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The Sinai Palimpsests Project: A View from the Imaging Room*

St. Catherine's Monastery is located in a remote area of the Sinai Peninsula, in a desert surrounded by granite mountains. At first glance, it appears an unfriendly place for humans to survive, but the history of the 1500-year-old Justinianic fortress tells us otherwise. In the monastery's library, we find treasures hidden from the outside world, which have survived alongside the monks for centuries. One of the main factors in the preservation of the objects is the natural environment of the location. Temperatures throughout the year range from 8° C to 30° C, but even under these harsh conditions no climatic damage is evident in the manuscripts, since the relative humidity, which drops to values of 10%–15%—very low from a conservation point of view—is very stable and causes only short-term fluctuations.¹ Among these treasures are the palimpsest manuscripts.

During the 19th and 20th centuries there were several attempts to make the erased texts legible by various means. For instance, Agnes Smith Lewis describes the 'cautious use of the re-agent' (hydro-sulphide of ammonia) to make the undertext of Sin. syr. 30 temporarily more visible to the human eye.² Also worth noting is the pioneering work of Arthur Hjelt, who attempted to photograph palimpsests by using an ultraviolet 'Wood's glass optical filter' under natural sunlight.³ More recently, the Sinai Palimpsests Project (SPP) used non-invasive techniques for image capture: human interaction was limited to positioning the manuscript on sophisticated book cradles, imaging was performed in climate-controlled environments, and the use of dark rooms ensured that manuscripts did not have to be exposed to the natural elements and the sun. Prior to imaging, the Monastery's librarian, Father Justin Sinaïtes, determined whether each object was safe enough to handle, and determined the exact approach of handling the manuscripts. The Sinai Palimpsests Project represents the first time a palimpsest collection has been systematically digitally imaged with non-invasive techniques.⁴

The Sinai Palimpsests Project started in 2009 with a Pilot Imaging Project identifying technologies and ways to approach this very special collection. Once financial support by the Arcadia Fund was secured, the imaging project officially started capturing spectral data in 2011, and concluded spectral digitization in 2016 after five years of systematic work in the library of the Holy Monastery. This work was carried out with the support of the Sinai Fathers, the Librarian Father Justin Sinaïtes, and the Egyptian Government.⁵

At the beginning of Sinai Palimpsests Project, 110 palimpsest manuscripts had been identified as palimpsest but had not yet been catalogued or studied page by page.⁶ Five years later, 160 palimpsest manuscripts were known and included in the Sinai Palimpsests Project database. At the time of writing, we are now aware of 172 manuscripts at St. Catherine's Monastery which are entirely or partially written on recycled parchment.⁷ It is estimated that the number may well exceed 200 if the entire collection of the Monastery is examined page by page.⁸ When the imaging project concluded in August 2016, 74 palimpsests had been imaged, amounting to a total of 6,800 pages spectrally imaged, resulting in more than 50 TB of data including the processed images.⁹

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* This work was supported by the Arcadia Foundation under Grant 3386.

¹ Strebel, *Passive Climate Control*, 23; Koufopoulos and Myriantheos-Koufopoulou, *Master Plan*, 30.

² Lewis, *Translation of the Four Gospels*, ix.

³ Hjelt, *Helsingistå Siinaille*, 118–123.

⁴ More on this in the contributions by Michael Phelps and Keith Knox in this volume.

⁵ Egyptian State Information Service, *Iktishāf makhṭūṭ atharī li-Hīrbūqrāṭ fi Dayr Sānt Kātrīn* [Discovery of an Ancient Manuscript of Hippocrates in the Monastery of Saint Catherine], <https://web.archive.org/web/20220525080808/https://sis.gov.eg/Story/144001?lang=ar> (accessed 01.07.2023).

⁶ Unpublished list compiled from existing catalogues by G. Foukaneli-Fyssa (2008), working under the direction of P. Nikolopoulos.

