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Material analysis of Aztec codices in Berlin Assignment of small fragments compiled as cutouts on one plate in Humboldt's "Atlas pittoresque du voyage"

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ABSTRACT

The collection Manuscripta Americana in Berlin consists of fragmented codices acquired by Alexander von Humboldt in Mexico. Some of these Humboldt Codices are published as hieroglyphic writings of the Aztecs in "Vues des Cordillères et Monuments des Peuples indigènes de l'Amérique". Starting from a special compilation of seven fragments on plate 36 in the "Atlas", we investigated the corresponding original fragments using material analysis in order to clarify their historical relations. The analyses were carried out with X-ray fluorescence analysis, VIS spectroscopy, and infrared spectroscopy in diffuse reflection and revealed typical indigenous colors like cochineal, indigo, and organic yellows (e.g. mangrove and zacatlaxcalli). Four fragments under investigation show exactly the same material and thus must once have belonged together in one compendium. An additional manuscript from Mizquiahuala also shown on plate 36 can be matched to another one that is not published in the "Atlas".

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Introduction

On his travels through America in 1804, Alexander von Humboldt acquired in Mexico pictorial manuscripts from the 16th–18th centuries from the estate of Leon y Gama. The main part of Leon y Gama's collection consisted of the collection of the Italian Lorenzo Boturini Benaduci, who resided in Mexico from 1736 to 1744 (Boturini Benaduci 1746). His documents were divided into pieces; parts of them (1/8) reached the palace of the viceroy, where Humboldt was still able to examine them (Thiemer-Sachse 2003). Before that, Boturini's manuscripts often were handed over to monasteries.

The Berlin collection Manuscripta Americana 1 and 2, known as the Humboldt codices, consists of sixteen unique manuscript fragments. They were published together with other codices discovered in Italy and Vienna in the picture book "Atlas Pittoresque du voyage" (von Humboldt 1810). It was about 100 years later before they aroused the attention of Eduard Seler, who interpreted them and hereby initiated further research on American anthropology (Lehmann 1906; Seler 1893). Beside indigenous pictographs, they show text written in Nahuatl and Spanish with Latin letters. Most of the fragments represent genealogies, tribute lists, calendars, or tribunals. The term "tribunal" first appears during the colonial period. The amount of wares and services regulated in tribute lists by the Aztecs was adopted by

Spanish landlords, who supervised it and performed their foreign domination in a system of regulations similar to European tribunals with punishment for underperformed demands. The diversity of the codices, including in their shape and content, presume little accordance in purpose, time, or locality of production. The historical context of the manuscripts is still not well known today. Even before the documents came to Berlin, famous scholars in Mexico collected, copied, fragmented, and continued to distribute relevant papers during the early colonial period, so we start from the premise that corresponding pieces may be detected also outside the Berlin collection.

For example, Fragment III of Manuscripta Americana 1 shows what seem to be scenes of war. It comes originally from Huamantla, like six related fragments in Mexico. In 1740, they belonged to Boturini's collection. The figure on plate 38 in the volume "Atlas pittoresque du voyage" of "Vues des Cordillères" (von Humboldt 1810) is entitled "Migration of the Aztecs". Eduard Seler interpreted the original in 1902 as "Representation of place names and tributes".

Registered as Manuscripta Americana 2 is a segment of a folding screen more than 4 meters long. It is a tribute list of gold and textiles from Tlalpa-Tlachinollan in the state of Guerrero, and it belongs to Codex Azoyu 2 verso in Mexico (Gutiérrez, König, and Brito

2009). In “Vues des Cordilleres”, it is compiled on plate 36 together with details of seven codices, most of them tribute lists. It is remarkable that these fragments are combined on one plate. The workmanship looks very similar. This representation is very different from that of other Aztec codices, so that a special common thread of these tribute lists is presumed.

To clarify: if there are common features among the represented fragments concerning place or time of their manufacture, we perform analyses of the material. This should also clarify their originality and will provide a reference data set to compare these fragments with other corresponding pieces from other collections.

Material

The tribute lists identified in the details on plate 36 in “Atlas pittoresque du voyage” (Figure 1, right side beside Ms. Amer. 2, left side) are set in relation to corresponding documents of the Humboldt Codices in the Berlin collection Manuscripta Americana 1. The segments that show three men tied on the wrist, burden bearers, and pigs (Figure 1, top right side) are identified as belonging to fragments X–XII of the collection. They are analyzed together with fragment IX, whose style looks very similar. Represented on these four codices are tributes of wood, pork, stones, and honey (Seler 1893). It is not known where the documents originated.

In comparison with this, the piece on plate 36 Figure 1, bottom right side, that belongs to fragment XIII is clearly from Mizquiahuala, Hidalgo state, in the fifteenth to eighteenth century an Otomi region with a double patronage by an Indigene and a Spaniard. It is a tribute list, also known as calendar. Seler sets it in relation to another list from Mizquiahuala, registered as fragment VII in the collection. Though the two documents show different symbols, they have common features concerning a Spanish text on verso, documenting the receipt of wares and support from a person named Manuel de Olvera with signature and date. Fragment VII is signed two years later.

Analytical methods

We applied non-destructive spectroscopic methods established for the analysis of manuscripts (Durkin-Meisterernst et al. 2016). Comparable approaches were used by Domenici 2019a, 2019b; Grazia et al. 2019, Gulmini et al. 2013; Miliani et al. 2012; Zetina et al. 2011.

The VIS spectral photometer (Gretag SPM 100 Imaging AG company, Regensdorf, Switzerland) enables us to determine dyes by their characteristic reflectance curves in the range of 380–730 nm. The spectral resolution is 10 nm. With this surface method, the sample to be examined is illuminated with visible light. The sample material interacts with the visible light by absorbing or reflecting it in a specific way. The reflected

light characteristic of a specific colorant is measured with a photometer and recorded in the form of a characteristic reflection curve. This curve represents the correlation between the intensity of the reflected light and its wavelength. Comparison with a databank makes it possible to ascribe the pattern to a certain pigment or dye (Fuchs and Oltrogge 1994; Oltrogge 2008).

