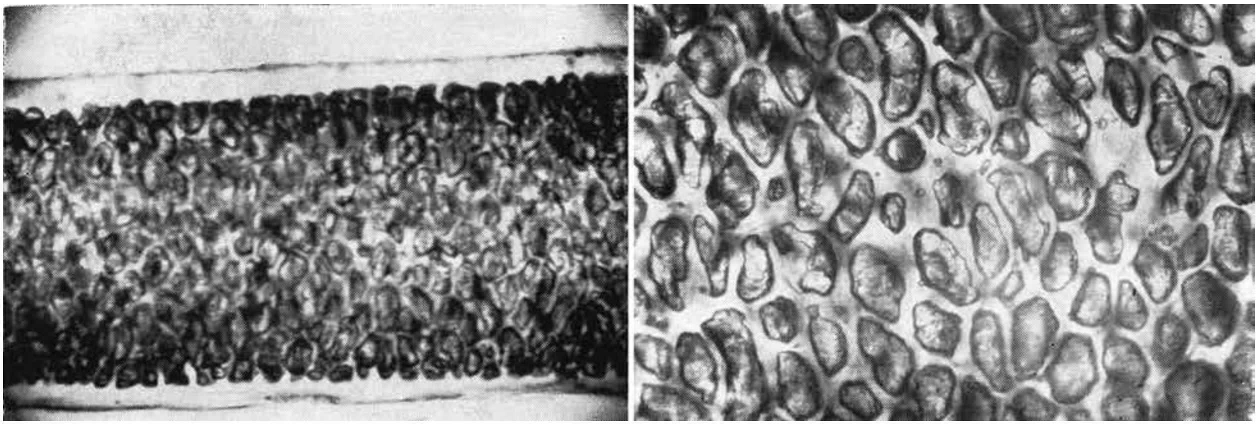

Figure 1.2: Microscopic images of hair and its marrow from Codex Iya Nacuaa (Colombino) enlarged 10x 25 and 10 x 50 respectively (from Alvarez, 1966, image 10 and 13).

the substrate of the codices indicates that the animal from which they came was relatively large. Codex Añute, for instance, is built-up of pieces that cover 3 to 4 pages of the codex, each page measuring 27.5 by 27.5 cm. The individual pieces of leather thus needed to be big enough to cut out a piece of roughly 75-100 cm by 27.5 cm. The most widely available source would indeed have been the most common species of deer in Mesoamerica: the white-tailed deer (Odocoileus virginianus). This deer has four subspecies that inhabit the current state of Oaxaca (Odocoileus v. oaxacensis, Odocoileus v. acapulcensis, Odocoileus v. toltecus and Odocoileus v. thomasi) (see Goodwin & MacDougall, 1969, p. 255), the area where a large part of the codices on leather comes from. On average, a skin of 0.9-1.3 m2 can be attained from a deer (Haines, 2006b, p. 15), which meets the size requirements for a document such as codex Añute. A second type of deer, the Red Brocket (Mazama temama), which is related to the tropical deer in South America, is found in the coastal tropical regions. But this animal is too small to yield enough skin for a good sized codex. Still, when considering the size of the skin which can be obtained, a number of other candidates for the fabrication of codex substrates must be taken into account. Eastward from the modern-day provinces of Oaxaca and Veracruz, a species of tapir (Tapirus bairdii) can be found. Throughout Mesoamerica a number of felines such as jaguars (Felis onca) and mountain lions (Felis concolor), and canines such as wolves (Canis lupus) can be found that would yield a skin large enough for the strips of material constituting the codices (Maldonado Alvarado & Maldonado Alvarado, 2004, p. 103).

In attempting to solve the issue, Alvarez (1966) was allowed to extract some hairs from the Codex Iya Nacuaa (Colombino fragment). These were microscopically analysed and compared with reference samples (see figures 1.2 and 1.3). This investigation showed that this codex had clearly not been made on a large feline or canine skin. The hairs are most similar to those found on a Pronghorn (Antilocapra Americana), though this animal currently does not live in the central or the southern area of Mexico, but is confined to desert areas further north. Alvarez (1966, p. 102) suggests that these hairs, and thus the skin, could come from the white-tailed deer only if the difference in appearance of the hairs could be explained by the tanning process or the degradation of the fibres over time. More likely, he states, is that the skin actually comes from the Pronghorn and that its range was more extensive in precolonial times. There is archaeological evidence for the use of Pronghorn in Nopalera cave (Hidalgo) from the period 350-1100 A.D. (Flannery, 1966, p. 801). In principle, this species could have lived in the central dry and hot region of Oaxaca as these areas are climatologically and ecologically similar to present day ranges (Alvarez, 1966, p. 102).

Whether or not it lived in Central Mexico, the Pronghorn was certainly an animal known to the

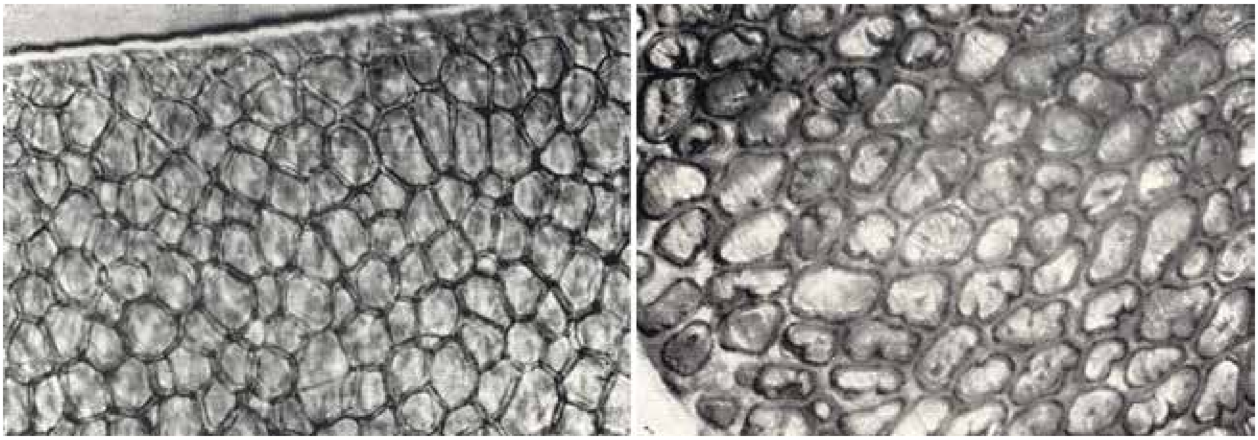

Figure 1.3 Left: Microscopic image of the marrow of white-tailed deer hair; right: Microscopic image of the marrow of Pronghorn hair (after Alvarez, 1966, image 12 and 14).

Aztec, under the name of Tlamacazcamazatl and is described in the Spanish text in the Florentine Codex (1577c, Book 11, fo. 16v) as:

"It is very big, very tall, it has a spotted face, black around the eyes; and below the eyes it has a white stripe going around the snout."
(translation by the author)

Although this is a quite clear description of the Pronghorn, it does not give an indication of whether or not this animal was used for anything like codex production. It is unclear whether the Pronghorn skin has any specific physical attributes other than perhaps its superior size that would make it a more suitable candidate for codex production. Iconographically, the Pronghorn seems to be absent, although perhaps this is to be explained by the fact that any image of a quadruped with horns is likely to be automatically identified as a deer. Although speculative, there may be a symbolical importance to this animal, as it is the fastest land animal in the Americas. Furthermore its name in Nahuatl is composed of the words Tlamacazca and mazatl. The latter can be translated as deer, while the former is a word translated by Molina (1970, p. 125) as "Ministros y servidores delos templos delos ydolos"; i.e. an indigenous priest or servant of the temple. Whether this is a reference to its likeness to the prototypical priests of Mesoamerican culture, often depicted with a black face, or a reference to a more general symbolic meaning, is unclear. If indeed there is some characteristic of the skin that makes it symbolically or physically more suitable for codex production, there is no reason to assume that Mesoamerican peoples could not obtain it, even if its range was limited to the south of North America. Long distance and down the line exchange or tribute payed by conquered peoples of the Aztec empire are known to have crossed great distances. Thus, the Pronghorn must also be seriously considered as a possible source for the raw material used for the codices.

Most forms of tanning will darken a piece of leather, making it less suitable as a writing surface. Though amate bark paper comes in both dark and light shades, this too is not completely white. While other writing systems may not need a completely white surface, the brightly coloured polychrome designs of the Mesoamerican writing system do make such a surface desirable. Besides this, both the natural structure of skin and the structure created by felting together amate fibres, is rather irregular. This hinders the smooth movement of a brush or pen over the surface, thus interfering with the creation of fine details. In order to solve both these problems, the surviving pre-colonial Mesoamerican books were covered with a layer of white material that could be smoothed. Multiple codices have been subjected to investigation of the chemical nature of this white layer. The codices Añute, Tlamanalli (Cospi), and Iya Nacuaa (Colombino-Becker) all have as major component gypsum (Dark & Plesters, 1958b, p. 532; Miliani et al., 2012, p. 674; Zetina et al., 2011, p.

351).[8] In his investigation of the pre-colonial Maya codices, Schwede (1912, p. 47) concluded that these are mostly composed of chalk (CaCO3) and not of gypsum. However, as Schwede undertook an optical investigation, M. D. Coe and Kerr (1998, p. 144) did not accept his conclusions and suggested instead that the white layer was probably similar to the one on central Mexican books, thus assuming that they were made with gypsum Recent spectroscopic investigation of one of the Maya codices, the Madrid Codex (Buti, 2012, pp. 65-66), has revealed that Schwede was correct and that indeed the major component of the white layer is calcium carbonate and not calcium sulphate.

Though the colonial sources do not give recipes for working with these materials, there are some Nahuatl names given to white minerals which may have been used to create the white surface of a codex. Three names are given by Sahagún (1577c, Book 11 of 221r.) for stones used to make white paints or varnishes. The first and second are closely related and seem to be the raw and the processed version of limestone. The raw version, Tetiçatl, is a contraction of tetl "stone" and tiçatl, the Nahuatl name for purified chalk. In the work of Hernández, d'Ardois, and Miranda (1960b, p. 408), Tetizatl is mentioned as a material which is used by painters to make something white, though it is, according to them, clearly less bright than Chimaltizatl (Hernández et al., 1960b, p. 405). The latter – Chimaltizatl – is the processed version and is described as a white diaphanous mineral that easily breaks into laminates. It is also likened to mezcuitlatl, which also breaks in sheets and is golden or purple and especially fireproof. The golden sheen may be the reason for the similarity in name of mezcuitlatl and teocuitlatl, the Nahuatl word for gold. This mezcuitlatl must be mica, famed for its heat resistant properties. Close observation of the surface of the Codex Tonalpouhqui (Vaticanus B) showed that on some pages the surface was different than on others. Pages 12, 72-73, and 95-96 have a surface that includes a sparkling material, suggesting that this mezcuitlatl could on occasion be incorporated in the writing surface as well. These pages are different in more respects than just the writing surface, however. The images painted on them are of a different colour and there seem to be other images hidden underneath as well (see chapter 3). When this over-painting was done and whether or not these materials used are completely pre-colonial warrants further investigation, but is beyond the scope of this work. The likeness to mica and the fact that it can be used for gesso indicates that Chimaltizatl must be selenite, a form of mineral gypsum. This is consistent with Clavigero (1970, p. 61), who indicates Quimaltizatl as a form of gypsum, which after burning can be used as a good gesso and a white paint.

