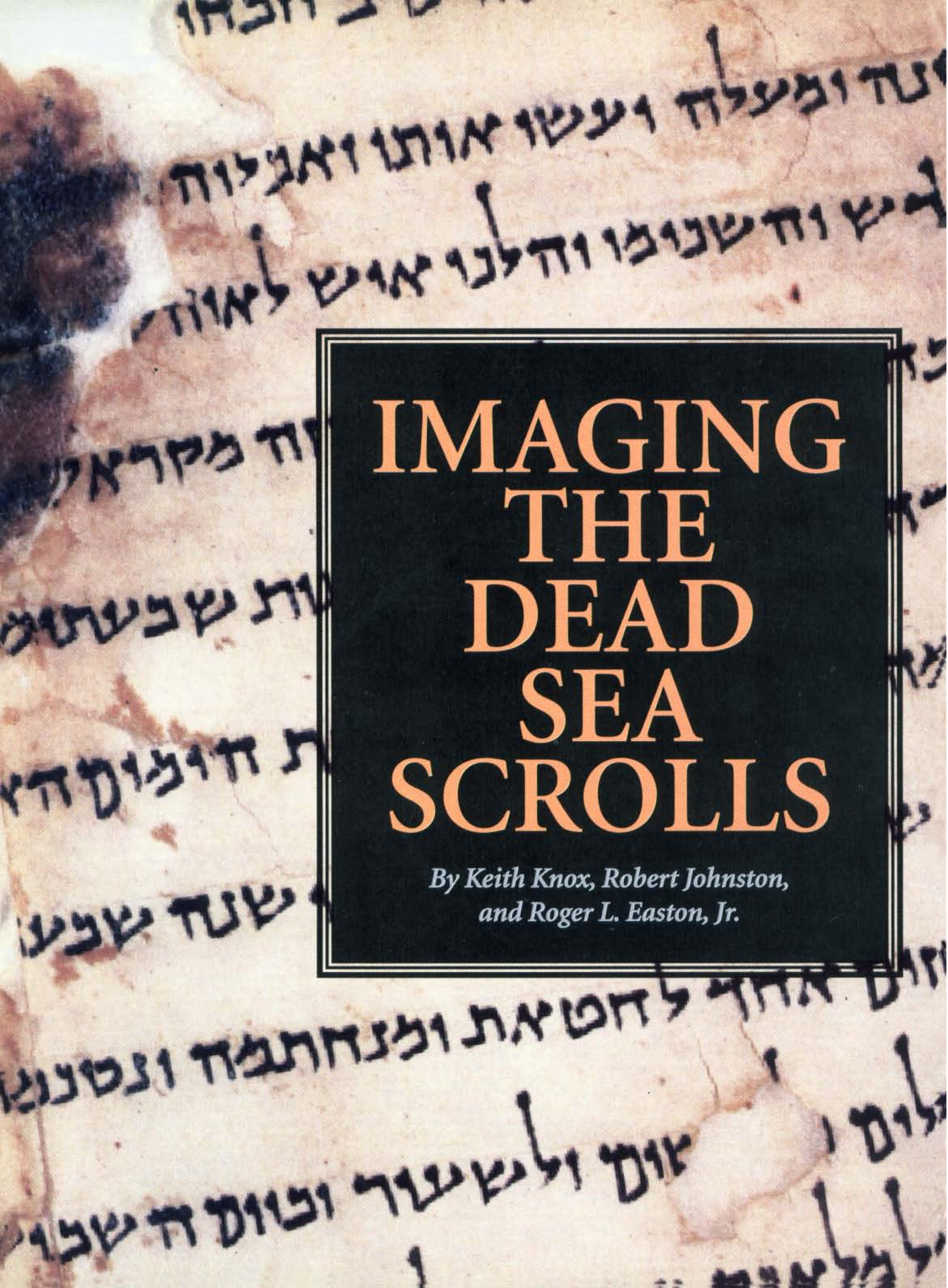

IMAGING THE DEAD SEA SCROLLS

By Keith Knox, Robert Johnston, and Roger L. Easton, Jr.

The authors explore the current use of modern image processing techniques to decipher ancient texts, and look toward future applications, including "discovering" original texts from overwritten documents.