⁷ Last updated: 22.09.2020.

⁸ Father Justin Sinaïtes (2016): Personal communication.

⁹ All images can be found online at this address: <http://sinaipalimpsests.org/> (accessed 01.07.2023, alternative URL: <https://web>).

WORKFLOW

Even before the spectral imaging of the manuscripts is carried out, data regarding the palimpsests is recorded by scholars, initially by cataloguing the manuscript page by page, and separating the erased texts into language groups.¹⁰ During this process, features of the folio are recorded such as: flesh or hair side, the colour of the ink, the attributes of the script (for example if it is a Greek majuscule or minuscule), as well as other observations that may be useful during the imaging or image processing of the folios. For example, knowing that a page is a flesh side is important for the image processing team to know, since that tells them whether good results can be extracted by using transmissive illumination images.

On the basis of this information, an entry is created in the Katlkon digital tool.¹¹ This allows us to create a Shoot List that acts as a guidance tool for the imaging team.¹² This Shoot List includes not just the order of folios that are to be imaged, but all the necessary metadata for each manuscript side, so that this information can be embedded during the imaging sequence while the image files are created. The MegaVision capturing software PhotoShoot allows the import of metadata in .txt (Text) format for individual sequence of images.

The process of digital imaging is the first and fundamental step in retrieving texts that are not easily readable by the naked eye. It lays the foundation for the subsequent image processing of palimpsest texts. It is here that we create the digital material that we call raw images. Raw images are digital files that have not been processed; they are uncompressed, unpacked, 100 megabytes each, in *.DNG format, and hold a dynamic range of 12 bits per channel.

The optical unit of the imaging system is a custom designed 120mm apochromatic lens made of quartz crystals. Typical lenses made of glass will allow longwave UV to pass, but absorb all the other UV wavelengths. The 120mm quartz apochromatic lens is corrected in three wavelengths (UV-IR-VIS) to minimize the magnification and focus changes between the UV-IR and VIS spectrum. Without this lens, one would encounter the common problem of misregistration of data between fluorescent and reflectance shots and the need to refocus between IR and UV. The lens is custom-built with multispectral applications in mind and uses a central, Copal 0, Schneider electronic leaf shutter. The lens design utilizes nine elements in seven groups. Six of them are special low dispersion (ED) glass, and the rear element is aspheric. The use of the specific lens is unique to the system developed by MegaVision and used by the Sinai Palimpsests Project.



Fig. 1: Current E7 MegaVision Spectral Imaging System, a product of the Archimedes Palimpsest Project, updated by the Sinai Palimpsests Project to its current form. The following components are visible: LED light sources, diffusers creating even distribution of light, E7 digital back, filter wheel, 120mm apochromatic lens, and capture computer controlling all of the above.

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archive.org/web/20220315215735/http://sinaipalimpsests.org/).

¹⁰ This work was the task of the Scholarly Director of the Project, Claudia Rapp, supported by Giulia Rossetto from October 2014.

¹¹ Emery and Rapp, Katlkon: A Digital Catalogue as Multi-Purpose Tool.

¹² A Shoot List is defined as a collection of individual .txt files, each representing a folio side of a specific manuscript to be imaged. This is automatically generated by Katlkon upon call of a specific function of the database, simplified to a press of a button named 'Download Shoot List' by the end user.

During spectral photography at St. Catherine's, Sinai, 33 different black-and-white images were recorded for each manuscript side, using a 50-megapixel camera manufactured by MegaVision Inc. that houses a Kodak CCD Imaging Sensor (KAF-50100) with $8176(H) \times 6132(V)$ pixels. A CCD array sensor gives an advantage over a CMOS sensor when capturing spectral images by having a better spectral response in the 350–1100 nm range.