Calcium sulphate is found in two different forms in nature: as the minerals gypsum (CaSO4·H2O) and as anhydrite (CaSO4). Both of these are precipitated when seawater evaporates, with the difference being that anhydrite requires a higher temperature to reach the complete dehydration required (Skinner, Porter, & Park, 2004, p. 90). Calcium carbonate is found in two natural forms of identical chemical composition. Both calcite and aragonite are forms of CaCO3, differing only in their crystalline structure (see Eastaugh, Walsh, Chaplin, & Siddall, 2008, pp. 80-81; Skinner et al., 2004, p. 89). Calcite is harder than gypsum; they are respectively 3 and 2 on the Mohs scale. But as the Mohs scale is not a linear scale, calcite is in fact three times as hard as gypsum. The rarer form of gypsum, anhydrite, with its more compact crystalline structure, is in turn harder than calcite (3.5-4 on the Mohs scale).[9] While aragonite is harder than calcite, it is also relatively unstable. When heated, it will spontaneously convert to calcite. This is an important material property because of the process by which gypsum and chalk are most

8. Although in the article by Zetina et al. (2011, pp. 349-350) it is stated that this codex dates to the 12th century, it must actually have been created in during the end of the Postclassic period (Jansen & Pérez Jiménez, 2011, p. 75). The confusion probably arose because of the content of this document, which does indeed deal with events taking place centuries earlier. However, I argue that the document itself should be seen as a literary work describing actions of heroic ancestors, not as a description of "current" events.

9. Though the crystalline structure is the only physical difference, this difference is the cause of some further differences in other properties, such as hardness, in much the same way that graphite and diamond have different degrees of hardness despite the fact that they are both completely constituted of carbon atoms.

commonly purified. Through an endothermic chemical reaction, both can be transformed into a powder that, by the addition of water, can be made into a paste which can in turn be moulded into any desired form. This paste sets and through another chemical reaction reverts back to the stable calcium carbonate or sulphate. The two chemical reactions can be expressed as follows:

Gypsum:

$CaSO_4 \cdot 2H_2O + 150°C \rightarrow$
$CaSO_4 \cdot nH_2O + (2-n)H_2O$ (steam)

$CaSO_4 \cdot nH_2O + (2-n)H_2O \rightarrow$
$CaSO_4 \cdot 2H_2O$ + heat

Chalk:

$CaCO_3 + 825°C \rightarrow CaO + CO_2$
$CaO + H_2O \rightarrow Ca(OH)_2$ + heat
$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$ (evaporates)

This way of working with these materials is very well known around the world and it is clear from the many architectural features moulded in chalk that this technique was also known in Mesoamerica (cf. Barba Pingarrón & Villaseñor Alonso, 2013; Villasenor, Graham, Siddall, & Price, 2011, pp. 329-334). It is not possible to work with Anhydrite in this manner. Since it has lost its crystallization water completely it does not readily reabsorb water, so it does not harden as quickly as gypsum would. Long-term exposure to water will, however, slowly convert it to gypsum.

It is striking that of all the investigated precolonial codices, all the Maya documents made on amate paper are covered with chalk, while the central and southern Mexican ones on leather are covered with predominantly gypsum. The corpus of codices is so small, with the number of published material analyses even smaller, that there can be no statistically significant statements made about the preference for chalk or gypsum when making a codex. If it were to be assumed that it is a general trend, however, then the reasons for this trend could be sought in three areas: availability; physical properties; and cultural preference. The geographic locations in which calcite can be found are spread all over Mesoamerica. Calcite itself can also be extracted from shells which are almost pure calcium carbonate. And, what is more, the Yucatan peninsula is largely composed of calcite. Gypsum, on the other hand, is found in large quantities in the north of Mexico, as the world-famous Cave of Crystals shows, though it is certainly not exclusive to this area. It can thus be concluded that in principle both in the Maya area as well as in central and southern Mexico the codices could have been made with either material, as both could have been obtained. The fact that there was an abundance of calcite in the Maya area, then, must have been the stimulating factor for its use. Not to mention that the use of chalk also has a number of downsides.

Chalk is harder and more durable, though that comes at a price. It is more difficult to process (Russell & Dahlin, 2007). In order to create quicklime (CaO), the powder from which the mouldable paste can be made, a source of calcium carbonate needs to be selected in the form of stones, shells, or coral. These stones, shells, or coral need to be either already rather small or broken down to a size that allows the applied heat to fully penetrate the pieces, so the calcium carbonate is completely converted into quicklime. As shown in the formulaic representation of the reaction above, a minimum temperature of 825° C is necessary to start the conversion process. However, in order to fully penetrate the stones a higher temperature of around 1000° C is generally needed (Russell & Dahlin, 2007, p. 414). As the reaction that releases CO_2 from the limestone is a gradual process, this high temperature needs to be maintained for hours. A structure that has been interpreted as a lime plaster kiln was discovered in the Southern Maya city of Copan, which could potentially have served this purpose (Abrams & Freter, 1996). Since this is one of the few examples of kilns discovered, it is likely that most lime was being made in an open fire. This would require a very large amount of fuel. An open fire is also very susceptible to wind. In their work, Russell and Dahlin (2007) noticed that in order to reduce the influence of the wind, the pyres were lit in the night when there would have been less wind in the area and additionally they were built in low-lying areas. To ensure a good result of the process, specific rituals were performed. This all shows the complexity of the process and the large amount of resources needed. Once the calcium carbonate has been completely turned into quicklime, the resultant material needs to be mixed with water. One advantage of using an open fire is the possibility of simply waiting for rain to mix with the quicklime. This would circumvent the need for a strong container capable of resisting the potential violent exothermic reaction. As long as this mixture is kept wet it can be stored, as it only hardens into chalk by the evaporation of water. If for some reason the mixture cannot be stored in wet condition, the quicklime would need to be stored. This should then be stored in a completely dry environment, with the added risk of causing possible dangerous uncontrolled chemical reaction if the stored material were to get wet accidentally.

Gypsum, in contrast, does not require any specialised equipment, as it does not need to be heated for such a long period nor at such high temperatures. As it is much softer, gypsum is easier to crush into smaller fragments, which allows for an even shorter heating time. Being this soft, however, means it is more susceptible to friction. A further difference between gypsum and calcium carbonate is that in the final reaction when these products harden, calcium carbonate produces water (which needs to evaporate) while gypsum absorbs it. This means that the gypsum would further dry out its substrate, lowering the dangers of microbial attack. The addition of small amounts of anhydrite could be a way to prolong the drying effect of the layer as the slow conversion of anhydrite to gypsum allows for it to continue to act as a drying agent. While calcium carbonate is harder than gypsum and thus more resistant to mechanical friction, it is very susceptible to chemical degradation because of its high reactivity with acids. When calcium carbonate comes into contact with an acid, the introduction of extra H^+ ions causes a reaction that causes the $CaCO_3$ to disintegrate into water and carbon dioxide gas. The carbon dioxide escapes in the form of gas creating the characteristic bubbles which are so useful for identifying a calcium carbonate material. The consequences of this high reactivity with acids will be discussed in the next chapter when the actual practice of working with these materials is considered in detail.

So far the assumption has been that the writing surface was made through a process involving a chemical reaction as it is commonly used to model three-dimensional architectural features. This heating and subsequent mixing with water is necessary to allow the modelling of three-dimensional objects or ornaments as the structural strength of such an object is created by re-crystallization of the minerals; i.e. the setting of the plaster. Once set, the model is rigid and strong. A very thin layer of gypsum or chalk on a somewhat flexible ground, however, requires more than the strength provided by the crystalline structure. Though there are no recipes or prescriptions for this process from the Americas, clues for working with these materials on a flat surface may be found in medieval European sources. Many medieval paintings were made on a layer of gessoed panel; i.e. a white inert substance mixed with an adhesive that covered an underlying wooden or cloth substrate. When it comes to understanding this material, however, inter-translatability becomes a big problem as many languages use only one word to refer to a range of ingredients. For example, the Spanish yeso can refer to the mineral gypsum or to the final product gesso made with either gypsum or chalk. English also does not distinguish different types of gesso and needs to resort to adjectives such as “thick” or “thin”. It is possible to catch a glimpse of the world of gesso through the famous work by Cennino Cennini written in the 15th century (1933). This Florentine artist wrote his treatise Il Libro dell’Arte containing recipes for materials and general tips for artists. During this time, different types of gesso were made for a range of purposes. In his description of the creation of an ancona[10] two types of gesso are used. The first is used as an under-layer to create the basis for three-dimensional decorations. In the translation by Thompson (1933) this gesso grosso is translated to “plaster of Paris”, which is hemihydrate gypsum ($CaSO_4 \cdot H_2O$). As such, this type of gesso would be similar to the material that we suppose was used to model three dimensional features in Mesoamerica. However, the gesso sottile that according to Cennini should be used to cover the grosso underneath is fully hydrated gypsum ground

10. An ancona is a type of panel or polyptych with modelled gothic decorative elements.

Figure 1.4A: Examples of colours as they appear today in a selection of the Precolonial Codices: Dresden; B: Mictlan; C: Añute; D: Ñuu-Tnoo-Ndisi Nuu (image A from SLUB-Dresden.de, B-D by the author).

down to powder. This top layer is thus made from powdered fully hydrated and inert gypsum mixed with a size (an adhesive such as animal skin glue). Whether or not the codices are made with dehydrated or hydrated gypsum is difficult to establish through either chemical or physical investigation, as the end result is chemically identical. And, moreover, hemihydrate gypsum absorbs water from the size and over time from the air and thus would also eventually turn into fully hydrated gypsum. Federspiel (1995, pp. 58-59) suggests that the translation by Thompson is actually incorrect when it comes to the gesso grosso. Instead of Plaster of Paris, she suggests that Cennini was referring to a soluble anhydrite (CaSO4), created by heating gypsum to 300-650 °C. Regardless, the end result is the same in this case: soluble anhydrite mixed with a size such as animal glue results, though slower, in the same dihydrate gypsum by absorption of water from the animal glue and over time from the air.

