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Multispectral Imaging and the Digitization of the Dead Sea Scrolls

INTRODUCTION

The Dead Sea Scrolls (DSS) are one of the greatest archaeological discoveries of the 20th century. Comprising around 1,300 manuscripts, including the earliest known copies of every book of the Hebrew Bible (except for the book of Esther), as well as nonbiblical and sectarian texts, this collection provides a glimpse at the era that saw the birth of Christianity and the formalization of Judaism. Since their discovery 70 years ago, the DSS have gone through several phases of treatment and documentation. At present, the dedicated conservation lab of the Israel Antiquities Authority (IAA) is not only overseeing the treatment of the scrolls, but for the last seven years has also been using a cutting-edge multispectral imaging system to digitize the entire collection with the goals of preserving the physical scrolls, preserving the content of the scrolls, and significantly increasing public access.

THE DISCOVERY OF THE DEAD SEA SCROLLS

The first scrolls were discovered in 1947 by a Bedouin looking for his lost goat in the caves along the western shore of the Dead Sea near the archaeological site of Khirbet Qumran. Three of the seven scrolls from this first cave were purchased by Eliezer Lipa Sukenik, a professor of archaeology at Hebrew University of Jerusalem, while the other four scrolls were purchased by the Syrian Orthodox Archbishop Athanasius Samuel. Mar Samuel smuggled his four scrolls into the United States and in 1954 placed an advertisement in the *Wall Street Journal* offering them for sale. They were bought, through an intermediary, by Yigal Yadin, Sukenik's son, who was a leading Israeli archaeologist. Together again, these seven scrolls are currently housed in the purpose-built Shrine of the Book at the Israel Museum where sections of these scrolls are always on display.

Starting in 1949, excavations in the region, led by Père Roland de Vaux, the director of the École Biblique et Archéologique Française of Jerusalem, discovered ten more caves with scrolls over a period of eight years. The excavated material was brought to the Rockefeller Museum in Jerusalem, where it was studied by an international team of biblical scholars. All together, these excavations yielded thousands of fragments comprising around 900 manuscripts spanning a period of time from the third century BCE to the first century CE.

In addition to the material found in the Qumran caves, the IAA's collection includes manuscripts from six other locations in the Judean Desert dating from the fourth century BCE to the seventh century CE. Around 80% of the collection is parchment while the remaining 20% is papyrus. The original scholars, working on the world's largest jigsaw puzzle, arranged the thousands of fragments of varying sizes into over 1,500 glass plates (fig. 1).

THE IAA AND CONSERVATION

In 1967, the Rockefeller Museum became the headquarters of the Israel Department of Antiquities, which was reformed into the IAA in 1989. The IAA is the government authority regulating all archaeological activities in Israel and serves as the national treasury of cultural heritage overseeing the conservation of and research into the excavated sites and material.

From the time of their discovery to the founding of the IAA, only eight volumes of the official DSS publication, *Discoveries in the Judean Desert* (DJD), had been published. The first director of the IAA greatly expedited publication, and, within 20 years, an additional 32 volumes were produced.

During this process, it was acknowledged that the scrolls themselves were in very poor condition as a consequence of their age and four decades of unintentional mishandling, including the extensive use of pressure sensitive tape, castor oil, British Museum leather dressing, and acrylic adhesives, and that without immediate intervention the world would soon have 40 volumes of publication but no original scrolls.

Therefore, in 1991, the IAA established a conservation lab dedicated solely to the DSS and a new work protocol using the most suitable and up-to-date methods was created with the assistance of an international committee of experts sponsored by the Getty Conservation Institute. The key parts of

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Fig. 1. The Scrollery at the Rockefeller Museum. Courtesy IAA. Credit: Najib Albina.

this ongoing treatment have involved establishing suitable environmental conditions and rehousing the entire collection, removing previous treatments where possible, and supporting and strengthening the fragments.