X-Ray Fluorescence analysis (XRF) is performed with the mobile ARTAX (Bruker Nano GmbH). It is especially suited for pigment analysis to differentiate the compositions of paints by determining their elements and trace elements. It consists of a 30W low-power Mo tube and polycapillary X-Ray optics (measuring spot size 70 μm diameter) operating at 50 kV and 600 μA with an acquisition time of 70–100 s (live time). The silicon drift detector with high speed, low noise electronics permits an energy resolution of 160 eV for Mn-K α radiation at a count rate of 10 kcps. It has an active area of 5 mm², and an 8 μm thick Dura-beryllium window. The geometry between the primary beam, the sample and the detector is fixed at 0°/40° relative to the perpendicular of the sample surface.

With FTIR spectroscopy, the molecular structures of inks and dyes are determined. Usually small samples had to be taken from an object for the analysis. Recently, non-destructive methods provide handheld investigation of materials' surfaces. FTIR spectra were collected with the Exoscan spectrometer (A2 Technologies) in diffuse reflection mode. Measurements were performed in the spectral range between 600 and 4000 cm^{-1} with a spectral resolution of 4 cm^{-1} . 500 scans are co-added per spectrum.

The three-color USB microscope (Dino-lite AD413T-I2V, at magnification: $\times 50$) possesses in-built LED illumination at 395 and 930 nm and an external white light source. The method provides an appropriate technique to classify black drawing and writing materials e.g. carbon-based (carbon ink) and non-carbon-based (iron gall ink, plant ink) materials (Mrusek, Fuchs, and Oltrogge 1995).

In combination with XRF analysis, it makes it possible to distinguish black inks. Iron gall inks for example are produced from the mixture of natural iron vitriol with gallnut extracts. Because the inks are based on natural raw materials, they show heterogeneous compositions (Krekel 1999). In addition to iron sulphate, they contain vitriols of the elements copper, iron, manganese, aluminum, or zinc (Lucarelli and Mando 1996). The varying composition of these different vitriols is a characteristic property of historical iron gall inks and makes their exact determination possible (Hahn 2010). Further discrimination is possible with the “fingerprint”. For a certain minor constituent “i” (such as Mn, Ni, Cu, Zn) a characteristic value, “W_i” can be specified. This value indicates the relative concentration of a minor constituent in relation to the main component iron (Hahn et al. 2004).

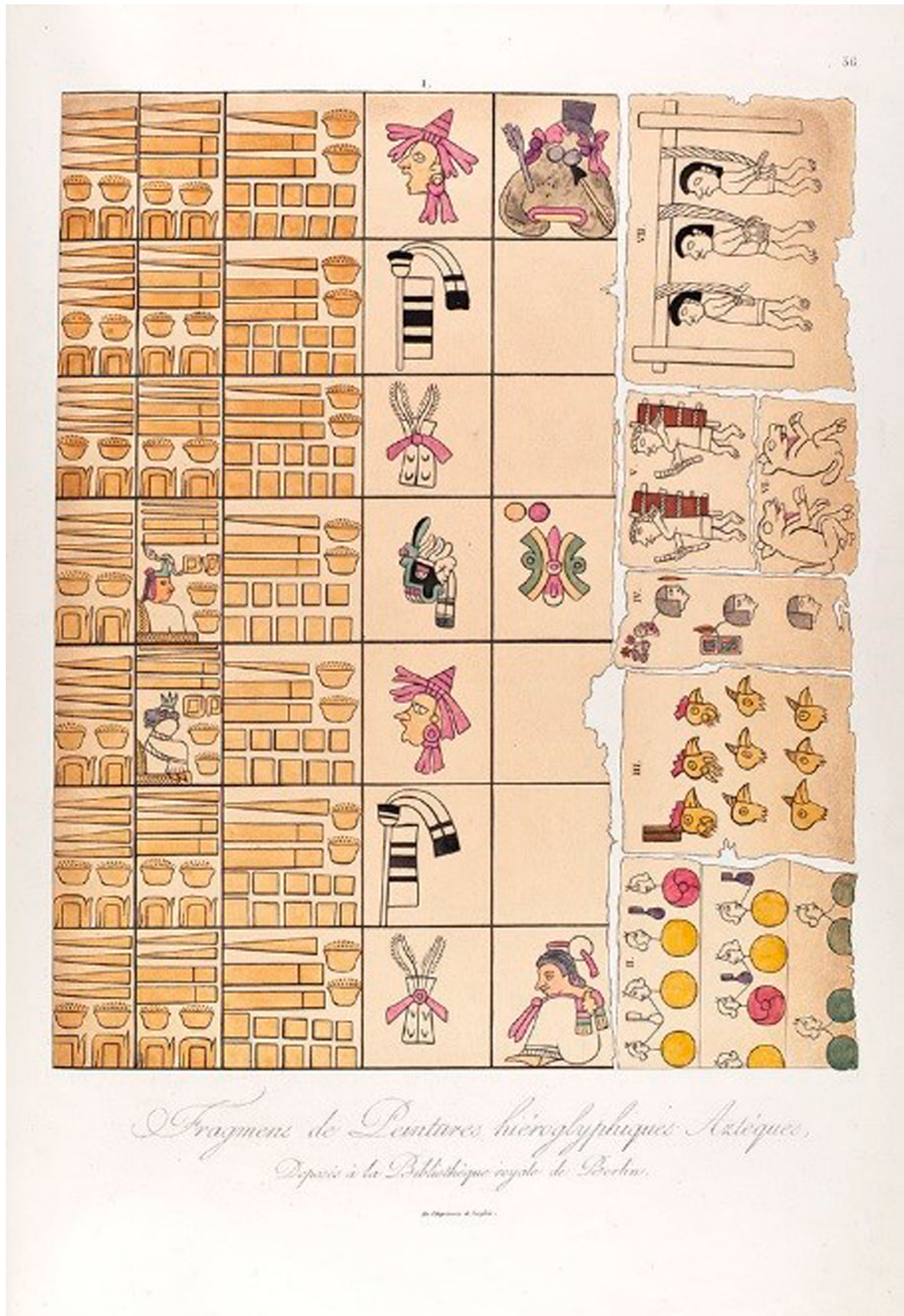


Figure 1. Plate 36 in "Vues des Cordilleres", Fragmens de peinture hiéroglyphique Aztèques, déposés à la Bibliothèque Royale de Berlin.