Natural mineral gypsum is difficult to process as it may contain impurities. As such, it is very likely that the gypsum was heated and subsequently ground and used for gesso, whether in dihydrate or anhydrite form. When gypsum is being heated to temperatures above 650 degrees, insoluble anhydrite is formed, which reacts with water very poorly. Mixing this type of anhydrite with size will not result in the chemical reaction leading to dihydrate gypsum, as the water will evaporate before it is able to be absorbed by the insoluble anhydrite. The essential difference between using either semi-hydrated or fully hydrated gypsum to make this writing surface is whether or not a chemical reaction and thus re-crystallisation takes place after application to the object. It seems that for the creation of a uniform writing surface crystallisation would be undesirable. Crystal formation would result in a heterogeneous surface, composed of individual crystals surrounded by glue. This would make the surface coarse and fragile.

Although it is therefore clear that both differences in availability and differences in material properties between chalk and gypsum exist, it cannot be ruled out that there were some other cultural factors that influenced the Mesoamerican's choice of one or the other. The aragonite in seashells such as Spondylus or conch is potentially a symbolically significant way of producing material for the creation of the symbolically significant books. Furthermore, it may well be that gypsum and chalk were procured from symbolically significant places, such as specific mountains or caves. But since both materials are geologically very common, it is impractical, if not impossible, to specify where the materials found on the codices were sourced. Still, a better understanding of the symbolical significance of these minerals may be gained if extraction sites are found and if these sites can be shown to be accompanied by a ceremonial assemblage.

1.2 IDENTIFICATION OF COLOURANTS

Cultures across the globe have used a wide range of materials to give colour to their world. Despite the fact that archaeological materials are often grey or brown after ages in the ground, the Mesoamerican world was, likely even more than our own, a brightly coloured one. Giving a colour to a surface can today be done in a myriad of ways. Modern pigments are for the largest part the result of centuries of alchemy and later chemistry (cf. Ball, 2001). Starting with the quest for the philosopher's stone, many new coloured materials were discovered allowing painters to use new stable, cheap, and beautiful colours. Most archaeological material, however, is coloured with materials already available in nature. These materials fall into two separate categories: mineral pigments and organic lakes. Mineral pigments are coloured minerals that, when ground down to a powder, retain or attain the desired colour. This powder can then be used directly, by mixing it with an adhesive and, if necessary, as a paint by thinning this with water. Organic lakes, on the other hand, are dyes extracted from plants or animals, which often need to be precipitated onto an inorganic substance in order to create a stable coloured substance (see Kirby, van Bommel, & Verhecken, 2014, p. 28). While this second material may be more complex than collecting stones and grinding them down to a powder, the organic lakes come in a much wider variety of colours. A disadvantage, however, is that the resistance to decolouration and the speed of decay of the dyes used to colour the inorganic substance varies enormously from plant to plant and from animal to animal. As such, it is very important when trying to make an organic lake that the appropriate source for the colour is used. In the case of the Mesoamerican codices, the colours used were mostly bright primary colours, though today some of these colours have become darker, faded, or even completely discoloured (see figure 1.4 and Chapter 3.4).

Though brightly coloured, the palette used for these works was relatively limited. The basic colours used and found in virtually all the codices were black, red, yellow, blue, and green.[11] The latter four are also often found in the numerals of the pictorial codices, though the blue paint is at times severely degraded. In general, the Maya codices seem to be less colourful, as the hieroglyphs they wrote were not filled in with colour. The images that accompany these texts, however, could be very complex and contain many colours. The best example of this is the Codex Dresden. The high level of degradation of this codex (see chapter 3) makes it the case that there is little left of the splendour this codex once must have had

11. It is important to take the linguistic differences into account here. Where most western languages differentiate between green and blue, most Mesoamerican indigenous languages do not distinguish these two "colours".

Material	Codex*	Source**
(Vegetal) carbon	Colombino; Cospi; Madrid	(Buti, 2012; Miliani et al., 2012; Zetina et al., 2011)
Cochineal	Colombino?; Cospi	(Miliani et al., 2012; Zetina et al., 2011)
Unknown red (not Cochineal)	Cospi	(Miliani et al., 2012)
Red Earth (Ochre)	Madrid	(Buti, 2012)
Yellow Organic Dye***	Colombino; Cospi	(Miliani et al., 2012; Zetina et al., 2011)
Orange Organic Dye***	Cospi	(Miliani et al., 2012)
Yellow Organic Dye on Clay	Cospi	(Miliani et al., 2012)
Grey Indigo	Madrid	(Miliani et al., 2012)
Blue Indigo on Clay	Colombino?; Cospi; Madrid	(Buti, 2012; Miliani et al., 2012; Zetina et al., 2011)
Yellow Orpiment	Cospi	(Miliani et al., 2012)

* Names as used in the articles.
** Publications are ordered to correspond with the codex investigated.
***Different shades are made probably with different plants, not by mixing of red and yellow.

Table 2. Colourants found in Mesoamerican codices by recent non-invasive investigation.

(see also chapter 5). Recently a number of both Maya and Central Mexican pictographic codices have been subjected to non-invasive research to uncover the composition of their colourants (see Table 2). Both pigments and lakes were used, though it seems that the Maya codices were mostly made with mineral pigments (see also M. D. Coe & Kerr, 1998, p. 151). As is seen in the table below, for many colourants it is unclear what organic source was used to make it. To provide an anecdote for these uncertainties, historical and ethnographic sources can be consulted. Using this information a more complete list of available materials can be gained. It must be kept in mind that the codices investigated thus far are only the tiniest fraction of what must once have existed. As such, they may not be completely representative of the material used for making books. Again, the historical sources are important, as they can suggest alternative materials. But these historical sources do need to be approached with care, as the Europeans also brought techniques and materials with them that quickly become incorporated in the Mesoamerican writing and art styles. In the following section, the available materials are discussed and categorised based upon the colours they produce.

BLACK

One of the most ubiquitously used pigments is carbon black. The X-ray fluorescence investigation by Miliani et al. (2012, p. 675) shows that the characteristic peak for carbon black from the charring of animal bones is absent. This peak is caused by organic impurities still present in the not fully burned black remains. It is, therefore, clear that the carbon black used in this case (on the Codex Tlamanalli (Cospi)) was of a vegetal origin and was not made by the burning of bones. The way to create carbon black is relatively easy, since carbon black is nothing more than pure carbonised wood in powdered form. In principle, then, it can be made by carbonising wood and grinding it. However, controlling a fire so that it completely carbonises, yet does not destroy the wood, is difficult. Besides that, grinding carbon is a laborious task. An easier, though possibly more lengthy way of obtaining the carbon black, is given by M. D. Coe and Kerr (1998, p. 151). They suggest that soot was scraped off the bottom of cooking vessels. Not much soot would be collected each time the vessel was scraped, making production a laborious process. However, since every household used cooking vessels on a daily basis, the supply would be continual and endless. The resultant soot is pure carbon, which, given that it was precipitated onto the vessel in the form of airborne particles, does not need to be ground down. A second source of soot may be the roof in the kitchens of precolonial Mesoamerican homes. Open fires are used to cook. The smoke of these fires deposits soot not only on the cooking vessels, but in much larger quantities on the roof. There it forms such a thick layer that it forms stalactites.[12] This is not recovered archaeologically, as the houses have long since decayed, though it can still be observed in indigenous communities today.

Next to carbon black, the Florentine Codex (Sahagún, 1577c Book 11, fo. 218r-219v) gives a very different recipe for a black ink:

"Ay en esta tierra un fructo de un árbol que se cria en tierras calientes: el qual fructo no es de comer, llamase este fructo nacazcolotl, usase este fructo para con el y cin aquella tierra que se llama tlaliyac o hazeche, y con casgaras de granadas y con goma que llaman mizquicopalli se haze muy buena tinta para escreuir."[13]

"There is in this land a fruit from tree which grows in warm lands: this fruit is not for eating, they call this fruit nacazcolotl, (Caesalpinia coriaria) they use this fruit with and without the earth which they call Tlaliyac (copperas i.e. Iron(II)sulphate) and with casks of pomegranates, and with gum which they call mizquicopalli (gum of the mesquite (Prosopis spp.)), see section on gums below) it makes a good ink for writing"
(translation by the author)

The underlying chemical principle of such an ink is explained by Cardon (2007, pp. 264-469). The pods are very rich in hydrolysable tannins which react with iron, introduced by the addition of Tlaliyac, to form a black dye. To this a gum is added to turn it into a well-adhering ink. This Nacazcolotl ink is chemically very close to the iron gall inks introduced by the Spaniards. As such, if Sahagún here describes a truly precolonial practice, the presence of an iron-containing black ink in a document cannot be used as proof that the document is post-colonial. The role of Nacazcolotl in the production of pre-colonial manuscripts has never been considered. It seems that any iron-tannin ink is automatically assumed to be a European introduction. Thus far, no clearly pre-colonial documents containing iron-gall inks have been found. The Nahuatl text about Nacazcolotl is different from the Spanish text, because it does not contain the reference to the "casgaras de granadas", which are not native to Mesoamerica. The Nahuatl text[14] rather extensively described the shape and form of a species of tree that grows pods. These pods have the shapes of scorpion tails and so can easily be identified from a description. The Nahuatl text, then, does indeed seem to refer to the pods of the Divi-Divi (Caesalpinia coriaria). If the native Nacazcolotl ink is indeed an iron-gall ink, it would be susceptible to degradation processes similar to European iron gall inks. It may be that this is one of the reasons for the lack of pre-colonial examples of this ink. Iron-gall inks can be notoriously damaging to the writing surface if the components are mixed in the wrong amounts (Daniels, 2006, p. 41). Furthermore, over time Iron-gall inks themselves degenerate to a

12. Thanks to Prof. Maarten Jansen for pointing out this possible source of carbon.
13. In the original text the separation between different words is sometimes unclear, therefore in transcriptions of the original texts, words have been separated according to modern Spanish conventions to facilitate reading.
14. Translated by R.Macuil.

brown colour and eventually may lose their colour altogether (Woods, 2006, pp. 206-208). The texts in the Florentine Codex give a prime example of this loss of colour by iron-gall ink.

Logwood is a third possible black colourant. The botanical name for logwood is Haematoxylum campechianum. It contains a flavonoid called haematoxylin. This flavonoid can be used to make a whole range of colours from blue to purple and black. However, with the exception of the black colours, these are not light resistant. If a black colour is desired, the haematoxylin can be oxidised to haematein, which is a very colourfast black dye (Cardon, 2007, p. 268). Next to this flavonoid this wood contains a large amount of tannins (Cardon, 2007, p. 268) which, as with the Nacazcolotl mentioned above, help to create a black colourant. Historically many species of tree have been used as dyewoods to obtain red, black and, blue colours, and this has led to some confusion about their naming. Oftentimes, the names reflect their place of origin. To make matters more complicated, in colonial times the Spanish referred to Logwood as Brasil (Eastaugh et al., 2008, p. 248). Haematoxylum campechianum does not grow everywhere in Mesoamerica, but is limited to the Yucatan peninsula and is also found in the Greater Antilles (Cardon, 2007, p. 264). Although it was available as a dye in the Yucatan area, whether this black material was used as a paint is unclear. Considering the availability of carbon as the by-product of any cooking or heating activity, it would seem unlikely that other sources for black inks were specially imported. However, since carbon does not work as dye for clothing, it may well be that other substances – such as logwood – were traded to dye textiles black. As such, it is not unthinkable that in those cases where it was available, this was subsequently used as ink.