DIGITIZATION AND THE DEAD SEA SCROLLS

From the very beginning, Najib Albina, the Rockefeller Museum house photographer, recognized the importance of photographing the scrolls and understood how infrared film could be used to make the invisible visible, especially since most of the scrolls are written in a carbon-based ink. In total, around 3,500 infrared photographs were taken in the 1950s to early 1960s, documenting the arrangement of the glass plates. These photographs were then used in the DJD and remained the primary photographs of the scrolls until the start of our digitization project.

From a conservation perspective, these photographs preserve the condition of the scrolls as they were found 70 years ago, prior to the 40 years of mishandling. Because of this, they are treated as important objects in their own right and kept in a dedicated climate-controlled storage room. As a preliminary stage of the digitization project, all of these negatives were scanned in 800 dpi.

The first step in the digitization process is to document the plate in its current condition. Each fragment is then stabilized where necessary, using small splints of remoistenable tissue made from Japanese tissue paper and 10% methyl cellulose adhesive. Methyl cellulose is also used to attach Japanese tissue paper hinges to each fragment, which are used to secure the fragments in their housing and limit movement. During digitization, these hinges provide a secure holding point for very small fragments when moving them to and from the camera (fig. 2).

A major decision was made at the beginning of the project to image fragments rather than plates, which was the first time

Fig. 2. Example of Japanese tissue splints and hinges. Courtesy IAA, LLDSSDL. Credit: Shai Haleyi.

that each fragment had been viewed as an individual physical entity. However, this meant that an entirely new cataloguing system had to be devised. Prior to this, there were two primary cataloguing methods. The first is the system used in the DJD where the fragments are recorded based primarily on their relationship to a specific manuscript rather than on their physical location in the collection; it is still the academic standard for referencing the scrolls. The second system was created by the conservators who numbered the fragments according to their placement in the plate in order to reference them in conservation documentation.

For the new cataloguing system, each plate is photographed in color with a standard camera, and then a software designed for this purpose creates a map of the plate with coordinates set at the center of each fragment. It then scans the plate and numbers the fragments according to their heightwise placement in the plate based on their topmost point rather than their center (fig. 3). This new numbering system as well as the system developed by the scholars will be used for the Leon Levy Dead Sea Scrolls Digital Library (LLDSSDL). Volunteers are correlating all three cataloguing systems in order to create a single unified searchable database. Although this continues to be a long and slow process, it has led to the rediscovery of "lost" fragments whose physical location had not been accurately recorded in previous catalogues (Ableman 2018).

THE MULTISPECTRAL IMAGING SYSTEM

The digitization is done with an LED-based MegaVision Multi Spectral Imaging System installed in 2011, after three pilot projects by Dr. Greg Bearman, an expert in spectral imaging, Dr. Bill Christens-Barry, a lighting expert, and Ken Boydeston of MegaVision. The system was tailored to the specific needs of this project and, during installation, each part was carefully measured and adjusted to ensure the correct angles and distances needed to achieve the best possible results (Shor et al. 2014).

The recto and verso of each fragment is photographed in 12 different wavelengths, seven in the visible light spectrum