Reference samples

For the identification of the colors, we prepared various references of those known to have been used in the colonial period of Mexico (Dupey Garcia 2017; Haude 1998; Magaloni Kerpel 2008; Roquero 1995; Sahagún 1576–1577). By comparing the spectra of differently prepared samples, we tried to find out if preparation method has an influence on the spectra.

A variety of different yellow colors are prepared from old fustic (*Chlorophora tinctoria*), curcuma (*Kurkuma o.A.*), and safflower (*Carthamus tinctorius L. o.A.*) with alum and tartaric acid including various mordants such as FeSO_4 , tannic acid, CuSO_4 , and CaCO_3 . Chips of old fustic are soaked in water overnight and cooked for two hours with alum at 90°C . Curcuma (Kremer Pigment 37220) is dissolved in water at 75°C and mixed with a warm solution of alum. Safflower blossoms are shredded and heated in water for three hours at 80°C . Dark and light amate paper, prepared with alum, is cooked for one hour in each dye bath. Dried in air for three days, the paper stripes are analyzed.

More references for yellow prepared on gesso were kindly provided by Tatiana Falcon (see Figure 2). These include mangrove (*Rhizophora mangle*), xochipalli (*Cosmos sulphureus*), and zacatlaxcalli (*Cuscuta tinctoria*). A detailed description of the preparation is given in Table 1.

For the identification of the red coloring, annatto (*Bixa orellana*), redwood (*lignum Fernambuci*), and cochineal (*Coccus Cacti*) are prepared on amate paper.

The seed capsules of annatto (Kremer pigment 37350) are ground in a cotton cloth, soaked overnight in water with soda, and heated for one hour.

Redwood (*Palo de Brasil*) is chopped and an extract (Kremer Pigment 36150) is soaked for one day in

Table 1. Preparation of reference samples (T. Falcon, personal communication, 2017).

Colorant source	Preparation	
Cochineal 1a	In a solution of 3 g miconia type 1, cochineal (0.3 g) is boiled for 10 min in water	+0.12 g alum +0.3 g FeSO_4
Cochineal 1b	In a solution of 6 g miconia type 1, cochineal (0.3 g) is boiled for 10 min in water	+0.7 g alum +0.3 g FeSO_4
Cochineal 2a	In a decoction of 1 l miconia, cochineal (1 g dissolved and filtered) is boiled	+ alum powder + a teaspoon of FeSO_4
Cochineal 2b	In a solution of 20 g miconia type 1, cochineal (1 g) is added, rested, boiled for 30 min in 1 l water	+0.8 g alum +0.1 g FeSO_4
Mangrove	A solution of mangle (40 g in 1 l water) is boiled up to 200 ml	Boiled + 30 ml alum and potash boiled + 30 ml alum and FeSO_4
Xochipalli	Dried petals of xochipalli (10 g) are extracted in a solution of alum (4 g)	+4 g potash precipitation
Zacatlaxcalli	Fresh zacatlaxcalli (60 g) is ground, boiled in water	+23 g alum +26 g potash boiled for 1 more hour
Maya blue	Indigo (0.5 weight% of palygorskite) from the foam of an indigo vat	Mixed + palygorskite heated at 180°C for 12 min
Maya green	Maya blue + zacatlaxcalli	n/s

water. It is heated for four hours, precipitated for three days, and filtrated.

The gray, dried female scale insect cochineal (Kremer Pigment 36040) is ground and soaked overnight in acetic water in a cotton cloth. Heated for fifteen minutes, a solution of potash-alum is added at 50°C with pH 6–7. Various mordants, such as FeSO_4 , tannic acid, CuSO_4 , CaCO_3 , and tartaric acid are also tested. Reference samples for cochineal are prepared on gesso in various ways with alum and FeSO_4 by Tatiana Falcon (Table 1, see Figure 3).

