A Codex Imaging Project at the Bodleian Library: The Recovery of Lost Mixtec Writing

With Contributions by Gene Ware, John Pohl, and Stephen Houston

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Chronology: Post Classic
Location: Oaxaca
Site: Nochixtlan Valley

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Introduction

The aim of the project is to test the feasibility of using multispectral and flash thermography imaging techniques to reveal details of the composition of the Codex Selden not perceptible through ordinary visual inspection.

The Manuscript

The Codex Selden was constructed from strips of animal hide, pasted together and covered with a gesso foundation upon which figures were painted. The entire document measures 11 inches by 20 feet, 4 inches when opened to its full extent. It was folded to create pages. The visible codex was painted over an earlier work sometime in the sixteenth century when the original was partially erased and then covered with a layer of gesso. Several more pages of hide were added, and were then also covered with gesso, and the new text, the visible codex, was drawn on the recto side. Mary Elizabeth Smith (1983, 1994) determined that the Codex Selden was composed for the cacicazgo of Jaltepec, a Mixtec political center located in the southern Nochixtlan Valley of Oaxaca. Its purpose was to support Jaltepec's claims in a dispute with neighboring Yanhuitlan over territory. She concluded that the artists of the Codex Selden had intentionally used a more ancient manuscript, probably to lend credibility of age and tradition to their case, and repainted it in order to portray their dynastic history in such a way as to lend the most support to their land claim. Another possibility, suggested by Dark and Plesters (1958) is that original codex was simply too old and worn to be used, so it was rewritten. In any case, it is curious that the manuscript does not include any colonial elements of the kind that appear in other manuscripts produced in the first decades after the conquest. There are no Spanish officials, priests, churches, horses or the like. A facsimile of the Codex Selden was first I published by Lord Kingsborough (1831-1848) and a second by the distinguished scholar Alfonso Caso, who included a commentary on the history of the manuscript and an analysis of the genealogical records contained in the visible Codex.

Previous Imaging work on the Codex Selden

Alfonso Caso recognized the Codex Selden as a palimpsest in 1950, and brought this fact to the attention of C.A. Burland at the British Museum. Burland had the codex transferred to the British Museum's research laboratory for analysis after it was exhibited at Cambridge during the bi-annual meeting of the 30 International Congress of Americanists in 1953. Technicians tried to remove the layer of gesso from page 11 on the verso side by scraping it with a scalpel, and then applying a bauxite grit spray at 90 pounds per square inch pressure. Another space on page 12 verso underwent the same procedure. Both areas were then coated with benzol, and attempts were made on page 11 to outline in pencil on the manuscript the figures that appeared. The pencil outlines visible on page 11 are presumably the ones made in the British Museum. Technicians also photographed the page under a blue filter and then under ultraviolet light. Although they refer to their procedures as "cleaning" the manuscript, the author of the technical report, H.J. Plenderleith, with was published by Caso (Caso 1964:64-65) expressed reservations about the damage their procedures were causing the codex. Investigators were able to determine, however, that the reading order of the original codex was distinct from the visible text, being divided by five registers separated by red lines for a horizontal reading order. This latter is typical of Precolumbian manuscripts, and differs from the visible codex which is read vertically in four registers (see Smith 1973:317). They were also able to distinguish "pink," gray, yellow and black pigments used in the figures, as well as silhouettes of seated personages, some of which are outlined in pencil.

In 1956, Philip Dark and Joyce Plesters undertook further technical analyses at the National Gallery's Scientific Department in London (Dark and Plesters 1958). They took samples of the gesso and paint to determine their chemical composition, employed infra-red and x-rays to try to read the original manuscript, and then applied xylene to make the gesso more transparent. The chemical analysis showed the materials used were largely organic, and therefore did not contain the kinds of metallic compounds that would show best on an x-ray. The Codex was then sent, again, to the British Museum, where Plenderleith proceeded to scrape away more gesso on page 5, verso (Dark and Plesters 1958:532-33). Dark and Plesters surmised, after examining the page, the original codex had been worn and smudged. Because it seemed to them that at least some of the colors still visible had been absorbed by the hide, and that the remaining paint visible through the gesso was hazy, they suspected the hide had been scrubbed or washed before the new layer of gesso was applied.