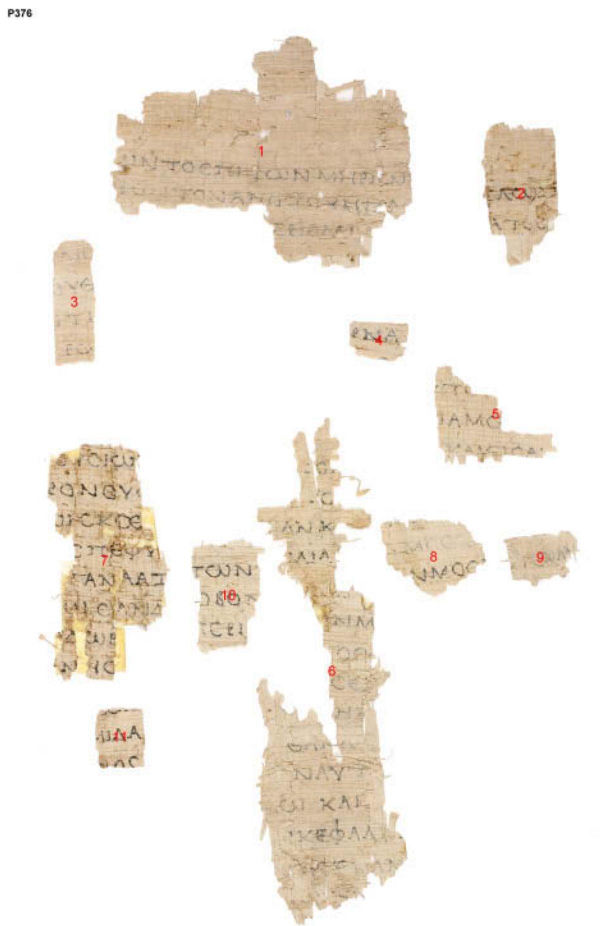

Fig. 3. Example of a plate map for Plate 376. Courtesy IAA, LLDSSDL. Credit: Shai Halevi.

Visible Light Wavelengths	Near-Infrared Wavelengths
445nm – Royal Blue	IR706nm
475nm – Long Blue	IR728nm
499nm – Cyan	IR772nm
540nm – Green	IR858nm
595nm – Amber	IR924nm
638nm – Red	
656nm – Deep Red	

Fig. 4. Multispectral wavelengths.

and five in the near-infrared. The specific wavelengths are listed in figure 4, and the camera set up is shown in figure 5. The circles indicate the LED lights for all seven visible light wavelengths, the triangles indicate the LED lights for all five of the near-infrared wavelengths and the squares indicate raking lights, which repeat the longest and shortest wavelengths of light (royal blue and 924 nm).

First, the fragment is lit evenly from both sides for 12 exposures, one in each wavelength. This uniform lighting produces a flat image that best captures the text. Second, the fragment is lit from just one side, using the upper light, for six exposures: one in each visible light wavelength, excluding royal blue. Finally, two exposures are taken with the raking light. These last two steps are then repeated for the other side, giving a total of 28 exposures. The side lighting captures the physical, topographical features of the scrolls, which is why only one infrared wavelength is used. All of the visible light

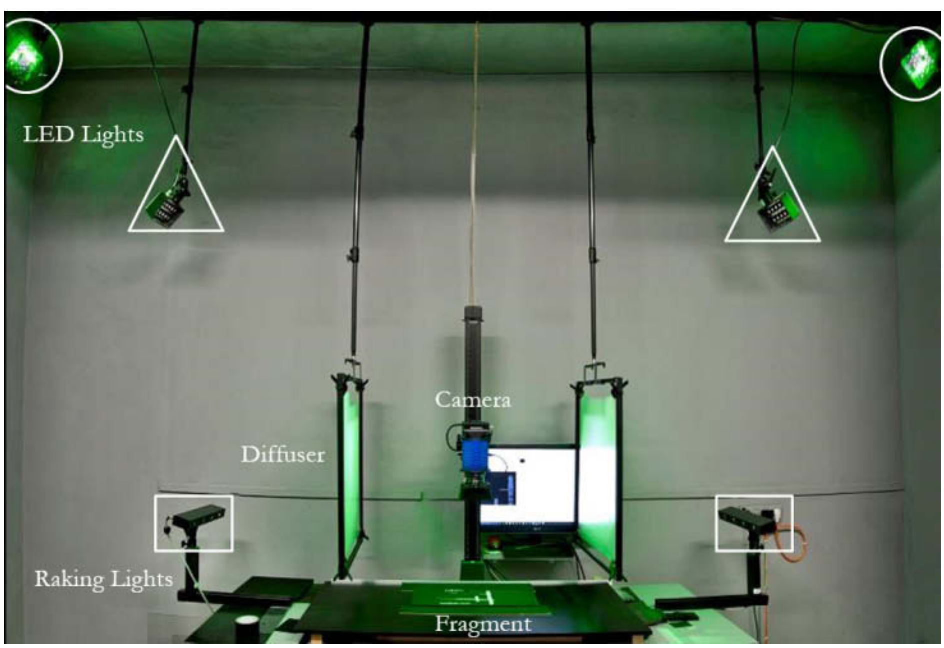

Fig. 5. MegaVision camera. Courtesy IAA. Credit: Shai Halevi.

wavelengths are then combined to create a full-color digital image. It takes four minutes to shoot the 28 exposures giving an average of ten minutes to complete the full 56 exposures needed to photograph the recto and verso of each fragment.