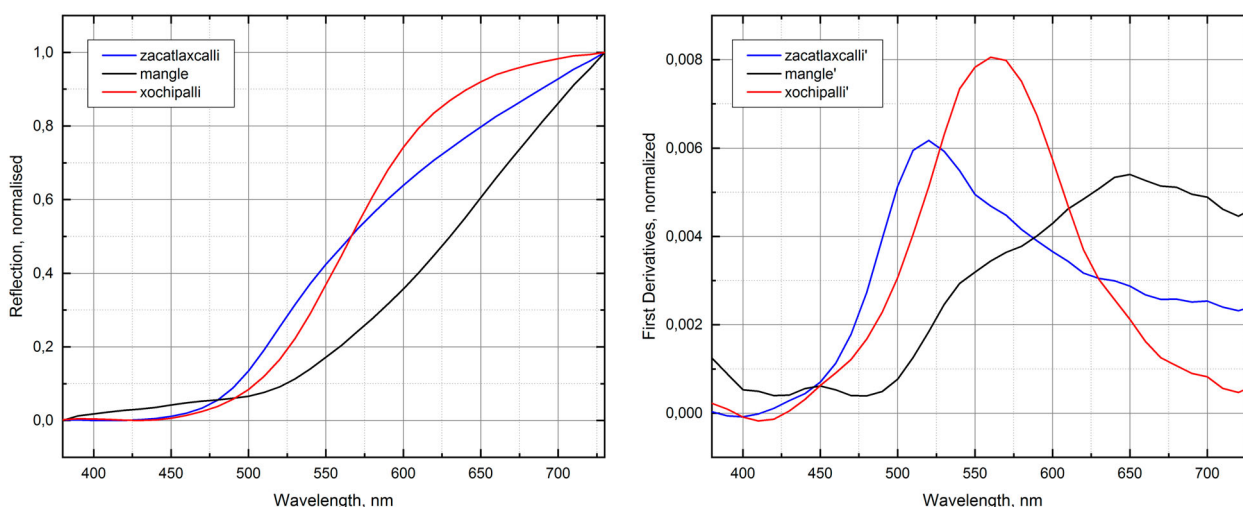


Figure 2. Left: Reference VIS spectra of zacatlaxcalli (*Cuscuta tinctoria*, blue line), mangle (*Rhizophora mangle*, black line), and xochipalli (*Cosmos sulphureus*, red line), right: with corresponding first derivatives.

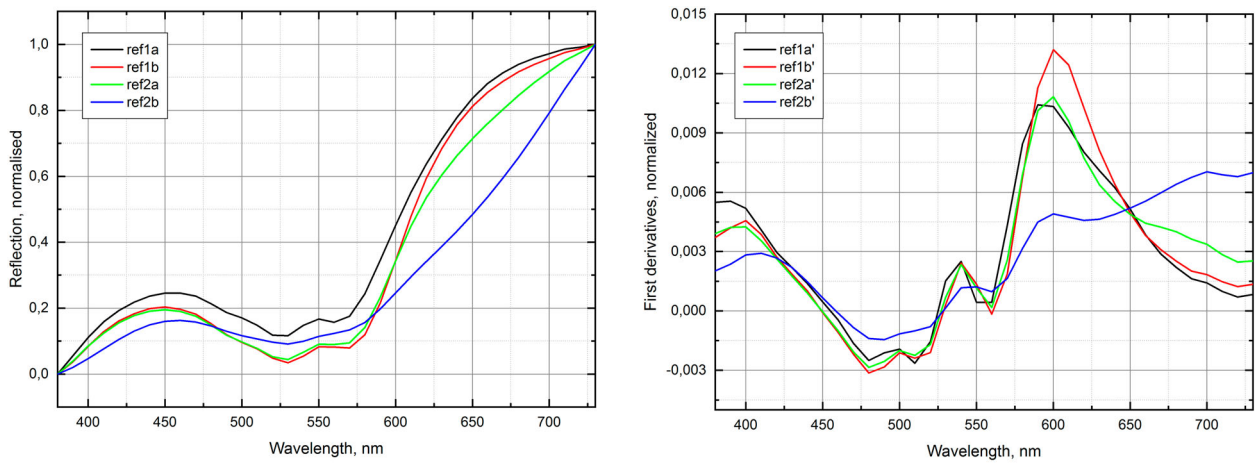


Figure 3. Reference VIS spectra of different cochineal lakes (left) with corresponding first derivatives (right), showing that the characteristic features of the spectra are not essentially influenced by the manufacturing process of this dye.

The green color is prepared as mixture of blue and yellow with Maya blue (Indigo (*Indigofera suffruticosa*) in palygorskite) and zacatlaxcalli (Table 1).

light). This is different to other black colorants, which lose their opacity in NIR light and become transparent.

Results and discussion

Fragment X (Figure 4a) shows red cochineal and an organic yellow dye by their color spectra (Figure 5). Compared with reference samples, the yellow seems to be a mangrove extract (*Rhizophora mangle*). XRF analysis shows no main elements that are characteristic of mineral pigments and thus confirms organic colorants. However, the analyses revealed certain trace elements (see Figure 6) that allow us to compare the different colorations in greater detail. Fragment IX (Figure 4b) is so very similar to fragment X that its material is compared. Analysis confirms identical dyestuff with the same trace elemental composition (Figure 7). Likewise, carbon ink is used as black.

Based on XRF line scans comparing colored and uncolored areas, it is possible to deduce different elemental compositions in the paper and colorants.

Based on these line scans, it is possible to extract specific trace elements present in the colorants. As an example, Figure 7 shows specific traces such as Si, P, S, K, Mn, and As in the red cochineal areas of fragments IX and X. Based on the results, we may conclude that potassium sulphate was possibly used as a mordant.

Fragment XI exhibits the same spectra of colors. The paper contains the same trace elements (e.g. Si, S, Cl, Ca, Ti, K, Mn, Cr, and Fe) as those of the other fragments.

Fragment XII also exhibits the same dyes: cochineal and an organic yellow that was extracted from mangrove. Investigation with the USB microscope again revealed carbon black (Figure 8). As mentioned in the “Analytical Methods” section, carbon-based materials absorb the NIR light (comparable to visible



Figure 4. Fragments X (18 × 57 cm) and XII (17.2 × 84.5 cm).