Although traces of these substances have not been found in the codices thus far, some minerals were clearly in use in Mesoamerica to make black paints. These have been encountered in murals in, for example, Teotihuacan. Next to carbon black, the murals at this site were made with black made of manganese oxide (Magaloni, 1996, pp. 212-213). Manganese oxides and hydroxides are also found on Maya pottery (Houston, Brittenham, Mesick, Tokovinine, & Warinner, 2009, p. 63). Black manganese oxides and hydroxides exist in different forms, each a different combination of Manganese, Oxygen, and Hydrogen (Eastaugh et al., 2008, pp. 256-257). Most mineral forms, such as the most common form Pyrolusite, form in shallow water, such as shallow seas, lakes, or swamps (Eastaugh et al., 2008, pp. 319-320).

RED

The studies performed thus far show that besides black, red paint has also shown a remarkable consistency in its material composition. In all the investigations of central and southern Mexican codices, red turned out to be an organic lake. The UV-vis reflectance spectra made by Miliani et al. (2012, p. 675), as well as the results of earlier invasive chemical reaction tests by Dark and Plesters (1958b, p. 532) on Codex Añute, were shown to be consistent with cochineal. Cochineal is a red substance harvested from the bodies of the cochineal insect (Dactylopius coccus) (Cardon, 2007, p. 620). This is a parasitic bug native to Central and South America that lives on the prickly pear cactus (Opuntia spp.) (Phipps, 2010, p. 10). It can also be extracted from other insects, some of which are native to Eurasia, though none of these insects yield such a high concentration of this red substance. The chemical component responsible for the red colour is carminic acid ($C22H20O13$). The processing and use of cochineal bugs is described in detail in colonial sources describing the pre-colonial situation (Sahagún, 1577c B11 216v-217r), as well as sources describing its colonial use (see Sánchez Silva & Ávila Blomberg, 2005). It remains an important industry in the province of Oaxaca (Mexico) today, as cochineal is used as a food colourant and as a tradition dye for clothing. In order to make the colourant, the insects are harvested from the cactus and dried in the sun for the best quality. An alternative method, of lesser quality but with a faster production time, involves drying the bugs in an oven or on a hot (metal) plate (Cardon, 2007, p. 623). Once dried, the carminic acid can be extracted from the eggs inside the bodies of the female insects, by crushing them and heating them in water (Phipps, 2010, p. 10). A range of colours can be achieved using cochineal, by adding acids or alkali, as the colour of the carminic acid varies from pink and red to purple and even black depending on the pH level of the solution (Cardon 2007, 625; Phipps 2010, 10). By the time of European colonisation, a full industry of cochineal dyeing was established in Mexico, being not only part of a system of trade but also of tribute, as is clear from the Codex Mendoza (1541, folio 45r.). What the principle use of cochineal was, however, remains unclear. Although it is possible to dye fabric made of vegetal fibres such as cotton, the dyeing process is far more effective on animal fibres such as wool. Sahagún describes the dyeing of rabbit furs with cochineal. It seems that cochineal originated from the Andean region, where many cochineal dyed alpaca textiles have been found. Lacking large wool producing animals, the corpus of Mesoamerican cochineal dyed textiles is smaller. In Mesoamerica, where the only animal fibres that could be dyed were rabbit hairs and bird feathers, it may well be that the principle use of the substance was as an ink for writing. Next to cochineal, a second organic red substance was found on the obverse of Codex Tlamanalli (Cospi), though it is uncertain what this substance is exactly (Miliani et al., 2012, p. 675). There are numerous plants in the area that could be used to make red lakes. Nicaraguawood (Haematoxylum brasiletto) and the very similar Brazilwood (Caesalpinia echinata), grow in highland areas throughout Central America (Cardon, 2007, p. 278). Both species contain a flavonoid that differs from the abovementioned logwood to which they are closely related. This flavonoid – called brazilin – can, like haematoxylin, be oxidised to form a stronger colourant – in this case brazilein – which has a bright red colour (Cardon, 2007, p. 282). Although the value of brazilwood as a dye is reflected even in the name of an entire country,[15] it does have one major drawback. Although bright colours can be obtained, brazilwood is not lightfast. Had this substance been used in the creation of the codices, then, it would most likely have faded to a yellow or brown colour.

Wallert (1995, pp. 655-656) identified six words in Nahuatl for plants yielding red colourants, taken from colonial sources, specifically the Florentine and Badiano codices and the texts by Hernández. Two of these could be the abovementioned Brazilwood, (in Nahuatl Uitzquauitl) however, Wallert identifies the same words as Haematoxylum campechianum, which, for previously mentioned reasons, can only be H. brasiletto if it is to be red. In the work of Sahagún (1577c fo. 218r.), the name Uitzquauitl is also mentioned, though here it is clearly meant to designate logwood. It seems, therefore, that for the early colonial writers the difference between these two types of wood was not well conceptualised.

Nacazcolotl is also identified by Wallert as a red coloured material, though it has been shown that this in fact refers to a black colourant (see above and see Cardon, 2007, pp. 464-469). Besides these plants, Wallert lists tlacuahuac and tlapalli, neither of which could be identified as red colourants. Tlapalli is given by Sahagún as a generic name for colour without specific identification:

> *"Este nombre tlapalli, que quiere decir color, y comprehende todas las colores, de qualquier suelte que sean negro, blanco, colorado, açul, amarillo, verde, etc*" (Sahagún, 1577c B11, fo. 222v.).

Tlacuahuac features in Sahagún's discussion of cochineal:

> *"A la grana que ya esta purificada y hecha en panecitos llaman tlaquahuac tlapallo que quiere decir grana recia o fina*" (Sahagún, 1577c B11, fo. 216v.).

Molina (1970, p. 133) gives the translation "cosa dura o empedernida" for Tlaquauac. In this phrasing, it seems that Sahagún uses the word as an adjective, simply referring to good or strong cochineal.

Other plants that could have been used to make red dyes or paints are the Poinsetta (Euphorbia pulcherrima) and the Purging Nut (Jathropa curcas)

15. Brazil was first Ilha, then Terra de Vera Cruz, but ultimately the name was changed to the name of the dye Brazil, since the richness of this source of wood was clear. Cut into logs of 20 to 30 kg., this wood was transported to Europe and processed into wood chips, which could be boiled to extract the dye (Cardon 2007, 280). The name brazil already existed as similar trees containing the same substance and thus used to make similar dyes were known from Asia such as Sappanwood (cf. Cardon 2007, pp. 274-289).

or in Nahuatl the quauhayohuatli (Wallert, 1995, pp. 655-656). The origin of the Nahuatl name for Poinsetta – Cuetlaxochitl – is debated. The disputed issue is where the first part of the word – cuetl- or cuitl- – derives from. According to popular belief it finds its origin in the combination of the words cuitlatl (excrement) and xochitl (flower). This name could be explained by the fact that the seeds of the plant under consideration are often eaten by animals, ending up on dung heaps where the flower can be often found (Karttunen, 1983, p. 74). Another possibility is the relation to the word cuetlaxtli (leather) (Hernández, d'Ardois, & Miranda, 1960a, p. 320) as the crimson flowers of the shrub have a colour similar to freshly skinned hides. Whether any of these explanations is correct is hard to prove. What is clear, however, is that this plant is still very widely known in Mexico today, and is commonly used for Christmas decorations.

According to the study by Wallert (1995, p. 655), no Madder type of plants, such as Gallium or Relbunium species, were much used in the creation of Mexica objects. He links this to the fact that there are many other dyes available that already compose a full palette of resilient reds. Other Mesoamerican societies, especially those with less direct access to, for example, cochineal, may have used these dyes. A piece of textile found in the Chihuahua caves of Mexico is reported to be dyed with Relbunium (Cardon, 2007, p. 164). In South America, many textiles have also been found that were dyed with Relbunium species (Cardon, 2007, p. 163). While in Mesoamerica it seems to have been rapidly replaced by other colourants, in South America it stayed in use until the Spanish conquest, though even there it was in the process of being slowly replaced by the use of cochineal (Cardon, 2007, pp. 165-166).

Next to the organic colourants, there are mineral pigments available for the creation of red paints. Red ochre (Fe_2O_3) and cinnabar (HgS) are the most common. The second of these has the downside that it is highly poisonous. As a result it is generally only found in archaeology sprinkled on burials or offerings, the most famous example of which is the tomb of the so-called Red Queen of Palenque. Red ochre on the other hand is found extensively throughout Mesoamerican antiquity, used as a paint on pottery, on architectural features, and, as seen in Table 2, in some or perhaps all of the Maya codices. It is also found in the descriptions of Sahagún (1577c, p. fo. 221r.) under the name Tlauitl. Generally the colour obtained from red ochre is less bright than cochineal, though the major advantage is that iron oxide is present in a very common type of red earth found throughout Mesoamerica. A recent study by Dauda, Jigam, Jimoh, Salihu, and Sanusi (2012) has shown the antimicrobial properties of ochre from sources in North central Nigeria, due to the presence of iron and other metals such as Copper and Zinc. The study also shows that presence of these metal ions can be highly variable between ochre sources, which in turn influences the antimicrobial effect. More in depth study of Mesoamerican ochres would be needed to see if similar effects against pathogens can be seen, taking into account which pathogens were present in Mesoamerica before the conquest.

YELLOW

Organic yellow colourants are the most difficult of all to identify, especially in a non-invasive manner. This is due to the nature of plants in general. Two chemical substances are very commonly found in plants: the flavonoids and the carotenoids. Most forms of these substances can be used to make yellow or orange dyes, which in turn could theoretically all be used to make lake paints. Because they are so extremely common, it is very hard to identify the exact species of plant from which the paint is made, based solely on chemical composition. This is made even more difficult by the fact that there are no good databases with which to compare the studied materials. For this category, then, the colonial sources are thus especially important. Based on the "Historia general de las cosas de Nueva España" also known as the Florentine Codex by Fray Bernardo de Sahagún, By reference to the Codex Badianus and the "Natural History of New Spain", Wallert (1995) compiled a list of plants used as yellow colourants. These are: Zacatlaxcalli; Quauhtepuztli; Tepozcavil; Achiotl; and lastly Xochipalli.

Figure 1.5: Left: Image of Zacatlaxcalli from Sahagún (1577c fo. 217v.). Right: wild Zacatlaxcalli on the road to Santa Caterina, (Hidalgo, Mexico).