In order to ensure that the first photograph from 2011 will have identical parameters to the last photograph yet to be taken, the system is calibrated weekly and monthly. Every week, Shai Halevi, the project photographer, uses the standard 28 exposures to photograph a pure white flat field, pure black, and the standard color targets used in every photograph. Every month he uses 30 exposures (all 12 wavelengths from each side separately and together excluding the raking lights) to photograph the white flat field and five specially designed color targets. He then compares these images to the previous month or week to ensure that nothing has changed.

Black was chosen as the background for the photographs because it does not reflect light, which could affect the image and reduce the system's stability. Certain scholars would have preferred a blue background, which would have made it easier for them to isolate the fragments from their background, a necessary first step in several of the new computer-based analyses of the DSS they are attempting.

To further help maintain stability, the entire system is bolted to the floor to prevent movement, and the camera is never moved. Instead, the fragments are placed on a moveable black tile that allows larger fragments to be moved under the camera and then photographed in multiple sections without having to touch the fragments, thereby minimizing the handling of such fragile objects. The multiple images are then digitally stitched together to create a single complete image. In the last seven years, more than 25,000 fragments have been photographed, totaling almost 300 TB of data.

PROJECT OBJECTIVES

The objectives of this project are threefold: the physical preservation of the scrolls, the preservation of the content of the scrolls, and increased public access.

PHYSICAL PRESERVATION

Because the color images are objectively identical to the original scroll, they preserve its current condition and can serve as a surrogate should anything happen to the scroll in the future. In addition, these images are used to create photographic reproductions of the scrolls that can be provided for exhibitions where the conditions preclude the use of the original scrolls. These reproductions are printed on cardstock with blank versos to prevent any possible confusion with an original scroll.

This project was originally developed in conjunction with a scientific team from Pasadena California, the University of Eastern Piemonte Italy, and the Library of Congress, who developed a completely noninvasive and nondestructive monitoring system that combines the multispectral images with multivariate statistics (Marengo et al. 2011a, 2011b). In this system, a fragment is photographed five times, alternating with a white field. This combination allows the computer program to filter out background noise and then make a pixel by pixel comparison between the most recent images and past images of the same fragment. In the results, blue and red colored pixels represent pixels where change has occurred even before it is visible to the eye (Manfredi et al. 2015) (fig. 6).

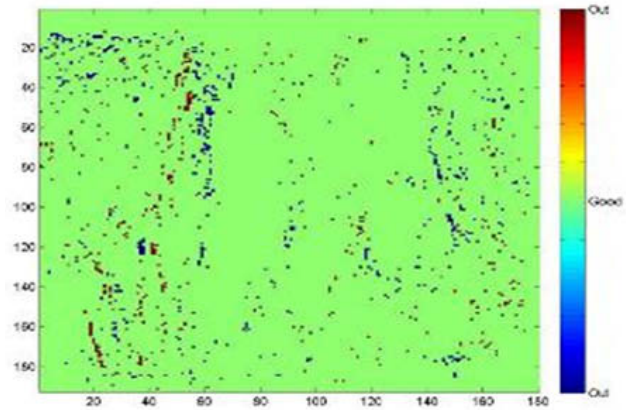

Fig. 6. Monitoring program sample results. Credit: Marcello Manfredi.

Every three months, six fragments with representative conservation concerns are photographed for this project. In its current format, the program is unwieldy and the results are not yet readily applicable to daily conservation practice. However, the collected data is being used to refine the program and create a more user-friendly monitoring system.