The MegaVision E7 Kodak sensor is a monochrome sensor, meaning that it does not have a Bayer filter. A Bayer filter, common in all modern digital cameras, uses pixel-level Red-Green-Blue filters and results in great losses both in the recording of the remaining wavelengths (colours) and in the light intensity (in brightness).¹³ Removing those filters from the sensor, we can use less energy to capture better data, meaning a better noise to signal ratio, as well as less exposure of the manuscript's surface to artificially-generated energy from the LED light sources. By recording information in the gray-scale, light intensity is captured for each specific wavelength with which the object is illuminated. As a result, we obtain a better resolution, and we are truly using all of the 50.000.000 pixels of our E7 digital back. This high resolution gives us the opportunity to study very closely, one by one, the elements of the text we are trying to identify. Such high-resolution images are important, in order to provide the scholars with the greatest possible amount of detail to identify individual letters or even parts of letters.

Each manuscript recto and verso side is captured by a sequence of 33 shots. Each time, the manuscript is illuminated by a different wavelength of light (colour) and in some cases also with light coming at different angles: two raking lights at 15 degrees, two main lights at 45 degrees, and one transmissive light source that is placed under the folio to capture erasures. The idea of implementing transmissive illumination is not new to the world of photography, but this was the first time that this technology had been integrated into a large-scale project along with spectral imaging for the photography of palimpsested manuscripts. More specifically, the lights that were used for imaging the Sinai palimpsest manuscripts had 12 different wavelengths. Since then, modern MegaVision systems have begun to use up to 16 or 20 different wavelengths. This is partly in response to the Sinai Palimpsests Project demanding more and more data to be recorded for future analysis. This high density of information gathered in the course of the imaging is a hallmark for the work of EMEL and its associates, who are leading developments and contributions in the field of Spectral Imaging.¹⁴ In the process of EMEL's work with the Sinai Palimpsests Project, on-site solutions were developed and are now driving the technology from which the rest of the world is benefiting.

Using LED technology avoids the production of heat on the surface of the manuscript and thus allows us to honour our responsibility to perform noninvasive and non-destructive examinations. The wavelengths utilized range from ultraviolet 365 nm to infrared 940 nm, including wavelengths visible to the human eye with the use of seven distinctive LED lights ranging from 400 nm to 700 nm. The LED light sources originally designed by William Christens-Barry¹⁵ received two upgrades during the Sinai Palimpsests Project, by Ken Boydston.¹⁶ In their original design, lights were recognized by the capturing computer as Serial Devices. As a result, they often conflicted with the Operating System and the capturing software, leading to random disconnections from the system. In 2013, the lights were updated with new control boards, allowing them to interact with the capturing system as USB devices, thus providing better connection stability as well as higher power output which in turn leads to shorter exposure times. The third and final update of the lighting system was the addition of two auxiliary light sources housing UV wavelengths at 365 nm and 385 nm that provided even shorter exposure times as well as more data in the UV and near UV spectrum.

There are four different imaging principles in the system: reflectance, transmissive, raking, and fluorescence. In reflectance, light hits the surface of the object from a 45-degree angle and gets reflected to the imaging sensor that is parallel to the object. In transmissive, light penetrates the object and exits from the other side if the object is thin enough. In raking, light illuminates the object from a low angle of 15-degree, creating shadows and highlighting the curvature of the object. In fluorescence, parchment absorbs the short UV wave-

¹³ Patent US3971065—Colour imaging array.

¹⁴ EMEL: Early Manuscripts Electronic Library, URL: <http://emel-library.org/> (accessed 01.07.2023, alternative URL: <https://web.archive.org/web/20220412092445/http://emel-library.org/>).

¹⁵ Equipoise Imaging, LLC (Baltimore, MD, USA).