Fifty years ago, Bedouin shepherds discovered a cave on the western shore of the Dead Sea, approximately eight miles south of Jericho. The Bedouin were members of the Ta'amireh tribe and were familiar with this region surrounding the Wadi Qumran, which is pockmarked with caves (see Fig. 1, page 32). The shepherds found 11 jars in this particular cave. One jar contained three scrolls, identified to be of ancient origin. Between 1947 and 1956, archaeologists examined 273 caves and openings, 39 of which contained some evidence of human habitation. Artifacts and pottery were recovered from 25 caves, but only 11 (later designated by number) yielded text documents. These writings, known as the Dead Sea Scrolls, include previously unknown Jewish documents, as well as Tanakh or so-called "Old Testament" biblical texts. The manuscripts date from around 250 BCE to 135 CE, which is over 1,000 years older than the previously earliest known Old Testament copies. Shortly after the discovery of the Dead Sea Scrolls in 1947, they were proclaimed as "the greatest Manuscript discovery of modern times" by eminent biblical scholar, William Foxwell Albright[1] of Johns Hopkins University.

Some of the discovered scrolls were stored in jars and therefore survived in fairly good condition. Others lay on the floors of the caves, unprotected from two millennia of damage from water, ground acids, and bat dung (which was more than six feet deep in some caves). The condition of the 800 discovered documents ranges from fairly intact scrolls to minute fragments. Some texts are partially "liquefied" as the result of chemical action and others are locally damaged due to various types of contamination.

Scholars from around the world were eager to decipher and study the texts of the Dead Sea Scrolls, and by 1997, the 50th-anniversary of the first discoveries, a large portion of the readable texts has been published. However, an even larger body of extremely fragmentary or otherwise damaged texts is still being studied. Many of these remaining texts are so fragile that further handling or exposure to light for direct study is subject to severe restrictions.

Advances in digital imaging technology promise to significantly impact the study of these damaged texts. For example, it is now possible to gather imagery of ancient documents in low-intensity light, both in the visible and at other wavelengths, with little or no damage to the them. Such imagery may be collected and processed using multispectral/color digital techniques that clarify the printed characters and provide scholars with

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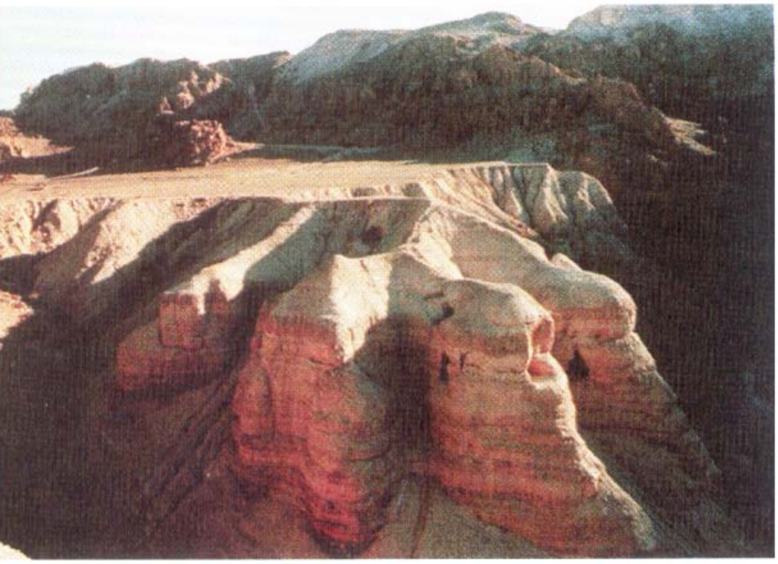
clearer images of previously unreadable areas. These may be electronically disseminated readily to scholars worldwide, thus enabling study and translation to occur with no additional handling of the fragile documents.

To demonstrate the potential application of using digital imaging technology for clarification of ancient documents, examples of the results obtained from the Temple Scroll will be considered.



Photograph by R.H. Johnston.

Figure 1. Open caves of Wadi Qumran where fragments of the Dead Sea Scrolls were found.

The Temple Scroll

The Temple Scroll, discovered in Cave 11 in 1956, remained in the possession of an antiquities dealer in Jerusalem until it was seized by Israeli authorities during the Six-Day War (1967). The scroll was unrolled, photographed, and translated by the Israeli scholar Yigael Yadin. Results of his work, including a discussion of the condition and process of unrolling the scroll, were published in 1983.[2]

The Temple Scroll[3] is written on animal skin and is the longest of the extant Dead Sea Scrolls, measuring 28 ft. It is believed to have originally contained 67 columns of text, devoted to a sequence of subjects including: the second covenant made on Mount Sinai between God and Israel; detailed measurements and plans for rebuilding the temple in Jerusalem, including the altar, chambers, and colonnades; an outline of sacrificial rituals and religious laws; a calendar of Feast Days and details for the celebrations; and a text related to the descriptions of the New Jerusalem.