PRESERVATION OF CONTENT

The use of infrared as well as visible light wavelengths for this project is preserving the content of the scrolls by providing high-quality images of text that is no longer visible to the eye. A number of scholars have been able to use these images to

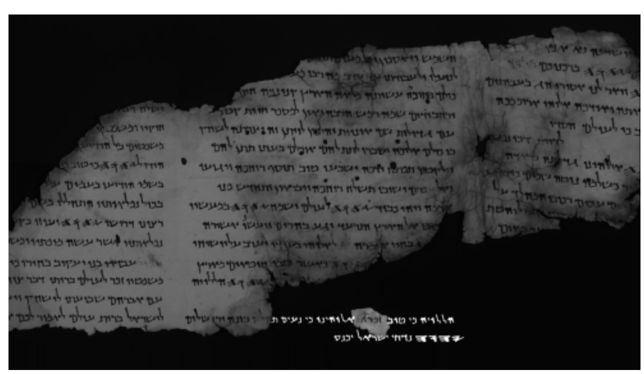

Fig. 7. Reconstruction of Psalm 147. Courtesy IAA, LLDSSDL, Shai Halevi, Orit Rosengarten, Oren Ableman.

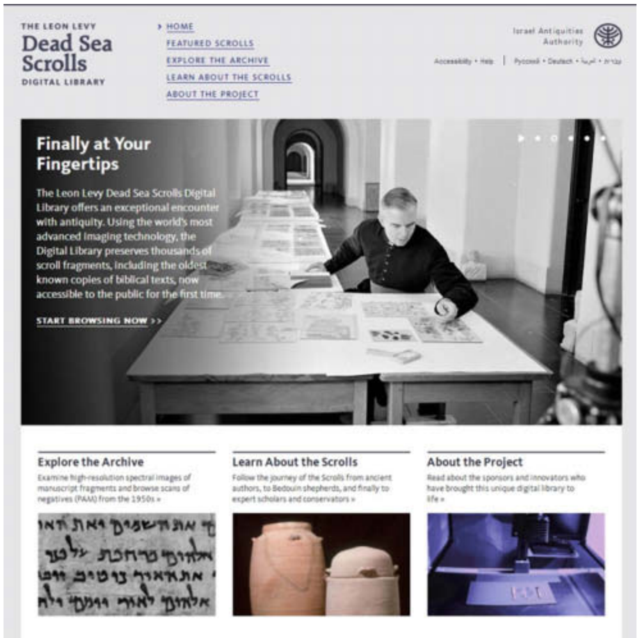

Fig. 8. Homepage of the Leon Levy Dead Sea Scrolls Digital Library. Courtesy IAA.

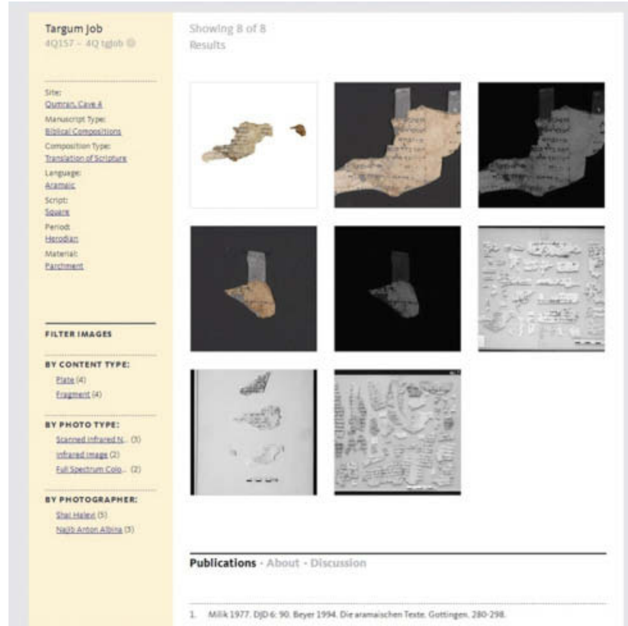

Fig. 9. Example of a LLDSSDL album page. Courtesy IAA.

provide new textual readings and discover previously indecipherable text.