According to Wallert, the name Zacatlaxcalli actually refers to a whole range of species from the Cuscuta or dodder family. All of these species produce a very bright yellow colour. The name Zacatlaxcalli comes from the Nahuatl çacatl and tlaxcalli, the words for "grass" and "tortilla" (Wallert, 1995, p. 658). The substance causing the colour in these plants is stated by Wallert to be carotene.[16] During fieldwork in February 2014, Zacatlaxcalli was identified by native Nahuatl speaker Macuil Martinez and collected for study. The plant is not really a grass, but rather a parasitic vine in trees. Once dried it has the look and smell of hay, which may explain the naming. The drawing in Sahagún (1577c fo 217v.) is quite clear as to its shape (see figure 1.5). Unfortunately, it is not in colour and thus the most striking feature of this plant – its bright colour ranging from green when it is young to bright orange in the older shoots – is not shown.

Quauhtepuztli or Cuauhtepoztli is listed as a yellow pigment by Wallert (1995) which, according to him, is also known as Tepozcavil or Tepozcahuil. He identifies this as Copaifera himenifolia. This Latin family name meaning "copal bearing" would indicate that this tree produces the incense resin Copal. However, a recent study by Stacey, Cartwright, and McEwan (2006) revealed that the origins of true copal are diverse and poorly understood, but definitely not limited to this species of Copaifera. No other sources mentioning Copaifera himenifolia or the Nahuatl names for it could be found. It therefore remains unclear what colourant this could be and how it would have been made.

The Annatto (Bixa Orellana L.) shrub – called Achiotl in Nahuatl – produces a fruit of about 4 cm long containing many seeds which are encapsulated in an orange-red fleshy coat. This coat can be used to produce an orange-yellow dye. To extract this colourant, the seeds are soaked and pressed in water to dissolve the seed-coat (Cardon, 2007, p. 313). Annatto contains the carotene pigments: bixin and crocetin (Eastaugh et al., 2008, p. 56).

Xochipalli is given in Sahagún (1577c fo. 217r.) as a yellow colour made from yellow flowers:

> *"Al color amarillo fino llaman le xuchipalli, que quiere decir, tintura de flores amarillas: este color amarillo, traen la, y criase entierras calientes"*

The accompanying image (see figure 1.6) shows that the paint made from these flowers was used

16. A Zacatlaxcalli sample was tested using High-Powered Liquid Chromatography (HPLC) at the Rijksdienst voor het Cultureel Erfgoed (RCE, the Dutch agency for cultural heritage) in Amsterdam. These tests showed that the main component was Quercetin, a flavonoid, rather than carotene. This difference in results may be due to the fact that the age of the plant influences its colour. A young sample is green, which later becomes yellow and finally orange. This contradictory finding suggests to the need for further study.

Figure 1.6: Drawings of Xochipalli harvesting and use in Sahagún's Florentine Codex (1577c B11, fo. 217r.).

for painting and/or writing. The same flower can be seen first harvested and in the bowl containing the ink or paint that is being used by a scribe wielding a pen. These flowers were identified by Wallert (1995) as Cosmos sulphurous (also known as Bidens sulphurea), a plant used for making an orange-yellow colour. Cardon (2007, 239) states that yellow paint could have been made from many different species of Coreopsis, Bidens, and Dahlia flowers. The name Xochipalli is a compound for the word for flower (xochitl) and the word for colour (tlapalli) (Karttunen, 1983 see also ; Wallert, 1995, p. 659), which does not help much for its precise identification. Its colouring substances are most likely flavonoids which have to be extracted from the flowers by boiling them for a long time (Cardon, 2007, p. 237). The images in Sahagún (1577c fo. 217r.) of xochipalli (see figure 1.6), which Wallert does not seem to take into account, throw some doubt onto the identification of this flower as Cosmos sulphureus. The many-petaled nature of the flower suggests that it is closer to the Cempaxochitl, a species of Marigold (Tagetes erecta). Despite the fact that this flower is often called African Marigold, it actually is indigenous to Mexico. Moreover, this flower was, and is today, ritually very significant, as an integral part of the celebration of the Day of the Dead. Marigold flower petals contain a high concentration of the carotene Xanthophyll, which

Figure 1.7: Drawing of Matlali in Sahagún's Florentine Codex (1577c B11, fo. 217v.).

is also commercially exploited as a natural food colourant (see Pratheesh, Benny, & Sujatha, 2009).

In Hernández (1615) B3, fo 131v. Xochipalli is described as well:

> *"La xochipalli, es una yerua de seys codos de alrgo, que produze las ojascimbossas, y en cierta manera semejãtes à las del Artemissia, los tallos de un dedo de gruesso, las flores del cempoalxochitl, pero menores, q de color amarillo tiran à rojo, las rayzes delgadas, y largas. Nace à cada passo en tierras calientes, y es yerua q todas la conocen, usase solamente de la flor. ...y es de grandissima utilidad para teñir las flores, digo las canas, y para pintar las ymagines, y cosas de color amarillo, y q en cierta manera tira à rojo, para lo se cuezen en agua, juntamente con salitre, y al final se exprime el çumo y se cuela, del qual usan los pintores y tintoreros para lo q auemos dicho."*

The flowers of the Artemisia with which Hérnandez compares xochipalli are also a multi-petaled, making the identification of xochipalli as Tagetes erecta likely. Houston et al. (2009, pp. 104-105), mention two other yellow colour-producing plants in the Maya area, which are Maclura tinctoria L. (also known as Chlorophora tinctoria) or Old Fustic and Gliricidia sepium or Mexican lilac. When using Old Fustic, only the heartwood produces a lot of colour (Cardon, 2007, p. 196). In the case of the Mexican lilac, the roots are used. One of the Maya names given for this plant by Houston et al. (2009, p. 105) is Kanté. Interestingly, Magaloni (1998, p. 76) mentions a paint made by present-day Lacandon Maya, also from the roots of the Kanté tree. She believes that Kanté is a likely candidate for the organic yellow pigment found on the Bonampak murals (Magaloni, 1998, pp. 75-76). One last possibility for the creation of an organic yellow colourant was suggested during the fieldwork in February 2014 by a local resident of Santa Catarina (Hidalgo, Mexico), Don Alejandro. According to Alejandro, the bark of the Colorin or Coral tree (Erythrina corallodendron) is used by some to create a yellow paint. All these yellow organic colourants have in common that they have a relatively poor light fastness (Cardon, 2007, p. 167), which inevitably leads to fading over time.

A very common yellow mineral is yellow ochre. Related to red ochre, yellow ochre is the hydrated form of iron oxide (FeO(OH)·nH2O). Like red ochre it is very commonly found as a type of earth. It is likely that this earth was used in the creation of the Maya codices. The investigated Madrid Codex, however does not contain any yellow areas. As previously mentioned, the Dresden Codex does contain yellow areas, although the colourants in these areas cannot be identified without the use of investigative methods capable of penetrating the glass pane to which the codex has become fused after the flooding of the Library basement (see Chapter 3.4). Like its red variant the colours obtained with yellow ochre are generally less bright than those from plant sources. On the Codex Tlamanalli, the mineral orpiment was identified as a yellow paint (Miliani et al., 2012, p. 675). This mineral is a compound of arsenic trisulphide (As2S3). The name orpiment (from the Latin Auripigmentum) is a good indication of the golden colour that is achieved when painting with this mineral. It is a sublimate of volcanic activity, meaning that it needs rapid cooling of the fused arsenic and sulphur, which happens above 390 °C and results in the formation of the crystals. It is commonly found in circumstances such as hot springs where water acts as a cooling agent for the escaping arsenic and sulphur compounds. Such circumstances are also where the abovementioned cinnabar is found. Another feature of orpiment that is similar to cinnabar is the fact that it is highly toxic (Eastaugh et al., 2008, p. 291). However, the toxicity of orpiment as a solid mineral is low. It is the arsenic contained within the orpiment compound that is dangerous and as the mineral is not very soluble, the arsenic remains bound with the sulphur and is thus relatively harmless. This changes if orpiment is being ground to use it as a pigment. The finer the substance is ground, the easier it becomes to dissolve in water and thus to be absorbed in the bloodstream after ingestion (see Buchanan et al., 2013). The implications of working with a poisonous powder are clear. For safety reasons, though orpiment has been securely identified as ingredient for at least one codex, it is not used in the experimental replication.

Blue

While yellows are so abundantly available, blue is a notoriously difficult colour to produce. The colour blue holds a special place in virtually all cultures (Ball, 2001, pp. 231-232). The main problem with blue is that there are virtually no minerals that retain their blue colour when ground to a powder, a requirement to make a smooth and brightly coloured paint. The few minerals that do have the right properties are scarce. Malachite, Azurite, and Veszelyite have all been attested on Mesoamerican painted objects (Garcia Moreno et al., 2008; Houston et al., 2009, pp. 54-56). These receive their blue and green colour from the copper that is bound with carbonates and phosphates in these minerals. However, on the codices that have been investigated so far, no trace of these minerals has been found, suggesting that the blues are of an organic origin.

In Sahagún (1577c) a number of different names of plants are given which were used to make blue paints. The first one is made from blue flowers and is called Matlali (fo. 217 v.). The images accompanying the text show a fourlobed flower on a plant with long, pointed leaves attached to the stem (see figure 1.7). Identification of this plant is made difficult by confusion regarding the translation of the terminology for green and blue. It seems, in fact, that Matlalin can be both a dark green and a blue. The interpretation of this colour being somewhere halfway between blue and green is further strengthened by the comparison made by Sahagún to Cardenillo, a copper acetate. This oxidated copper has a blue-greenish colour that is difficult to name in English.

Figure 1.8 left: Matlalxochitl (Codex Badianus 1577, fo 10v.); middle: Çacamatlalin (Codex Badianus 1577, fo. 48r); right: example of Commelina coelestis (photo by the author).

Making a blue colour from a blue flower is not straightforward. The colourant that gives blue flowers their colour is anthocyanin, a type of flavonoid that is generally very unstable (Cardon, 2007, pp. 241-242). Using blue flowers on a large scale means that the plant needs to produce flowers in large quantities. In the Codex Badianus (Cruz & Badiano, 1991[1552]), two plants can be found that may be the same as the one given by Sahagún: Matlalxochitl and Çacamatlalin (fo 10v. and fo. 48r, see figure 1.8 left and middle). Both these plants have blue flowers and the structure of the leaves is very similar to the drawing in Sahagún, even though the number of petals seems to be different. These two plants are both identified as Commelina coelestis, a species of dayflower common in central Mexico (see figure 1.8 right). According to Cardon (2007, p. 242), the related Commelina communis was used in Japan on awobana paper. What makes this flower special is that it gets its colour not from regular anthocyanin, but from a complex metalloanthocyanin. Similar to the process used when making a stable pigment from a colourant, the anthocyanins are bound together with metal ions (see Shiono, Matsugaki, & Takeda, 2008). The result is that the blue extracted from the Commelina flowers is much more stable than most blue flowers.