Palimpsest is derived from the Greek word palimpsestos, a compound of palin, "again" and pestos "rubbed smooth." This procedure was used in the Old World when writing materials were scarce or expensive, so that scribes would recycle manuscripts and lose pages by washing the surface to weaken the hold of the ink and then rubbing them down with some sort of abrasive to clean them and finally writing over them. While something like this probably occurred to the Selden, it appears that the procedure was not as thorough as it was in Old World manuscripts, where ink had to be removed from the fibers of the page, since dates and portions of figures can clearly be seen in cracks in the gesso on the verso side. Perhaps because the scribes were going to cover the original manuscript with a thick layer of gesso anyway - Precolumbian Mixtec manuscripts never seems to have been written directly on the hide - the time-consuming practice of completely washing and scraping the original may not have been necessary.

One observation made by Dark and Plesters that has not received attention is that recto side also has an original text underlying the visible codex, and the gesso layer of the original manuscript they observed (along the side of the page) appears relatively undamaged compared to the gesso layer on the verso. This observation implies that the recto side is not technically a palimpsest, but contains an overcodex and an undercodex, like a portrait that has been painted over an earlier work.

Multispectral Imaging of the Selden

One aim of the project was to see if multispectral imaging can improve the manuscript's readability. More specifically, the team wanted to find out if multispectral imaging would allow investigators to see "under" gesso.

Infrared and near-infrared light is absorbed and transmitted differently than visible light. Materials that appear solid in visible light become transparent when viewed at Near-IR and IR wavelengths. Imaging techniques have advanced considerably since the 1950s when Dark and Plesters first employed infra-red and x-ray technology to view the Selden. The use of this technique to see through visibly solid materials has been broadly used by art historians to reveal composition details, covered-over images and to authenticate paintings. Today multispectral imaging allow the manuscript to be viewed through a range of wavelengths, instead of just one. This is an advance because relatively precise wavelength windows sometimes exist that allow optimal viewing. Moreover the technology can now be used in a way that is not destructive of the manuscript. Chemicals are no longer necessary to enhance visibility, and digital imaging does not raise the surface temperature of the manuscript beyond what one would get in a normally lit room. Ware has also successfully used the technique to read manuscripts where chemical changes in the surface material has turned them black, which has left the text in black ink in visible wavelengths from the page on which it was written.

The multispectral system used for the Codex Selden Feasibility Study consisted of a digital camera, filter wheel, lens, control computer, lights, camera tripod and associated equipment.

Camera: A Kodak 4.2i Megaplus scientific-grade camera was used. This camera has a class 1 array of 2033 x 2044 active pixels with three defective pixels. It was operated in a 10-bit model resulting in images with 1024 level of gray. All functions of the camera are controlled by the system computer.

Filter Wheel: A 12 position filter wheel, containing two-inch interference filters was mounted on the front of the camera. The interference filters include wavelengths of 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900 and 1000 nanometers each with a bandwidth of 40 n. The position of the filter was controlled by the system computer.

Lens: The data collected were imaged using a standard Nikon 90 mm. Marco lens with an aperture nominally set a f2.8.

System Computer: They system computer is an IBM ThinkPad A 30 mounted on a docking station. A custom software application, MSI-Acquire, controls data acquisition, display, control, storage and filter-wheel position.

XY Grid: In order to preserve high resolution when imaging a document such as the Selden, it is necessary to divide it into small image cell. Each image cell is then individually recorded preserving the desired resolution. A grid notation is used to identify the position of each cell, and cell grid location is recorded as part of the image metadata. The x-position increased from left to right and the y-position increased form top to bottom as the manuscript is read. The size of each grid cell is 40 x 40 mm while the image size is approximately 75 x 75 mm.

Lights: Lighting was provided by four PowerArc PAG lights manufactured by PAG Limited of London. The lights produce a color temperature of 5500K and consume only 32 Watts of power each. The equivalent light brightness of each

PAG light at visible wavelengths is approximately equivalent to a 300 Watt quartz-halogen lamp.

Gray Scale: A small Kodak gray scale was positioned near the Codex. This gray scale is 20 cm wide with 1 com-gray parts.

At the behest of Mr. Richard Ovenden and Mr. Martin Kaufman of the Bodleian Library, who were concerned that handling could damage the manuscript, Gene Ware constructed a positioning table controlled by the computer. Each morning a library representative, or "handler" set the manuscript on the positioning table, and it would then be moved automatically as each cell was recorded.