The beginning of the manuscript is badly mutilated and liquefied. During unrolling, Yadin noticed that characters had been abraded or detached from the face of the scroll and were found either adhering to the back side of the next column or transferred in mirror image. The unrolled scroll exhibits crenulations (scallops) formed at regular intervals. Also, in the degraded sections, the color of the parchment is darker from exposure to moisture and damaging elements. Here, the color of the parchment has changed from light tan to dark reddish-brown, and thus the contrast between the background and the existing text characters is much reduced. Figure 2 shows a digital reconstruction from scanned photographs of four columns of the Temple Scroll.[4]

Digital processing of scroll images

In preparation for image processing, photograhs acquired[5] of some of the Dead Sea Scroll manuscripts were scanned using commercial desktop scanning systems. The initial goal of the image processing effort was to make the characters in the darkened, degraded regions more visible. A simple contrast stretching was tried first. Since the amount of stretching needed was different depending on the region, an adaptive algorithm was written to stretch the contrast relative to the average gray surrounding each pixel. While there was an improvement in contrast and some improvement in legibility, the algorithm took a long time to compute and gave very blocky results. After it was noticed that color was the distinguishing feature in the degraded regions of the scroll, an attempt was made to use this information to decipher the illegible text.

The first and obvious step was to look at the individual red, green, and blue separations. Neither the green nor blue separation showed anything unusual, but the red revealed some faint shadows in the degraded regions. Since the degraded background is a dark, reddish-brown, the background is lighter in the red separation, which increases the contrast between it and the characters in the degraded regions. But, although shadows can be seen, no new characters were recognizable.

The most significant results were obtained when the three-dimensional red-green-blue (RGB) color image data was projected onto the components of a luminance-chrominance color space and displayed as monochrome images. The chrominance channels of this color space exhibit a great deal of character information. The particular operation transforms the RGB data to a linear opponent-color space defined by Xerox Corp. and called "YES."[6] The luminance component Y is a weighted sum of the RGB values, while the two chrominance channels, E and S, are proportional to red minus green, and yellow minus blue, respectively.

A section of column 17 of the Temple Scroll is shown in Figure 3. The Y and E components are shown on the left and right, respectively. The Y separation gives the same visual impression as the full color image. Several lines of text are visible, but they are very hard to read in the darkened, degraded regions of the image. However, the E separation on the right of Figure 3 shows a great deal of character information. New characters are visible in all the lines in this part of the image. Several new lines of text are visibly superimposed on each of the existing lines of text in the image.

The most dramatic result of the YES separation was the appearance of several "new" characters in a space that appeared to be vacant in the original image. These characters were unexpected because the region in which they appear was not obviously degraded. A careful inspection of the original color image shows faint colored smudges in this region, but no recognizable characters. Therefore, this particular monochrome projection of the color data has made visible several previously unnoticed characters.

Once these characters were found, the next problem

Figure 2. Discovered in 1956, the Temple Scroll describes how to rebuild the Temple in Jerusalem. Shown in this image are columns 18 through 15, from left-to-right. By measuring the circumference of the scroll, some new characters, found in the region marked with the dashed box in column 17, have been determined to come from a missing section of the neighboring column 16.

was to determine their origin. Were they erasures or were they transferred from another part of the scroll? If the latter, where was their original location? This needed to be determined to identify whether or not these characters were known to biblical scholars. Early in our research, James Charlesworth (Princeton Theological Seminary), expressed his conviction that the letters now visible on column 17 had been transferred from the upper portions of column 16 (now lost). He postulated that the letters had been transferred to the back of column 17 during the 2,000 years the scroll had been rolled up in Cave 11.

There are several hypotheses for how characters could be transferred. If the rolled scroll was lying in fluids that degraded the parchment, partially dissolved ink could seep through the parchment and be deposited on this part of the scroll. Another possibility is that a thin layer of the parchment became detached during the unrolling of the scroll and stuck to the back side. Or, perhaps the ink alone was transferred to the back side of the scroll and is being "read" through the parchment by the enhancement. No matter what the mechanism of transfer, the significant result is that additional characters were rendered visible.

The language of the Temple Scroll, Hebrew, is read from right to left. The rightmost part of the scroll is the beginning of the manuscript. Since the scroll had been rolled from the left with the beginning on the outside,[7] sections of the scroll that are to the right were situated behind sections that are to the left. Therefore, any transferred text comes from a section to the right.