¹⁶ MegaVision (Santa Barbara, CA, USA), URL: <http://www.mega-vision.com/> (accessed 01.07.2023, alternative URL: <https://web.archive.org/web/20220517101938/https://www.mega-vision.com/>).

lengths and re-emits them back at longer wavelengths, which are visible to the eye and can be captured by a digital sensor. This makes the object a broad-band light source and for these specific shots filters can be applied in front of the lens to capture selectively narrower bands. Areas of the parchment that have erased ink on them react differently in their fluorescence from the parchment. This difference is essential in recovering erased writing and is captured in the images. While processing the spectral data these small differences will allow the two-dimensional captured images to be differentiated into separate groups: parchment with no ink, parchment with erased ink, and parchment with more recent ink.

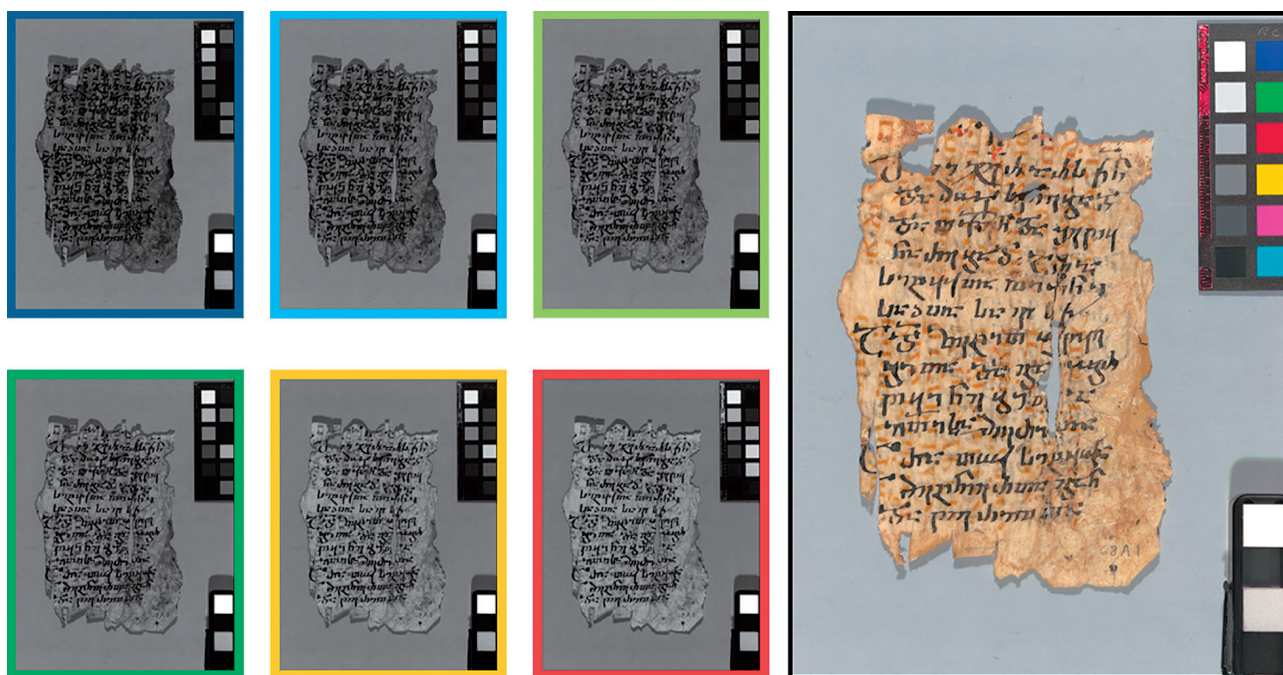


Fig. 2: Colour image produced by a combination of visible wavelengths. Seven visible wavelengths are used to produce the colour image. In this example only six images are visible for reasons of space
(© St. Catherine's Monastery, Sinai, Egypt)