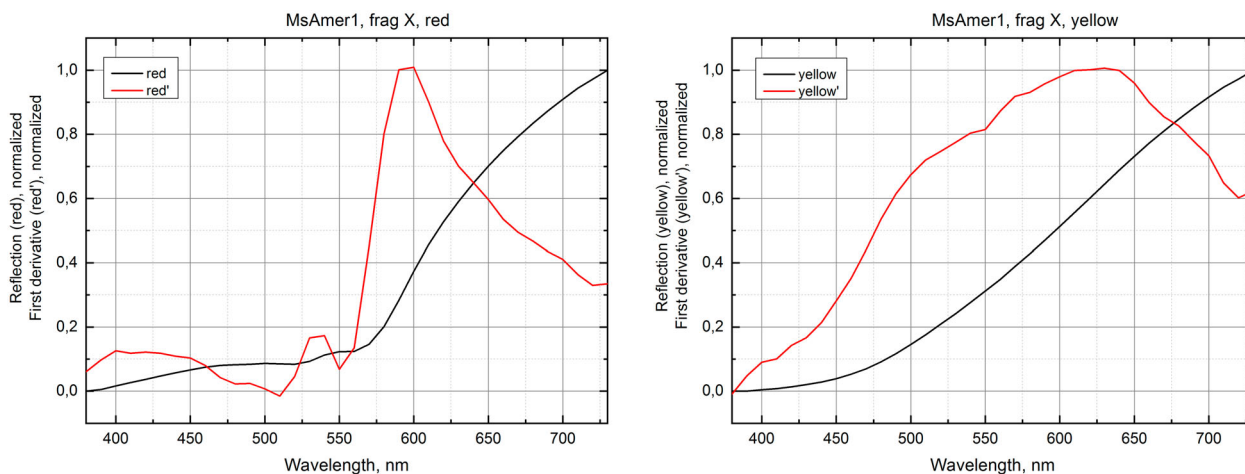


Figure 5. Fragment X. Normalized reflection curves of the red (left) and the yellow (right) dye with corresponding derivatives. The curves display characteristic features of red cochineal and a yellow dye extracted from mangrove (*Rhizophora mangle*).

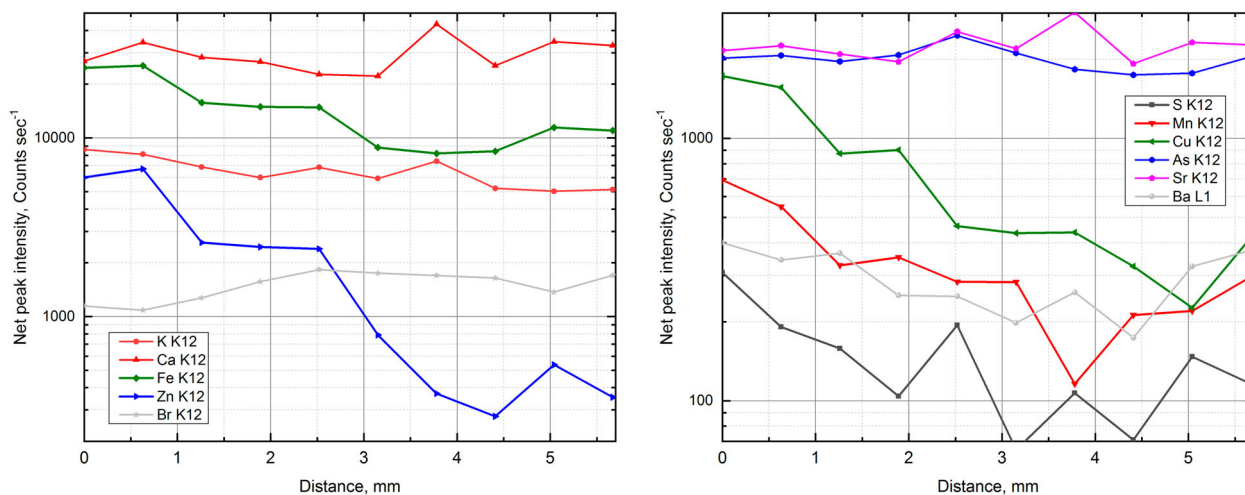


Figure 6. Representative XRF line scan revealing specific elements within the paper and in the colorants (MsAmer1, frag XIII, yellow/paper). The line scan starts in the colored area and ends in the paper region. A decrease in the profile of different elements (such as Fe, Zn, S, Mn, Cu) is clearly visible. Please note the logarithmic scale of the y-axis.

The dyes of fragments IX–XII are identical: they show exactly the same color spectra and elemental composition. This is also the case for their black inks: these are carbon inks without enrichment by special trace elements. The paper of the four fragments consists of rough fibers glued together coarsely in more than one layer (Figure 9). It is prepared in the same way and looks like amate. An exact biological determination would be destructive and thus is not possible.

Based on our analysis, we can conclude that these fragments were produced in local workshops using the same manufacture tradition. Regarding workshop practices, however, it is definitely not possible to distinguish between different hands. The use of indigenous colors, also for additions like the figure of a Spaniard on fragment XI, indicates the early colonial period. Cochineal, the carminic acid extracted from the female scale insect that lives on opuntia, was

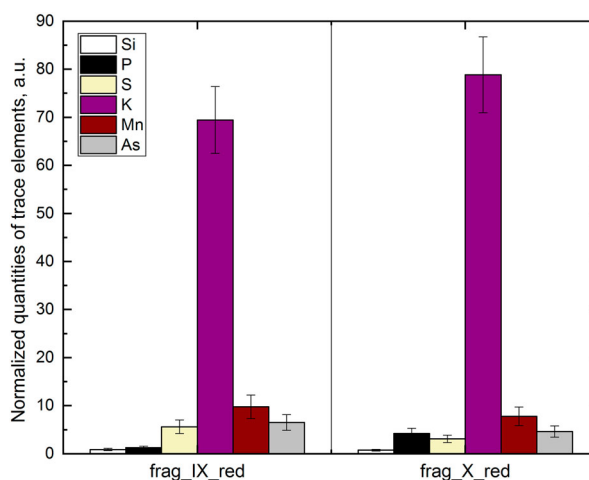


Figure 7. Specific trace elements such as Si, P, S, K, Mn, and As in the red cochineal areas of fragments IX and X.