To test Charlesworth's hypothesis on the origin of the newly discovered characters, an investigation was made of the physical metrics of the scroll that could be determined from the photographs. Figure 2 shows a reconstruction of columns 18 (on the left) through 15 (on the right). This image was created by aligning two different photographs and "stitching" them together digitally. The periodicity of the degraded regions on the scroll is evident in this figure. By measuring the period of these degradations, it is possible to determine the circumference of the rolled scroll and thus to identify those locations in column 16 that were aligned with the text discovered in column 17. The location indicated in Figure 2 confirms the hypothesis that the newly discovered text was transferred to column 17 (dashed lines) from a missing section of column 16 (solid lines).

Figure 3. In this enlargement of one section, the luminance channel (on the left) looks similar to the color original. The chrominance channel (on the right) shows characters that were previously unknown to biblical scholars.

These and other images were given to Charlesworth and his graduate student Henry Rietz, who compared them with a new transcription of the Temple Scroll.[8] They have shown that at least 18 of these "new" characters represent information previously unavailable to scholars.

Charlesworth reports that the "new" characters help clarify that this section of the scroll concerns the yearly investiture of Jerusalem's high priest with power to represent the nation. This yearly check on the high priesthood was a creative addition to Jewish law by the Qumranites, many of whom were priests who had been driven out of Jerusalem by those who had obtained the high priesthood illegitimately.

Future work

Though some of the described results have assisted scholars in making new discoveries about the text of one of the Dead Sea Scrolls, the application of digital imaging technologies and algorithms for clarification of degraded ancient documents is still in its infancy. The technology to assemble a complete multispectral digital image gathering and processing laboratory that fits in a single suitcase already exists, and the trend of dramatic increases in capability-to-cost and capability-to-size ratios of digital imaging technology shows no signs of abating. New advances in image-gathering equipment will be applied on a wider scale, including new large-format CCD cameras (4K $\times$ 4K, and larger) and electronic color filtering technologies (such as the tunable liquid crystal filter). We expect this trend to make the requisite facilities for gathering and processing color imagery of degraded documents even more affordable and portable in the near future. G. Bearman of the Jet Propulsion Laboratories, an early pioneer in the application of multispectral digital imaging to archaeological artifacts, has shown the advantages of narrow bandwidth imaging, especially in the infrared.[9]

A very promising application for color/multispectral imaging is the discovery of intentionally overwritten ancient documents. Such documents, known as palimpsests, are fairly common, as the high cost of parchment often forced scribes to recycle documents, such as duplicates, deemed less valuable. The parchment was "erased" by washing and scraping or otherwise abrading the surface and then overwritten with new text. In many cases, the original text is of significantly greater interest to modern scholars than the later overwriting. If the ink used to inscribe the later text differs in color from that of the original, then multispectral image processing may be able to reveal the original text. Even if the overwritten ink is totally opaque, image processing and pattern recognition techniques may assist scholars in reading the remaining underwritten text. Back-side illumination may also be used with some beneficial effects.

A great need of antiquities scholars is the development and dissemination of useful image processing algorithms. The future of software development for clarification of ancient writings will likely be the migration of techniques developed for multispectral pattern recognition in environmental remote sensing and medical imaging. In their most highly evolved form, the software could be collected by application-specific imaging toolboxes capable of analyzing and enhancing color or multispectral images with little or no human intervention. For example, processes that "adapt" or "learn," such as neural-net processing of multispectral imagery, could be applied to clarification problems. Automatic character recognition based on fragmentary evidence might also be effective.

The migration of techniques and algorithms between (and among) disciplines is apt to be bidirectional; multispectral imaging tools developed to clarify text may very well be applied successfully in other fields, particularly if useful automated techniques are developed. The most probable fields to benefit from any such cross-fertilization are medical imaging, environmental remote sensing, and forensic imaging, but other applications may be imagined without much effort.

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3. Y. Yadin, "The Temple Scroll: The longest and most recently discovered Dead Sea Scroll," Biblical Archaeology Review, (Sept/Oct 1984).
4. The original photographs were provided by B. and K. Zuckerman, in collaboration with J.H. Charlesworth, the Princeton Theological Seminary Dead Sea Scrolls Project, and the Shrine of the Book, Jerusalem, Israel. The original scroll fragments are housed in the Shrine of the Book and the old Rockefeller Museum in Jerusalem. Because of the fragile nature of the scroll material, access to the original manuscripts is limited to biblical scholars with permission from the Israeli Antiquities Authority.
5. Our interest in enhancing images of the Dead Sea Scrolls began with Emanuel Tov, Editor-in-Chief of the Dead Sea Scrolls Publication Project at Hebrew University in Jerusalem. He provided us with several photographs of manuscripts found at Qumran and encouraged us to experiment with digital enhancement to increase visibility. The authors subsequently acquired the photographs seen in this article from the Zuckermans.
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