Multiple individual visible wavelengths of light, when combined, produce a very accurate representation of the actual colour of the object. Where Bayer-filter digital cameras use only three colours (RGB) to produce a colour image, the Spectral Imaging System uses seven colours (Fig. 2) (Royal Blue, Light Blue, Cyan, Green, Amber, Red, and Dark Red), and more recent ones use up to 12 visible wavelengths. This is achieved by a combination of seven different gray-scale pictures captured under the conditions of a dark room with the only illumination coming from those specific wavelengths, configured manually according to $L^*a^*b^*$ readings of the digital pictures, and white balanced according to $L^*a^*b^*$ measurements from colour targets (more specifically: the MacBeth colour target).¹⁷ Calibration of all images can be traced back by using unique serial codes of the colour targets which are manufactured under specific standards, so that an accurate reproduction of the results can be achieved at any given time.¹⁸ The MegaVision digital camera back E7 and MegaVision Photo-shoot capture software are linked in such a way that new calibration files can be captured, if needed. These can then be compared to older calibrations in tables of numbers for each individual colour patch, since what we have as a system is essentially a high-resolution colorimeter.

¹⁷ GretagMacbeth GmbH became X-Rite GmbH in September 2012 but the team is still the same. URL: <https://web.archive.org/web/20220328070852/http://gretagmacbeth.de/> (accessed 01.07.2023).

¹⁸ Colorimetric measurements using the CIE 1931 2° standard observer and Illuminant C, and also in terms of the Munsell colour system. Using measured reflectance spectra, it is possible to derive CIELAB coordinates for Illuminants D65 and D50 and coordinates in sRGB.

In cases of folios where the ink has eroded the parchment surface, or—as we used to say during the Project—where ‘the ink has eaten into the parchment’, a specially built surface—the transmissive light source—is used to illuminate the folio from below so that the light penetrates more easily in the area of the letters where the parchment has become thinner. Two transmissive light sources were designed specifically for the Sinai Palimpsests Project: a device that can be inserted between folios with an edge that progressively becomes thinner so that light can illuminate the folio all the way to the gutter, and a second device that resembles a photo box platform upon which unbound or fragmentary objects can be placed for imaging from a 90-degree angle in a copystand setup. The experience of the Sinai Palimpsests Project has shown that the use of spectral transmissive light sources yields significantly better results if the original text was written on the flesh side. The transmissive light source used in Sinai was built by William Christens-Barry and featured four visible wavelengths and four IR wavelengths, though only the longest IR wavelength (940 nm) has proven to be consistently useful in processing. For this reason, recent transmissive light sources by MegaVision reduce the number of wavelengths.