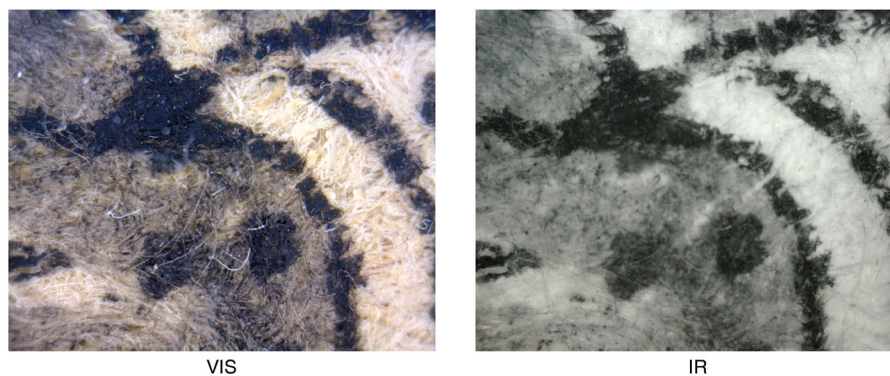


Figure 8. Fragment XII. Carbon ink under VIS and NIR light (150x magnification).

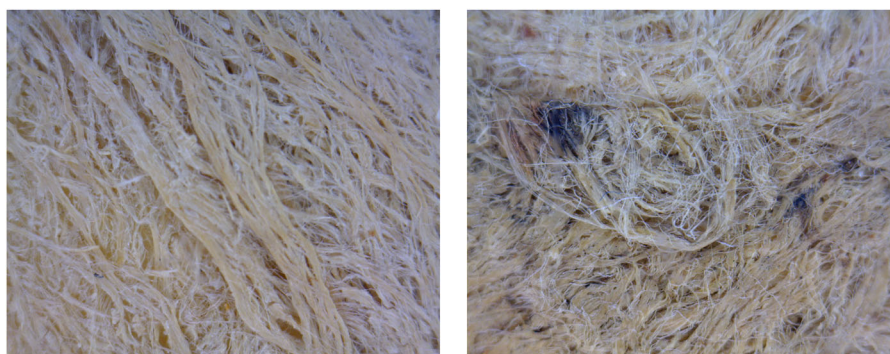


Figure 9. Paper qualities of fragment X and XII (150x magnification).

commonly used as red color in Pre-Columbian Mexico and has been identified on most of the codices manufactured during the colonial period (Anderson 2015; Buti et al. 2018; Domenici et al. 2014, 2017, 2019a, 2019b; Dupey Garcia 2017; Pottier et al. 2019; Snijders, Zaman, and Howell 2016; Zetina, Ruvalcaba, and Falcón 2014).

In his treatise, Seler explains the unusual similarity of the fragments by saying that they came as two documents to the Royal Library of Berlin, where they were cut and each piece was given its own signature. His depictions illustrate how the originally more than 2.49 cm long document was cut into fragments: IX (18 × 44 cm), X (18 × 57 cm), XI (17–21,5 × 63 cm), XII (17.2 × 84.5 cm) (Figure 10).

Fragment XIII from Mizquiahuala was analyzed to further assign manuscripts representing tribute lists (Figure 11).

XRF analysis indicates organic dyes with elemental compositions similar to that of the paper. A text on the verso written in Latin letters and captioned with the date 1569 shows iron-gall ink enriched with Fe-Zn, a completely different ink than the black ink used on the recto and on fragments IX–XII.

The color spectra of this manuscript show, beside red cochineal, a more distinct yellow that may be

identified as zacatlaxcalli and a green consisting of indigo (Figure 12). FTIR spectroscopy indicates the existence of the mineral palygorskite $[(\text{Mg}, \text{Al})_2\text{Si}_4\text{O}_{10}(\text{OH})]$ with bands at 1028 and 986 cm^{-1} (Figure 13) corresponding to the stretching mode of the Si-O bond. These bands disappear at temperatures higher than 300°C (Nabais 2014; Wenchang et al. 2012). We presume the clay hybrid color Maya green.

Well known is Maya blue, which is prepared with indigo and palygorskite at temperatures around 150°C (Arnold 2015). It is the main component of Maya green, with an admixture of a yellow dye. Maya green may also be prepared directly with a different indigo plant or a clay mineral similar to that of palygorskite, because the color depends sensitively on the charge balance in the structure and thereby on the possibility to incorporate indigo. A greyish-green color appears if less of the indigo molecules undergo hydrogen bonding with the hydroxy groups in the channels of the clay material, forming dehydro-indigo. This is also the case at higher temperatures or with longer heating time (Doménech-Carbó et al. 2014) due to the release of H₂O and OH groups and structural disorder.

Fragment XIII is also compared with fragment VII (Figure 14), another tribute list from Mizquiahuala. Here, too, the red is identified as cochineal, and the



Figure 10. Fragments IX (18 × 44 cm), X (18 × 57 cm) and XI (17–21,5 × 63 cm), XII (17,2 × 84,5 cm), and their outlines (Seler 1893).