Recently, Oren Ableman, the IAA's in-house DSS scholar, used the multispectral imaging system to identify letters, and in some cases words, on fragments that the original scholars had set aside as being too small and damaged to decipher. He identified one of these fragments as belonging to the Great Psalms Scroll from Qumran Cave 11, and was able to reconstruct a vanished line of text showing that, in this particular case, the first line of Psalm 147 is one word shorter than the version used today (Ableman, forthcoming) (fig. 7).

INCREASING PUBLIC ACCESS

The history of the DSS since their discovery has been troubled with complaints and accompanying conspiracy theories regarding the lack of access to the scrolls both from scholars and the general public. Even now, the price of a complete set of DJD volumes puts it out of reach of anyone other than

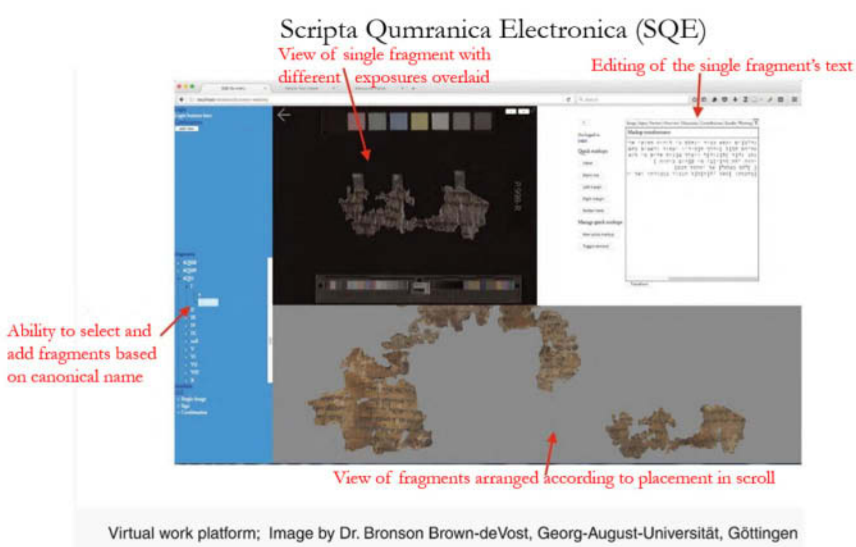

Fig. 10. Scripta Qumranica Electronica Virtual Work Platform. Credit: Dr. Bronson Brown-de Vost.

large institutional libraries. Therefore, a key component of this project has been the creation of a website (https://www.deadseascrolls.org.il) offering free-for-all access to the digital images of the scrolls (fig. 8). It launched in 2012, enabled by Google and funded by the Leon Levy Foundation and Arcadia Fund.

In the digital library, each manuscript has an album (fig. 9) with Najib Albina's original images, a color image of the complete plate, and two images of the recto of each fragment—the full color image and the infrared image at 924 nm—all uploaded with their metadata. The verso is uploaded if there is text. The other exposures are available for free to scholars on request. The website also includes a search engine, featured scrolls, and several interactive content pages. The current version has 34,000 images and is available in Hebrew, Arabic, English, German, and Russian. An updated version is currently being prepared and will include an additional 15,000 images, the translation of the content pages into Chinese, an upgrade of the metadata, and new additional content.

This project has been very successful in engaging public interest and involvement with the DSS, including educational activities and virtual exhibitions. In addition, the site has become an invaluable tool for DSS scholars who now how have free access to high-quality images.

There are a number of ongoing international collaborative research projects that seek to considerably increase the functionality of the website. One of these projects, named Scripta Qumranica Electronica (fig. 10), funded by the German-Israeli Project Coordination (DIP), is developing computer-based algorithms to not only connect transcriptions and translations of the text to the images, but also to create a virtual workspace where scholars will be able to manipulate the fragments, create new manuscript reconstructions, and publish digitally (Brown-de Vost 2016).

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