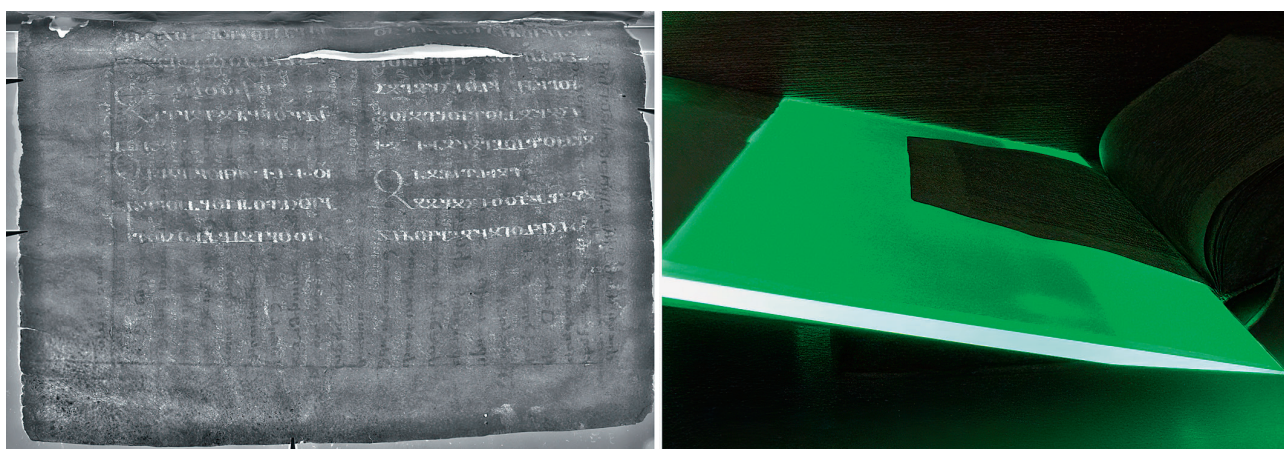


Fig. 3: Light illuminating through parts of parchment that have been eroded by the ink. Transmissive light source inserted close to the gutter of the folio. Designed and used for the Sinai Palimpsests Project
(© St. Catherine's Monastery, Sinai, Egypt / Early Manuscripts Electronic Library)

The digitization process was made possible using equipment that already existed at St. Catherine's, as well as equipment that was specifically designed for this project. One part of the pre-existing equipment was the manuscript support mechanism for the digitization of fragile manuscript codices, the Preservation Book Cradle by Stokes Imaging.¹⁹ The Stokes Cradle is a support mechanism (book cradle) that is considered to be one of the best options for supporting fragile codices and ideal for the collection of St. Catherine's. This mechanism allows for the natural movement of the spine of the manuscript codices without exerting pressure. Fragile codices are not harmed during digitization or put under any stress, since the book cradle can support books that open even at a ~90 degree angle.

The actual process of spectral digital imaging is lengthy in terms of time. In the Sinai Palimpsests Project it took up to ten minutes per side to capture the necessary data. Of these ten minutes, six were required for imaging, and one to four per material handling. For the imaging, exposure times ranged from a little less than a second up to 30 seconds. Visible spectrum and infrared sequences needed short exposures, but the lower range wavelengths of violet and ultra-violet needed longer exposures. In sequences that required the use of filters, longer exposures were used to compensate for the loss of illumination as light was passing through the filters. As anticipated, material handling took up to four minutes, since the priority during the imaging was the safety of the fragile manuscript objects. It took great effort to securely position a single page in such a way that the object would not move at all for the duration of the imaging sequence. Any movement would lead to

¹⁹ Stokes Imaging (Austin, TX, USA), URL: <http://www.stokesimaging.com/pbc.html> (accessed 01.07.2023, alternative URL: <https://web.archive.org/web/20220217072724/http://www.stokesimaging.com/pbc.html>).

misregistration of the data, or blurry images in the longer exposures. The imaging of Sin. ar. NF 8 (*Diktyon* 58318) can serve as an example of the time needed for the imaging of a single manuscript. 256 sides, i.e. rectos and versos, were captured from the manuscript. For each side it took 6 minutes of imaging and another 2 minutes of material handling to switch between folios. In total, 2,048 minutes, or approximately 34 hours, were needed to complete the imaging of the manuscript. This amounts to about a week for the imaging, not counting the frequent electricity outages.

The subsequent task of image processing was also time consuming, as it could take less than one minute per page in the case of batch processing, but up to 180 minutes or more per page for manual statistical image processing. The end result of this lengthy process, which began with 33 different black-and-white photographs, is one or two final pictures in which the erased writing becomes as legible as possible.