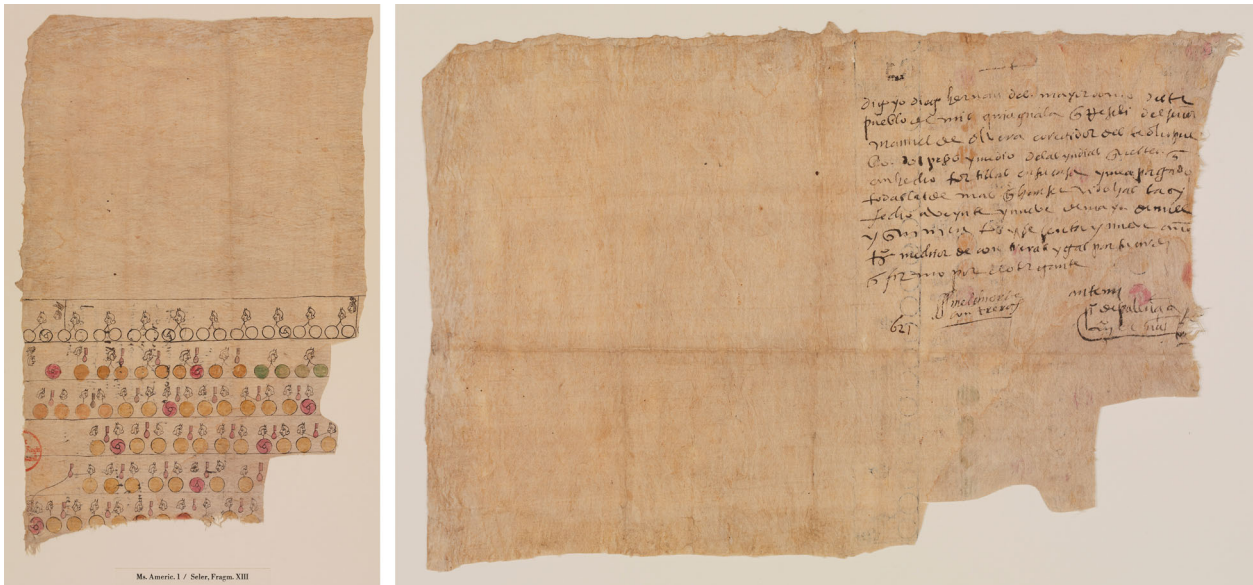


Figure 11. Fragment XIII (49 × 31 cm; left: recto; right: verso).

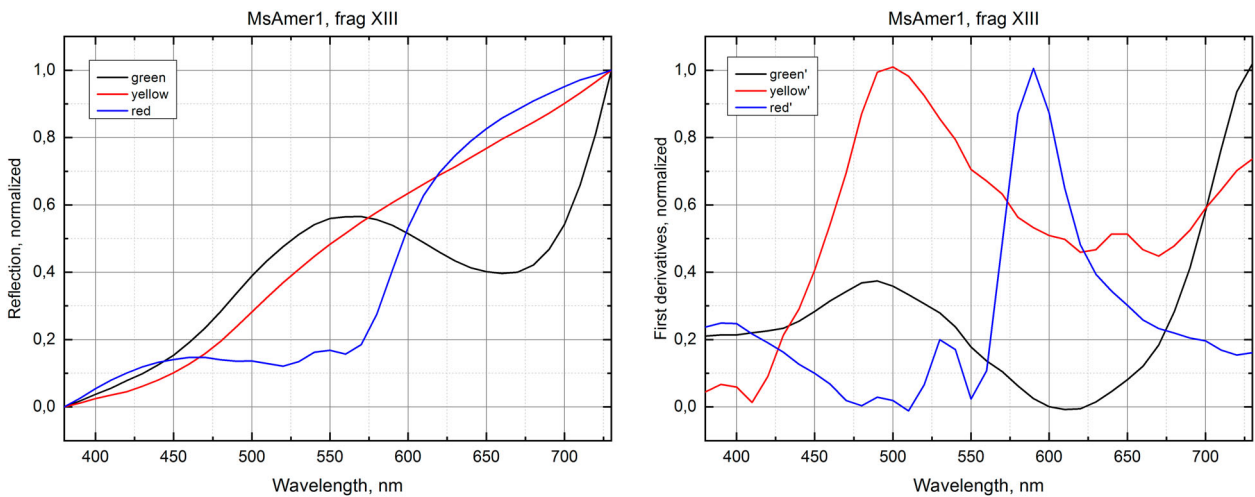


Figure 12. Fragment X. Normalized reflection curves of the green, yellow, and red colorants (left) with corresponding derivatives (right). The spectra display characteristic features for red cochineal, indigo, and yellow zacatlaxcalli.

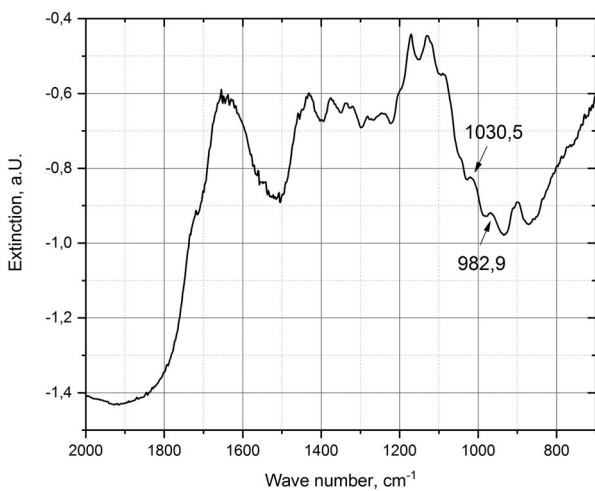


Figure 13. DRIFT Spectrum in extinction mode; the two peaks are not very distinct but still visible at 1031 and 983 cm^{-1} .

yellow shows a similar characteristic color curve of its first derivation with a peak at 490 nm, attributed to zacatlaxcalli (Figure 15).

However, the identification of the yellow still has to be seen as uncertain. It will be compared with further reference samples of indigenous plant dyes mentioned by Sahagun (Magaloni Kerpel 2008; Sahagún 1576–1577) and with yellows applied on other fragments from the region.

Similar to fragment XIII there is a black inscription on the verso side of fragment VII. The text written on the verso in Latin letters and captioned with the date “4.2.1571” shows an iron-gall ink. Fragment XIII is captioned with the date “29.5.1569”. The comparison of both iron gall inks reveals similarities, e.g. the same trace elements (Figure 16). However, the relative concentrations (normalized to Fe) differ remarkably.



Ms. Americ. 1 / Seler, Fragm. VII

Figure 14. Fragment VII (25 × 18 cm).

This could be caused by dilution effects during ink production. Both fragments show similar but not identical inks. This confirms that the two documents were not signed at the same time or by the same writer.

The paper of the manuscripts from Mizquiahuala (Figure 17) shows the same structure as that of fragments IX–XII. An accumulation of special elements was not detected, showing that no special preparation was carried out. Here, too, we suggest that the substrate is amate, the best-known paper of indigenous Mexico.

Summary and conclusion

Details of Mexican codices figured on plate 36 in “Vues des cordillères et monuments des peuples indigènes de l’Amérique” are found to belong to fragments of tribute lists from the Berlin collection Manuscripta Americana 1, acquired by Alexander von Humboldt. We have shown the degree to which these pictorial scripts are related to each other and even belong together or to other writs.