Multispectral imaging produces a set of gray-scale images which records the reflexivity at the wavelength selected by the filter. As such, these images do not contain color in the normal sense. Instead, they may be thought of as an image cube with two spatial dimensions and one wavelength dimensions. Every pixel then, has these three dimensions.

The page number and page size is first indicated with r designating the recto side and v designating the verso side. The xy-cell coordinates of the image is then given after a dash. The x-cell coordinate begins with 0 at the left of the Codex page and increases as the page segment under the camera moves from left to right. The y-cell coordinate begins with 0 at the top of the page and increases as the page segment under the camera moves from top to bottom. This results in a left-to-right and top-to-bottom positioning as a book is read. An entry of p01r-x02y03 indicates that the recto side of page 1 at cell coordinates of 2 in the x-direction and 3 in the y- direction is positioned under the camera.

The cell size used for the Codex Selden is 40 x 40 mm while the typical image size is about 75 x 75 mm yielding about 25 mm of overlap. The resulting image resolution is about 75 pixels per millimeter.

Preliminary Findings of the Multispectral Component of the Project

- Analysis of the results show it is possible to use MSI to see "under" gesso. After imaging several pages it became clear that a window of relatively high transparency exists in the near infrared range, just at the very boundaries of visible light, or 750 nanometers. It is also clear however that the thickness of the gesso lowers transparency in all the tested wavelengths (400-1000 nanometers). Time did not allow the team to image the manuscript further out in the infrared where other windows may exist. Based on these results further multispectral imaging of the manuscript is warranted.

- The MSI revealed much more clearly than the naked eye the compositional guidelines used by the scribe of the Codex Selden and the carbon-based pigment used to sketch out and help align the figures (see Dark and Plesters 1958 for a description).
- The MSI showed numerous pentimenti - perhaps as many as 50 on the recto side. In the Selden many of the changes were made by using a gesso coating as a kind of correction fluid, to cover over a part of the text (see Boone 2000:24). The pentimenti range from reducing the number of dots on a name or day sign to altering a figure so that it better fits the composition. An example of the former is the seated figure on page 41 (x04y07) who clearly originally had three dots in his name until one of the circles was covered over. An example of the latter is the platform on 5 recto (x02y03) was considerably shortened, apparently to make room for the footprints leading to the next set of figures. It appears that most of the changes were made soon after the initial composition was laid down. The overall impression is that after getting the narrative down on the surface, an insignificant degree of editing then occurred.

It will be recalled that after the conquest scribes used gesso to cover the original manuscript. It should be pointed out that this procedure differs only in degree, not kind from the use of gesso as a kind of correction fluid. It may be that the occasional comparatively large blank spaces on the codex, which seem odd given the way each page has been filled in and that they sometimes appear in places where on other pages figures would be seated, may contain figures that have been covered over. In this light the alterations in the Codex Colombino-Becker do not seem so anomalous. Instead of using a gesso coating to cover up the errors/erasures, in the Colombino-Becker the changes were made by scratching out the figure, in some cases removing the gesso down to the hide. It may be that by the time the changes were made in the Colombino-Becker the ability to make the codex-quality gesso was lost.

- The MSI detected some support for Dark and Plesters' contention that the recto side has an undercodex, independent of the evidence they present. This consists of what may be reading lines in the seams of 12r (x02y04) ,perpendicular to the visible codex, and carbon traces on the hide that appear much like those found on the verso side, where carbon from the original text had worked its way into the hide (e.g. x00y08). However because the reflectivity of the gesso decreases the thicker it is in the tested wavelengths, the MSI data did not allow us to see the undercodex in near-IR wavelengths. It may be that gesso becomes reflective at wavelengths further out in the IR.
- Magnification and the MSI aids in understanding how figures were painted and the kind of instruments used by the scribe to produce them. Careful analysis of this material would allow conclusions to be made about how many scribes worked on a particular manuscript.

- The MSI helps to reveal portions of damaged figures that are not visible to the naked eye.