A VIEW FROM THE WORKROOM

A personal experience from the library during our work resulted in an unexpected discovery while imaging the manuscript Sin. ar. NF 8. In the captured images some strange shapes were barely discernible behind the Arabic overtext instead of the usual letters. These shapes at first seemed like flowers. It is worth noting that when imaging a codex, the order that was followed was imaging all the recto sides first, and then all the verso sides, so there was no possibility at this stage of seeing the pages as a continuation of each other. After the completion of one side of the codex, and while imaging the facing side, I again observed further strange shapes under the Arabic overtext, this time in even more distinct form. The answer came a few weeks later²⁰ when Roger Easton processed the images, and I was able to read the name of the plant called ‘phileterion’ (φιλετέριον in the manuscript; corr. φιλεταίριον) and the text in Greek in the lower left of the new image, describing how the leaves of the plant could be boiled in oil to be used as a healing paste against scorpion bites. Initial quick research showed that ‘phileterion’ was mentioned as ‘polemonium’ by the ancient medical author Dioscorides. Polemonium is still the Latin name of this plant.²¹ A further check by Giulia Rossetto, participating scholar in the Sinai Palimpsests Project, confirmed that the exact text was not found in the existing corpus of Greek texts of the *Thesaurus Linguae Graecae* (TLG).²² Subsequent study of this ancient illustration and the accompanying text by participating scholars Agamemnon Tselikas and Nigel Wilson has revealed that the illustrated folio was written in a loose majuscule of small size from the 5th–6th century, and could originate from a herbal earlier than that of Dioscorides, possibly by the physician Crateuas.²³

This discovery conveys the excitement of being the first, in the imaging room, to recognize unusual features in the erased layers that are being made visible thanks to a long chain made up of interconnected links. It is a chain that connects us, as we work with the most up-to-date technology of the 21st century, with the monks who wrote, used, and owned these manuscripts across the centuries.

²⁰ May 29, 2014.

²¹ Adams, *The Seven Books of Paulus Aegineta*, 304: ‘Πολεμώνιον, Polemonium, Greek Valerian (called by some Philetaerium), is attenuate and desiccative. Hence some give the root of it in wine for ischiatic disease, dysentery, and scirrhus of the spleen. [...] It occurs in the Hippocratic treatises (Hippiatr. 108, ed. Basil) but is not found in the works of Celsus. Dioscorides recommends it to be given for the bites of venomous reptiles, for dysentery, dysuria, sciatica, and diseases of the spleen, and also as a masticatory for toothache. He further mentions that it was used as an amulet for the sting of the scorpion (IV, 8). Our author copies from Galen, as does also Aetius. We have not been able to trace it in the works for the Arabians, with the exception of Ebn Baithar, whose account of it is made up entirely of extracts from Dioscorides and Galen (I, 186).’

²² Rossetto, Giulia (2015): personal communication.

²³ See more on this text in Giulia Rossetto’s contribution in this volume.