The presented fragments are clearly associated stylistically and culture-historically with other tribute

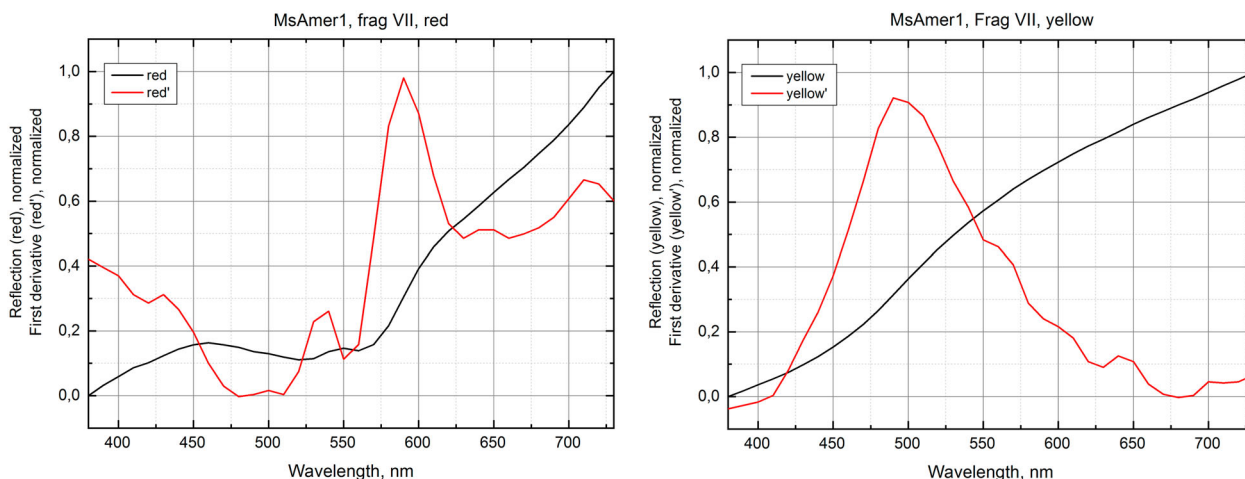


Figure 15. Fragment X. Normalized reflection curves of the red (left) and the yellow (right) dye with corresponding derivatives. The curves display characteristic features of red cochineal and a yellow zacatlaxcalli.

lists. Analysis shows that fragment X is part of fragment IX (not represented on plate 36) and fragments IX–X and XI–XII are originally two cut pieces of very long documents with the identical material. This means that they were manufactured in the same workshop.

Another group of similar documents takes fragment XIII as a starting point. The material confirms its close relationship to fragment VII (not represented on plate 36) (Table 2).

We suggest that these two fragments belong to further tribute lists from Mizquahuala, preserved in the National Library of Anthropology and History BNAH in Mexico. A very long strip that was also cut into two pieces and now has been assembled in its original form again corresponds to fragment XIII of the Berlin collection. It is registered as “Poinsett 2” (Brinton 1893; Seler 1893). Clearly related to fragment VII by its style is another tribute list from the Mexican collection. In contrast to the document in Berlin, it shows a green coloration, not seen on Poinsett 2. Analysis of the Mexican documents should prove the close

relationship. In contrast to the two documents in Berlin, those in Mexico do not show a date or text in Spanish on the verso, so that a comparison may be helpful also for dating them.

In accordance with the results of earlier analyses of codices written during the colonial period of Mexico, the determination of colors like cochineal and Maya green permits a clear cultural attribution for the documents. The amate paper also confirms indigenous material.

The yellow dyes classified as organic, probably a mangrove extract for fragments IX–XII, and

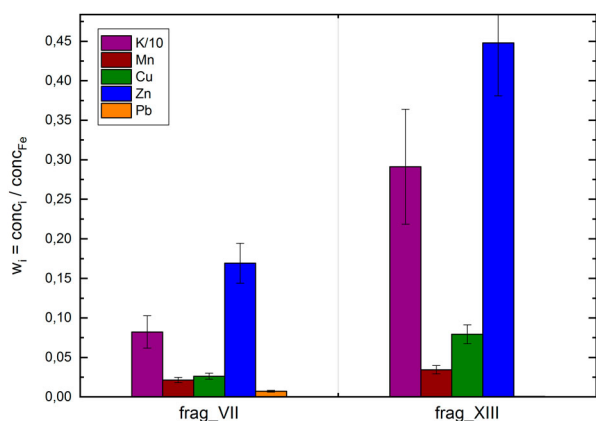


Figure 16. Results of the XRF investigation of the iron-gall inks on fragment VII and XIII verso: fingerprint values (relative concentrations) of several elements in relation to iron.



Figure 17. Paper of fragment VII (150x magnification).

Table 2. Colorants identified on the fragments.

MsAmer1 fragment	Red	Yellow	Green	Black	Script
IX	Cochineal	Mangle		Carbon	
X	Cochineal	Mangle		Carbon	
XI	Cochineal	Mangle		Carbon	
XII	Cochineal	Mangle		Carbon	
VII	Cochineal	Zacatlaxcalli		Carbon	Iron-gall ink
XIII	Cochineal	Zacatlaxcalli	Maya green	Carbon	Iron-gall ink

zacatlaxcalli for those from Mizquiahuala, need to be ascertained in further studies.

The material analysis of the fragments enables us at least to confirm the assumed assignment to similar documents, thus completing them as a group. This makes it possible to determine that single pieces of fragments cut in the past are related and may even fit together. This makes them more readable and allows an approximation to their original form.

The material historical facts, including the separation and transfer of these rare documents, have been perfectly determined. What remains to be verified is if the mentioned corresponding pieces in other collections are identical, then their derivation from one document and their single origin can be ascertained. If not, more localities of manufacture have to be considered.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

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