According to Sahagún (1577c fo. 217v.), however, this same Matlalli is used for the creation of the blue clothing:

> *"Ay color azul claro, de color del ceilo, lo qual llaman texotli, y xoxouic: es color muy usada en las ropas, que se visten, como son las mantas delos hombres, y uipilles de las mujeres: haze se de las mismas flores, que se haze el matlalli, o/ o color fino."*

This does not fit the description of the Commelina, as the metalloanthocyanins are insoluble and thus not suitable as a dye. Thus, it seems that either multiple flowers are known by the same name or the Spanish chroniclers were themselves confused by the many different names.

The other blue paint given by Sahagún (1577c fo. 219r.) is easier to interpret. It is a herb named Xuiquilitl or Tlaceuilli, which is macerated and

Figure 1.9: Drawing in Sahagún (1577, B11 219 r.) of Tlaceuilli or Xuihquilitl.

squeezed to extract the required juices:

"Ay una yerua, en las tierras calientes que se llama ~~Tlaceuilli~~[17] Xuihquilitl, maian esta yerua, y esprimela el zummo, y echan lo en unas vasos: allo se seca o se guaja: con este color se tinen lo verdes azul oscuro, y res plan deciente: es color preciada."

Although the plant in the drawing (see figure 1.9) copies the structure of one individual side branch rather than the entire shrub, it bears a great similarity to Indigofera suffruticosa, source of the dye Indigo, or as it is known in Mexico today, Añil.[18] The process to make blue colours with indigo has been described extensively elsewhere (see Balfour-Paul, 2006, pp. 89-145; Cardon, 2007, pp. 335-353). Chemical dyeing with indigo involves the conversion of indican and isatan in the plant to indoxyl, which is colourless but water-soluble. In practical terms, this means that the leaves of the indigo containing plant need to be cut and crushed in hot water. Enzymes then convert the indigo in the leaves into indoxyl, making the solution colourless. This state needs to be maintained by adding an alkali such as lime potash or sodium carbonate to counteract acidification. Only when fully converted to soluble indoxyl can the substance penetrate the fabric that needs to be dyed. Once the textile has been saturated it can be hung out to dry. Two colourless indoxyl molecules combine by the absorption of oxygen and turn to blue indigotin. Often more than one bath in the indoxyl solution is needed to attain the desired shade of blue.

17. Corrections appear in the original.

18. This term has had a long history showing the route that indigo took in the Old World. It is derived from the Sanskrit word nila meaning dark blue, transferred to Arabic as an-nil which became añil in Spanish (Balfour-Paul, 2006, p. 11).

Indigo was used as a dye for centuries in the Americas before the Europeans arrived. Although most archaeological evidence for its use comes from South America, the fact that indigo is a much better dye for vegetal fibres (unlike cochineal discussed above) makes it likely that it was used in Mesoamerica as a dye as well. It was not only used as a dye though, as Arnold (1987, pp. 69-70) points out when cataloguing the use of indigo as a medicine for a range of diseases.

While indigo is stable when bound to a textile, it is fugitive in its unbound state. It surprised researchers, therefore, when it was encountered in a bright blue paint, called today Maya Blue, in murals that had been exposed to the elements for centuries, all the while remaining stable in colour. When this substance was first studied by Merwin (1931) in Chichen Itza's murals, it was assumed not to be organic, though it was recognised that it did not have any relation to copper minerals or ultramarine (Gettens, 1962, p. 557).

In rejecting the possibility that the Ancient Mesoamericans had overcome the susceptibility to decay that plagues all organic blues, Merwin (1931) believed the material to be related to a blue clay called beidellite. It turns out that Merwin was not completely wrong in the sense that this paint did indeed contain clay. However, its colour was the result of Ancient Mesoamerican people's ingenuity, not nature. In 1962, while the material was still believed to be an inorganic pigment, one constituent was identified as attapulgite, today called palygorskite (Gettens, 1962). By 1966, van Olphen managed to produce a stable blue colourant by colouring palygorskite with indigo. The exact molecular structure of Maya blue is still under debate (Arnold, 2005, p. 53). The underlying principle giving stability to the indigo must however be explained by the shape of palygorskite, showing that Maya Blue is truly an ancient nanostructured material. Palygorskite has a laminar structure with holes in each layer which overlap (see figure 1.10).

19. Giustetto et al. (2012) show the possibility of a red colourant being stabilised by encapsulation in palygorskite, indicating the possibilities of creating a whole spectrum of colours based on this ancient technology.

This creates a series of tunnels that are of just the right size for an indigo molecule to enter, where it is shielded from biological and chemical attack (José-Yacamán, Rendón, Arenas, & Puche, 1996). Van Olphen (1966) discovered that heating the clay-indigo mixture was the key to fixing the indigo inside the clay structure. Eastaugh et al. (2008, p. 262) state that to make Maya blue the material need to be heated to about 150 °C for about two days. Variation in temperature during the production process has been shown to produce other colours such as a "Maya Green" and "Maya Yellow" (Domenech, Domenech-Carbo, & Vazquez de Agredos-Pascual, 2011).

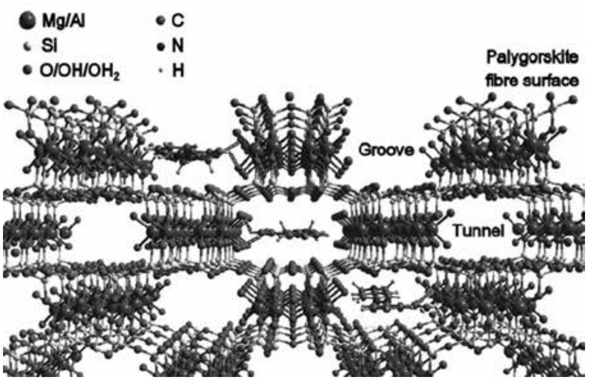

Figure 1.10: Structure of Palygorskite. Positions a, b & c are examples of locations where indigo could enter the structure and be protected from degradation. (from Giustetto, Seenivasan, Pellerej, Ricchiardi & Bordiga, 2012 fig. 10).[19]

OTHER COLOURS

Apart from the already mentioned colours black, white, red, orange/yellow, and blue, a few other colours which can be called "derived colours" are also found in the precolonial codices. The green thus far identified on the codices was made by mixing blue and yellow, most likely Maya blue or Matlallin combined with an organic yellow colourant on a clay base. Sahagún (1577c fo. 221v.-222r.) describes how, by changing the relative amounts of yellow and blue pigment, brighter or darker green was made, each having a different name (quiltic and yiapalli respectively). As it is known that in the Maya codices mineral pigments were used, green may have been made from green earth. This mixture of minerals, most of which is glauconite or celadonite, is mostly Iron Aluminium Magnesium Silicate (Eastaugh et al., 2008, pp. 180-181). This may well be the green seen in the Dresden Codex. Though used extensively in murals (see Magaloni, 1998; Magaloni Kerpel & Falcón Álvarez, 2008) no minerals such as Malachite have been securely identified on the codices. Malachite is in general a brighter green colour than that made with green earth. Besides these minerals, the green colour created by varying the temperature when making Maya Blue is a third candidate for these green paints.

Both pink and grey are relatively often found in the codices, but thus far they have only once been identified as truly separate colourants. Generally they are simple dilutions of red and black, allowing the white surface to shine through. Only when investigating the Codex Madrid, the presence of indigo on a grey area could be established (Buti, 2012, p. 69). It has been suggested that there is a symbolic similarity of blue and grey (see Buti, 2012, p. 69). However, this use of indigo as grey may also be unintentional as it may be the result of discolouration over time. The Codex Añute displays areas of degraded blue that now are grey or cream coloured. Inferior quality of either processing method or raw materials may have led to a less stable Maya Blue, and thus to the degradation of the indigo molecules over time.

Purple is a colour found only very rarely in the surviving precolonial documents. Both Codex Tlamanalli (Cospi) and Tonindeye (Nuttall) exhibit some areas that can be called purple. In the descriptions on mixed colours Sahagún (1577c fo. 221v.) describes how a mixture of cochineal and alum is used to make purple. His description continues, however, with the statement that this is the way painters make shadows, which is a colonial drawing technique. A famous purple dye was used in precolonial Mexico and is still used today, which is similar to a technique used in Ancient Rome. A purple dye extracted from sea snails was used to dye the robes of the Roman Emperor, and is used today on the Mixtec coast to dye cloth as well. A precolonial expression of this can be found in the Mixtec codex Añute. On page 7 of this manuscript a huipil can be seen on which a shell is drawn. Most likely this is an

Figure 1.11: Image of the Codex Mictlan (Laud) before and after removal of red and yellow channels, showing thee pattern of black spots.

expression that is to be read as a purple dyed huipil. The sea snails producing this purple dye all belong to the same family: the Muricidae. The source of the Mexican dye is the Purpura patula pansa, (Sayer, 1988, p. 24). The chemical component that gives the dye its colour – and pungent smell – is 6,6'-dibromoindigotin (Eastaugh et al., 2008, p. 379). The presence of bromine should make a pigment made with this material relatively easy to distinguish, if non-invasive investigation is performed on these areas in the future.

1.3 COVERS

Leather or paper covered with a white mineral layer is both fragile and susceptible to water and dirt. Furthermore, the contents of these books were very important and thus warranted both physical and symbolic protection. One way of protecting a book would be is to attach covers to front and back. Only of three codices, the Codex Tonalpouhqui, the Codex Mictlan, and the codex Tonindeye, is it certain they still have their original covers, though there is clear evidence that others once had a cover as well. None of these original covers has received much scholarly attention, however, thus far three identifiable types are: fur, feather mosaic, and inlaid or encrusted wood. The cover of the Codex Mictlan, for example, was identified by the author (Snijders, 2014) as a jaguar fur cover. The front and the back of the codex have a second piece of leather attached to the outer surface. These pieces are thinner, harder, and slightly larger than the main part of the codex, overlapping the folios about 1mm on all sides (see also Burland, 1966, p. 9). On the front of the document, some texts were written when the book entered the collection of the Archbishop of Canterbury in 1634 and later when it entered the Bodleian Library of the University of Oxford. While all the texts thus postdate the creation of the codex itself, the material of the cover has already been described by Burland (1966, p. 9) as pre-colonial. Although currently only one small patch is left, according to earlier descriptions (Burland, 1966, pp. 9-10; Paso y Troncoso, 1961, pp. 31-32), the front cover once contained multiple small patches of fur. Since the process of creating leather involves as one of the first steps the removal of hairs, it is clear that these are fur, rather than leather covers. Apart from the small surviving patch of dark fur, the overall colour of the covers has become dark beige due to the tanning and aging of the skin. When digital images of these covers were studied using Photoshop© and the yellow and red channels were removed in order to reduce the discolouration of the skin, a clear pattern of black spots became visible (see figure 1.11).