Flash Thermography

The physical characteristics of Mesoamerican texts such as the Codex Selden present unique imaging challenges. Because they are not written directly on the surface of the page, but on a layer of gesso, the amount of paint absorbed in the fibers of the hide is limited. Texts such as the well-known Archimedes manuscript have been recovered because ink from the original text had been absorbed in the page so that even though the ink is not visible to the naked eye, it could be recovered through MSI. A second challenge is that the undertext in the Selden is covered by a thick layer of gesso. While the gesso is reflective at 750 nanometers, it becomes more opaque the thicker the gesso becomes, making MSI less useful than it is for recovering lost texts in other writing traditions. The second project goal was therefore to see if a different imaging technique could be applied to the Selden to enhance the text's legibility. The most promising technique currently available appears to be flash thermography.

Flash thermography, also called pulsed thermography, is a recent non-destructive evaluation technique used to detect subsurface flaws in various materials. Flash thermography has been used in bonding defects in semiconductors and flaw detection in a range of composite materials, such as carbon-carbon composite tiles on the space shuttle, and carbon-carbon composite on the nose cone and wing edges of the X-33 spacecraft. Its advantage is that it allows an extremely precise measurement of temperature at many different points simultaneously. Although flash thermography, to our knowledge, has not previously been used to sense subsurface texts, it does present the possibility of overcoming some of the imaging challenges presented by manuscripts such as the Codex Selden.

Flash thermography uses a flash lamp to impart a pulse of energy, primarily in the visible and infrared spectral regions. In the Codex Selden, this energy is either immediately reflected or absorbed by the document. Most of the absorbed energy is converted into vibrational or thermal energy which conducts through the material of the document. Subsurface changes in material properties, such as density and thermal conductivity, may accelerate or retard the conduction of the thermal energy through the material of the document. If the thermal conduction is accelerated, the surface temperature of the document will appear lower, while a retardation will result in a higher surface temperature. These temperature variations occur after the flash is over and result in a delayed thermal image which carries information about the subsurface properties of the document.

The delayed infrared image fades after a period of time, usually on the order of tens of milliseconds, and the thermal energy diffuses through the document. A high-speed infrared camera capable of producing hundreds of images per second, is required to record the rise and fall of the delayed thermal image. While the resulting image sequence may be viewed as a movie, the rates with which various segments of the document respond are important in the computer I analysis of the image. Various computer algorithms may be implemented to enhance images of the subsurface variations in the document.

Flash Thermography Equipment

The infrared camera selected to obtain flash thermography images of the Codex Selden was the ThermaCAM Phoenix 600 camera produced by the Indigo Operations division of FLIR Systems, operating in the mid-infrared spectral range of 1.5-5.0 µm. This camera uses a 320x256 pixel array of indium antimonide detectors each 30x30 µm in size. It is capable of producing 120 full frames per second. For the Codex Selden test, the camera was operated at a frame rate of 67 frames/second.

Two SunPax Pro System 622 flash units with Dh-1 Diffusion flash heads were used to provide the impulse of energy required. One unit was positioned on each side of the Codex about 25 cm from the surface. The illumination produced was not completely uniform but was sufficient for the test phase of the technique. The flash units were synchronized with the sync signal from the camera.

Because the technology used in the Phoenix camera was developed for military purposes, it cannot be taken from the United States without a security clearance that none of the project members has. The FLIR corporation office in London helpfully agreed to allow the team to use its demo model of the Phoenix camera, but it could not leave the control company personnel. FLIR sent two representatives to the Bodleian for a day to monitor the use of the camera. Dr. Austin Richards of FLIR systems, one of the developers of the Phoenix Camera, generously consulted on the project.

Using the Bodleian Library's dark room, 29 different flash thermography test image sequences were performed on the Codex. These were performed on pages 1v (x01y04, x02y04, with PAG light), 6v (x00y06, x00y07, x01y06, x01y07 with flash light only), and 10v (x01y05, x01y06, with both flash and PAG light), and pages 10r (x01y06 with no illumination and flash), 14r (x04y07 with flash) and 19R (x01y02, x01y03, with flash). Because of technical problems the data from 6v x00y07 was corrupted.

Although the conditions placed on the team by security requirements were less than ideal since the use of the camera for a single day did not allow for a preliminary analysis of results and adjustments to be made as was the case with the MSI imaging. However useful data was generated. The flash thermography technical details of the set-up and imaging process did work sufficiently to generate an appropriate image sequence. It remains to process and examine each still for evidence of texts under the gesso, and to properly analyze each sequence of images using the computer to search for the same evidence before conclusions about the feasibility of this technique for reading the Codex Selden can be made.

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