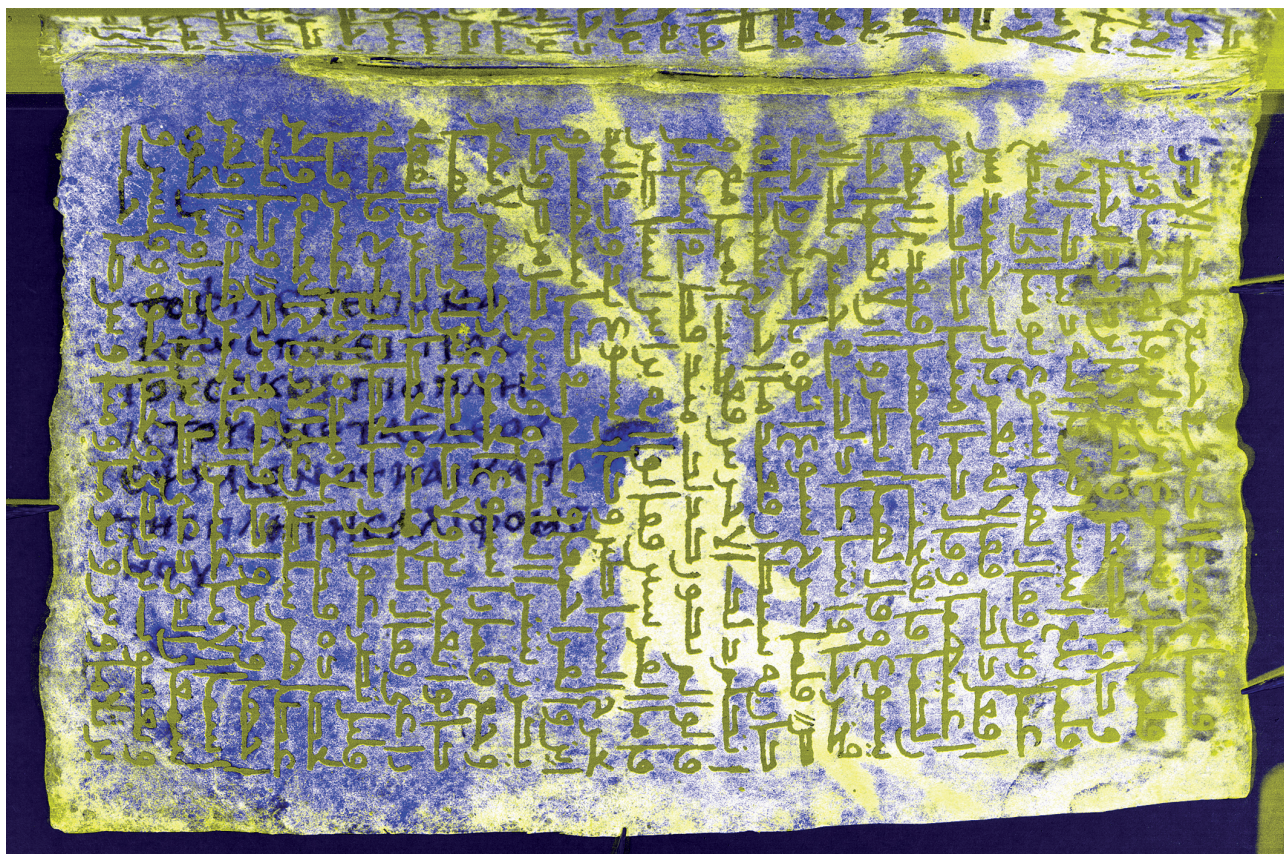


Fig. 4: RAW image of Sin. ar. NF 8, f. 16v under UV illumination: two folios stitched together and rotated through 90° reveal the 'phileterion'

(© St. Catherine's Monastery, Sinai, Egypt)

ΤΟΦΙΛΕΤΕΡΙΟΝΑ ΚΡΩΣΠΟΙΕΙΠΡΟΣ ΤΟΥΣΣΚΟΡΠΙΟΠΑΗ ΚΤΟΥΣΜΕΤΑΕΛΕΟΥ ΕΨΥΜΕΝΟΥΚΑΙΚΑΤΑ ΥΤΗΣΠΛΗΓΗΣΑΛΙΦΟΜΕ ΝΟΥ	ΤΟ ΦΙΛΕΤΕΡΙΟΝ ΑΚΡΩΣ ΠΟΙΕΙ ΠΡΟΣ ΤΟΥΣ ΣΚΟΡΠΙΟΠΑΗΚΤΟΥΣ ΜΕΤΑ ΕΛΕΟΥ ΕΨΥΜΕΝΟΥ ΚΑΙ ΚΑΤ ΑΥΤΗΣ ΠΛΗΓΗΣ ΑΛΙΦΟΜΕΝΟΥ²⁴	The phileterion acts/works perfectly for those who are stung by a scorpion after having boiled some oil, and having used it to anoint the wound.
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²⁴ Τὸ φιλεταίριον (φιλετεριον cod.) ἄκρως ποιεῖ πρὸς τοὺς σκορπιοπλήκτους μετὰ ἐλέου ἐψυμένον καὶ κατ' αὐτῆς <τῆς> πληγῆς ἀλιφομένου.



Fig. 5: Phileterion, an ancient illustration of a medicinal plant.

The image of Sin. ar. NF 8 (ff. 16v+17r) processed by Roger Easton Jr. reveals a pharmaceutical recipe
(© St. Catherine's Monastery, Sinai, Egypt)

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