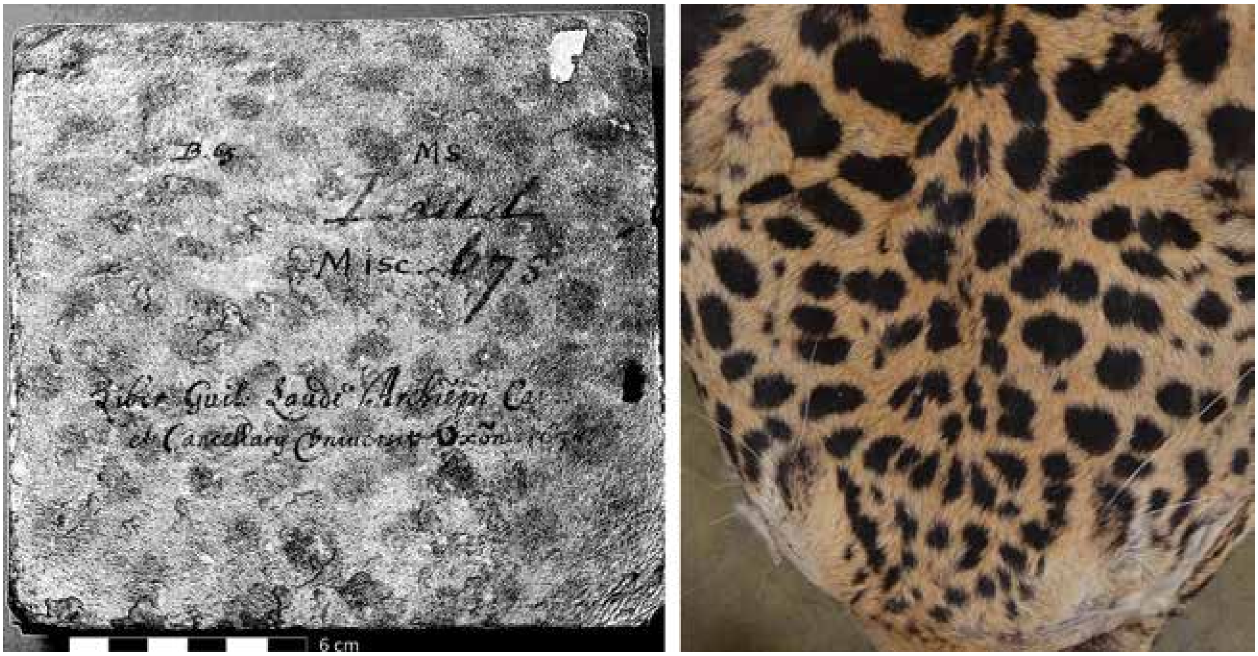

Figure 1.12: Comparison of the edited image of the cover with the head of an average sized jaguar (images by the author).

In order to identify the animal used to make this cover, detailed photos of the front and back cover were compared with modern skins in the natural history museum Naturalis (Leiden, The Netherlands). As these skins retained their fur, it was only possible to make a comparison based on the size, frequency, and distribution of the spots. The earlier assumption that these covers are made of deerskin (Paso y Troncoso, 1961, p. 31) were easily dismissed. Though young deer may have spots of the appropriate size and distribution, their spots are white on a dark background. Only three species of spotted animal live in Mesoamerica that have black spots on a light coat: the ocelot (Leopardis pardalis), the margay (Leopardus wiedii), and the jaguar (Panthera onca). Both the margay and the ocelot have spots that form large, linear shapes, very different from the pattern found on the cover. The jaguar's spots usually form large rings, except for the area on the top of the head, where the individual spots are more evenly distributed. If the image of the spots on the cover of Codex Mictlan are compared at the same scale with the head of a jaguar of average size (body length of 1,2m), it is clear that the spots are also of similar size (see figure 1.12).

Considering the fact that the jaguar shown in figure 1.12 was not very large and that furs can be stretched significantly, the area on the top of the jaguars head would be large enough to create the cover of the relatively small Codex Mictlan. On the back cover spots of similar size can be seen as well, though with more difficulty. They form two large rings as is the more general pattern found on the jaguar's back and sides.

Because of the relatively poor state of conservation of one of the skins in the Museum Naturalis, one small piece (approximately 3 by 6 cm.) detached from the main skin during the investigation. This piece was made available to the author for the investigation of the skin itself, allowing for a comparison of the follicle pattern on the skin of the jaguar with that found on the cover. Though the piece came from the relatively light-coloured and longhaired belly side of the animal, some valuable information could be gained. Due to early conservation treatment of the pelt, the removal of hairs was difficult as the sin had become brittle, causing the epidermis to easily detach from the corium. Once shaved, it was studied under a stereoscopic microscope (Nikon

Figure 1.13: Comparison of the skin of a modern jaguar (left) with the cover of the Codex Mictlan (right) (images by the author).

SMZ800) with a magnification range: 10x-63x. The downside of using a 60 year old and desiccated skin became immediately apparent, as it was impossible to remove the hairs completely without damaging the skin and thus destroying the follicle pattern. It could be observed however that the hairs grow in clear clusters. Furthermore, the dark hairs sprout from hair follicles that are themselves darker than the surrounding skin. As a result the dark spots of the jaguar's fur are seen on the level of the skin as clusters of darkened hair follicles. A similar pattern can be discerned on the cover of the codex (see figure 1.13).

As with the substrate, definitive identification through such follicle pattern analysis is problematic due to variation within the species and individual skins. As such, definitive identification of this fur, just like the definitive identification of the leather used as substrate for the codices, may only be possible with (invasive) DNA analysis. Depictions of codices, especially those found in Maya art, generally show the books with a black spotted cover. Given the high quality of the codex, it is only fitting that it was given a special cover. The symbolic significance of the jaguar in the Americas has been well established (cf. Saunders, 1994). Using the skin of the head may have made this cover even more symbolically significant, though there are two practical considerations as well. First of all, as the book is so small, selecting an area of the jaguar skin with small and more or less equally distributed spots may have been more aesthetically pleasing. Secondly, as a result of its size the skin on the head of the animal is not the most versatile and it may thus have been a practical consideration to use a piece of fur that fitted nicely as a book cover but could not have been used for anything else.

It is likely that another original fur cover exists underneath the silk velveteen cover of the Codex Tezcatlipoca. Burland (1971, pp. 20-21) observed that the thicker leather attached to the front and back of the codex exhibits large hair follicles. Therefore, he suggested that this codex had a fur cover similar to the Codex Mictlan, though of a coarser fur. From what animal this fur was obtained is unclear, however, and warrants further investigation. The loss of hair of both the cover of the Codex Mictlan and possibly that of the Codex Tezcatlipoca can have multiple causes. The first is desiccation. When a skin dries out, the hair follicles open up and the hair may fall out (Kite, 2006b, p. 167). Secondly, insects may have caused the loss of much of the hair as was already noted by Burland (1966, p. 10). A third problem may be mechanical friction caused by sliding the manuscript in and out of the box it has been kept in, or between other books if it was kept vertically on a shelf. Codex Mictlan is today kept in a box, the leatherwork of which does not seem to be English in style. It may be, then, that the book was put in this box before it arrived in England. This box is, however, slightly too big, suggesting that, if the box was made for this particular manuscript, the book used to be thicker. This could be explained if the covers were still covered in hair when it arrived in Europe, presumably at some time in the 16th century. By 1634, however, most of the hairs on the cover of the Codex Mictlan must have been gone, as the alphabetic text and date is written over the damaged areas.

A second type of codex cover is that found on the Codex Tonalpouhqui. This cover is made of wood on which in one corner a single piece of turquoise-coloured inlay remains. The rest of the design has been lost, though close study of the original shows that it was probably not very complex. Next to the one remaining inlay in the upper right corner, a second circular indentation in the bottom right corner suggests a similar inlay was placed there. In the central part of the cover four clusters of indentations are found. What these originally depicted is difficult to assess as the indentations are rather uneven and are filled with a partially decayed resin used to hold the inlays in place. Next to these indentations the colour of the wood itself indicates that something may have been glued onto the entire surface. The wood has, in places where it is not worn off, the same dark colour as the resin found in the indentations. Neither the wood nor the inlays have been definitively identified, though the inlay has been called turquoise (Anders, Jansen, & Reyes García, 1993c, p. 16). Because of the size of the inlay and inability to take samples it is difficult to truly determine the nature of this green-blue stone. Many chemically different, yet visually similar, precious stones were in use in Mesoamerica (see Ruvalcaba-Sil, Melgar-Tisoc, Curado, Laclavetine, & Calligaro, 2013). A second wooden cover can be found on the Codex Yuta Tnoho. This cover was identified by Anders, Jansen, Reyes García, and Pérez Jiménez (1992, p. 17) as a type of Pine. This tree is native to Mexico and it could therefore be an original cover. The wooden boards are both split and held together with more modern metal clamps. The surface of the wood has dark discolourations similar to the Codex Tonalpouhqui. The corners of the wooden boards are worn and rounded again similar to the Codex Tonalpouhqui. Investigation of the original is needed to compare the way this wooden cover is attached to the leather in order to establish if this could be another original cover.

Very little has been written about the cover of Codex Tonindeye. In facsimiles it is visible that both the front and the back show traces of a brown material adhering to the leather surface. When studying the surface in detail, Troike noticed that this brown was a resin or glue into which the imprints of feathers were visible (Anders & Troike, 1987, pp. 39-40). A square imprint may be the only remaining trace of stone or shell inlays that also decorated the surface. Since there are only very few imprints left, as the brown resin or glue is severely worn, it seems unlikely that it will ever be possible to recover the design of the cover. The other codices exhibit either post-conquest covers or have no cover at all. The Codex Añute, for example, does not have a cover, but has a year glyph written on the verso side of page 1. This glyph clearly is contemporary with the images of the known codex, as it is written on top of the gesso that covers the palimpsest (see chapter 6). In order to protect this document, however, the leather at the end of the document is long and flexible so it can be wrapped around the book. A protective white parchment-like material has been attached to this by the curators of the Bodleian Library to further protect the whole document. All the Maya books, as well as the Mixtec Codex Iya Nacuaa, are broken up into sections or individual leaves. There is no clear evidence where and how a cover may have been attached to these manuscripts. The Paris Codex has a dark discolouration on the first page, which may be glue to attach a cover. However, this leaf is so damaged that it is difficult to ascertain whether or not a cover was ever actually affixed to the page.

Next to the previously mentioned Codex Tezcatlipoca, two more codices were given at some point in their history a European cover. The clearest of this is the Codex Tlamanalli, which received a new leather cover when it was given to Count Cospi, as can be read in the text on this European leather cover. Another European-style cover has at an unknown point in time been added to the Codex Yoalli-Ehecatl. Around the edges of the first and last page of the document small holes can be seen that have been discoloured. Through these holes iron nails were once placed to attach the document to this cover. The codex is still stored between these covers, though the nails have been removed. The two covers have since then been connected by a spine, making it impossible to attach the cover without making half the book inaccessible. When this new cover was added is unclear, and the reasons for the removal of the old cover are also unclear. It appears to have been common practice in the Vatican Library to give books new covers.[20]

1.4 ADHESIVES

All the elements described above need an adhesive to hold them together. The term adhesive is an overarching term that covers any material that can create a bond between two substances. The adhesives available in Mesoamerica are all organic and thus suffer from the same difficulty for identification as the organic paints: they are difficult to detect using non-invasive investigation techniques. An additional challenge is that the concentration of binding medium relative to what is bound is generally very low. Because of this, no non-invasive technique exist at this time that can securely identify adhesives. From historical sources and from invasive tests done on pre-colonial objects other than the codices, it is possible to determine the range of options available to the pre-colonial codex makers. Evaluation of the advantages and disadvantages caused by their physical properties can help to select the most likely candidates for specific parts of the codices. The three types of adhesives available in Mesoamerica are glues, gums, and resins. These three categories differ in the sources of the material and in their properties. Natural glues are often won from animal origins, being composed of hydrolysed collagen, and extracted from the connective tissue in bones and skin (Kite 2006, 192). Hot water is used to break the hydrogen bonds between the individual collagen molecules, thus untangling the triple helix structure into a mass of gelatine. The animal glues are of different strength depending on their source. Both the species of animal, as well as the part of the animal used, are factors that influence the strength of the resulting glue. These factors have an impact on the purity of the gelatine extracted. Hide glue is, as the name suggests, made of the skins of land animals. It is relatively strong and had historical applications ranging from bookbinding to furniture making. A special type of hide glue is rabbit glue, made from the skin of rabbits or hares. This type has less structural strength, but more flexibility than regular hide glue. Another type of glue can be extracted from bones and is predictably called bone glue. It is generally considered inferior to hide glue, as its structural strength is weak and it is quite inflexible. Fish glue is made from swim bladders or, if it is of inferior quality, fish bones and skin. One of the properties of fish glue – its ability to stick to a porous surface – made it the glue of choice in Medieval Europe for the illumination of manuscripts (Kite, 2006a, p. 194). Both skin and bone glue were probably available in Mesoamerica as they are natural by-products of the hunt. Whether or not fish glue was used, especially outside of the coastal areas of Mesoamerica, is uncertain. Like the process of leather making, the fabrication of glue from skins and bones is not a subject that receives attention in the colonial codices. Most likely this was a job so familiar and of such little value that it was not considered necessary to describe it. The physical properties of animal glue, however, do put one restriction on its use. If it is to be applied, it needs to be mixed with water and warmed up to 30-50° C. to melt the glue (Kite, 2006a, p. 192). When the mixture cools down, it becomes a gel. Overheating the mixture should be avoided as this breaks the collagen molecules, which will make the glue lose its adhesive strength.

Mesoamerica is an area rich in plants that secrete gums and resins. Both are won from trees, the only difference being the extraction method. Gums are naturally secreted from the bark of trees, while resins require cuts to be made in the tree to make it "bleed'. Gums generally harden when exposed to air, but they are also generally water soluble. Resins on the other hand do not generally dissolve in water, though they too harden over time. One of the most useful gums in the world is Gum Arabic, won from

20. According to Dr. Roth, Director of the Department of Printed Books of the Vatican Library, who described this practice, the general policy had been to throw the old covers out.

species of Acacia. Although, as the name suggests, the best gum of this type is won from an Arabic species of Acacia (Vachellia seyal), similar gums are extracted from Mesoamerican Acacias. One example which is used today by artists is extracted from the mesquite tree[21] (Acaciella angustissima). The most well-known resin from Mesoamerica is Copal. This resin was ritually very important, as it served as a form of incense. It was also used as an adhesive, especially in order to make stone mosaics. The investigation by Stacey et al. (2006, 338) of the adhesives used to make the Mesoamerican mosaic objects now kept in the British Museum showed that copal-like resins could be extracted from different sources such as Pine; i.e. Boswellia spp. and possibly Bursera spp. The material commercially sold today as Copal ranges in colour from white to brown and black, reflecting different origins. While very useful for mosaics, Copal resins have one key disadvantage: their insolubility in water. Unless it is used directly after extraction from the tree, Copal resin will first need to be liquefied if it is to be used as an adhesive (McEwan, Middleton, Cartwright, & Stacey, 2006, p. 41). This can be done in the case of Copal by heating it to several hundreds of degrees Celsius.[22] On cooling it will again set and create a strong bond between, for example, a wooden surface and stone mosaics. However, both of the materials between which the bond is created need to be able to withstand the high temperatures required to liquefy the Copal resin. One problem of resins is that they set rather quickly, as the experiments of Berdan (2007, p. 18) have shown. As a result, they are not applicable to situations where the applied material needs to stay liquid, as is the case with the gesso and the paints and inks.

A fourth type of adhesive that needs to be considered in the Mesoamerican context was produced from orchids. These have been the subject of recent study, most prominently by Berdan, Stark, and Sahagún (2009) who also tried to replicate the process of making the glue. Martinez-Cortés (1970, pp. 17-22) provides an overview of the plants identified by various authors as having been used to make the different versions of tzacuhtli. He based his taxonomy on the information found in Hernández (1615), Sahagún (1577c), and the Badiano Codex (Cruz & Badiano, 1991). The use of a plant specifically named tzacuhtli by painters is recorded in both Sahagún and in Hernandez:

> *"...se prepara con ella un gluten excelente y muy tenaz que usan los indios y principalmente los pintores para adherir más firmamente los colores, de suerte que no se borren fácilmente las figuras."* (Hernández, 1615, p. 377)

And

> *"El color amarilla mezclando que se llama Çacatlaxcalli con color açul clara que se llama texotli y con tzacutli: hazese un color verde escuro, que se llama yiapalli: que es verde escuro."* (Sahagún, 1577cBook 11, fo. 221 r. and v.)

Atzauhtli, an aquatic plant, was clearly seen as related, at least in function. The name is composed of the word for water "a(tl)" and the same tzauhtli as seen above:

> *"sirve de pegamento a los indios,y principalmente a los pintores, que procuran y consiguen así la firmeza y adherencia de sus colores."* (Hernández, 1615, p. 373)

While the importance of this material for the understanding of Mesoamerican paint compositions is clear, to this day there is no agreement as to the identification of the species of plants used to make these glues. Martinez-Cortés (1970, p. 21) identifies Tzacuhtli as the epiphytic Epidendrum pastoris and Chranichis speciosa as Atzauhtli. Berdan et al. (2009, p. 149), however, argues in contrast that the drawings in Hernández (1615) of Tzacuhtli look more like Bletia or Govenia species which are terrestrial orchids. The experiments conducted by Berdan et al. (2009) show the difference in strength between the glues made from the different species of orchid, which helps explain why sources such as Hernandez stress the difference in quality between the glues

21, During fieldwork in Mexico in 2014 the author met with a local artist, José Luis García in Huajuapan de Leon, who explained he used mesquite gum in his mural paintings.
22. Slightly variable, depending on the species of plant from which the Copal is extracted, but on average 300 °C.

Figure 1.14: Bottom right corner of the cover Codex Mictlan, no traces of white "cement" are visible, only what appear to be the remains of brown glue.

made from the different plants they mention. The general principles for working with orchid-glue are also given by Sahagún (1577c). First the roots or pseudo-bulbs need to be cut into small pieces, which are subsequently dried in the sun and ground into a fine powder. Berdan et al. (2009, p. 149) found a large difference between the terrestrial and epiphytic orchids in the amount of fibres in their bulbs, making the terrestrial orchids much easier to process to a powder. They also yield a stronger gum, though overall it is clear that orchid gums are relatively weak in their adhesive strength. A major advantage of this glue, however, is that it is completely clear. As such, it leaves no discolouration on the surface it is applied to.

There are numerous bonds in a codex that need to be created using adhesives, each one between specific materials and at different times in the production process. Many of these bonds are not directly visible, resulting in some confusion about which materials are attached to what. For example, for the cover of the Codex Mictlan (Burland, 1966, p. 9) states that "…the cement used for affixing these pages is the white paste which covers the rest of the codex…". This would mean that the covers were attached using the gypsum gesso. Close observation of the original, however, shows that this is not the case. The bottom right corner of the front cover is slightly detached and curled up, allowing for a view of the inside between these two pages (see figure 1.14). There is no trace of a white layer in-between these two sheets. Instead, a brown residue can be seen.

For their application in the production of a codex, three properties of the glues need to be taken into account: strength, colour, and way of application. The structural components of the codex require the strongest bonds. In principle, this would be copal resin. However, the application of this resin while being hot makes this impossible, as the leather could not resist the heat required. Besides this, both the paint and the gesso cannot be made using copal, as this would set too quickly. Furthermore, the paint requires glue that does not interfere with the colour. The experiments in the next chapter will provide more insight into which adhesives are best for what purpose.

DISCUSSION AND CONCLUSIONS

The amount of direct data on the materials used in the Mesoamerican writing traditions is limited by three factors: the size of the corpus itself; the amount of investigations; and, finally, the types of techniques that can be applied on the material categories that are encountered. Given these limitations, it is impossible to determine how the codices must have been made. Variation between the codices indicates that there was more than one recipe. The historical and ethnographic sources are essential as they provide alternatives to the materials identified and likely candidates for those that cannot be identified. These sources together allow for a creation of a first list of materials that have the affordance to make a codex. Following the approach in Hodder's Entangled (2012), it is possible to continue with the materials that are identified in these books and search for their dependences and dependencies. This reveals that many more things will be needed when one works with them. For example, making a stable pigment of a specific red colour out of cochineal requires more materials than just the cochineal insects. Making a codex thus requires technology and a specific toolkit, all of which may not leave a directly identifiable trace on the codex. The few investigations that have been done in this area have stopped at the chemical or physical identification of major components. Although these kinds of identification are interesting from a scientific point of view for present-day researchers, one may argue that the chemical or physical identification of a specific substance used in a codex should not be the end of investigation. For some purposes it may be enough, for example when the process of chemical decay is studied. It does not, however, contribute to a better understanding of past human behaviour. In order to get a better grasp of precolonial writing technology, the materials have to be followed from the moment of acquisition through all production steps until they are finally combined into a book. The lack of eye-witness description and the inability to observe the process first-hand means that the only way to come to a better understanding of the practice of codex making is by re-doing it: that is, by undertaking a process of experimental replication. Thus, both the materials securely identified as ingredients of the codices and the materials that are given by the historical and ethnographic sources as possible ingredients, need to be used as the basis for experimental replication of the production process. It will be seen that the materials themselves limit what can be done with them and require in some cases whole ranges of material in order to function properly. In the next chapter, this experimental replication will be a central tool in an attempt to come closer to precolonial Mesoamerican codex production technology.