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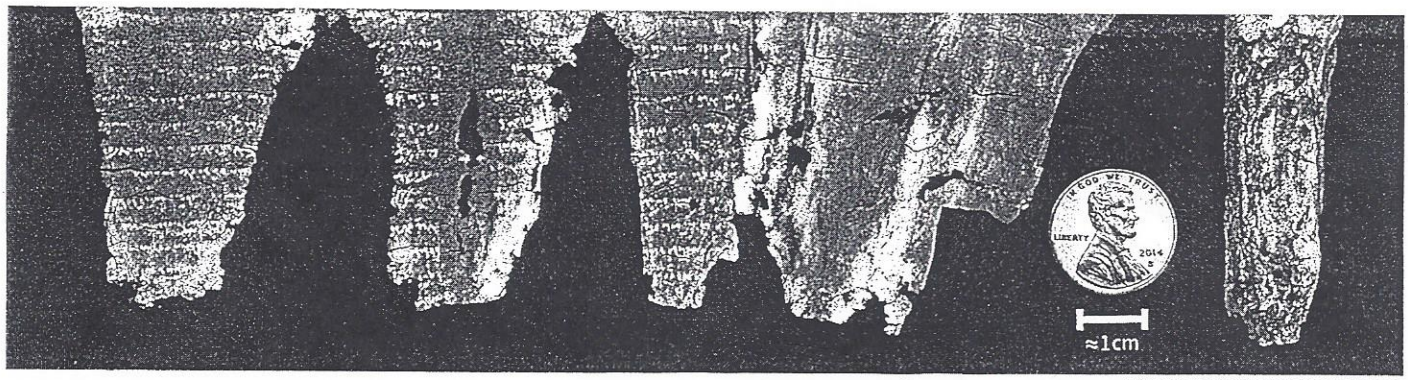

BRENT SEALES University of Kentucky-Lexington

THE SCROLL is shown digitally unfurled, left, and in the burnt form in which it has remained, right, since found 40 years ago in the Dead Sea village of En-Gedi.

A charred scroll, inscrutable no more

Scientists virtually reveal the words on ancient biblical parchment too fragile to unfurl

DEBORAH NETBURN

Sometimes science seems like science, and sometimes it seems like magic.

This week, computer scientists at the University of Kentucky-Lexington described how they virtually unfurled a charred and crushed biblical scroll dating back nearly 2,000 years.

Thanks to their work, scholars are now able to read the words embedded in this ancient text for the first time in a millennium.

This is particularly amazing because to the untrained eye, the still-intact, rolled-up parchment looks like a small piece of burnt charcoal.

It is also so fragile that it disintegrates every time it's touched.

"The discovery of the text in the En-Gedi scroll absolutely astonished us," said Pnina Shor, head of the Dead Sea Scrolls Projects at the Israel Antiquities Authority, which keeps the scroll in its archives. "We never dreamt we could bring it back to life."

The damaged parchment was discovered more than 40 years ago in the ancient village of En-Gedi on the western shore of the Dead Sea. The scroll was found in the remains of a Holy Ark in a synagogue that experienced a fire in the 6th century.

Because the scroll was so delicate, archaeologists were too scared to analyze it.

"Physical intervention was unthinkable," the researchers wrote in a paper published this week in Science Advances. "Like many badly damaged materials in archives around the world, the En-Gedi scroll was shelved, leaving its potentially valuable contents hidden and effectively locked away by its own damaged condition."

The study was led by Brent Seales, a professor and chairman of the department of computer science at the University of Kentucky-Lexington who has been working with technology and damaged materials for two decades.

He and his colleagues never actually saw the parchment itself. Instead, their work was based on a micro-CT scan that Shor and her team had made of the scroll years before.

After receiving the scan, the Kentucky group devised a multi-step system that allowed them to take a digital representation of a rolled-up object and produce a flattened-out picture of what's written on the layers inside. They called it virtual unwrapping.

The process starts with a scan that reveals the internal structure and contents of an object, like the one the Israel Antiquities Authority made when it decided, on its own, to conduct the micro-CT scan.

Next, the researchers used an algorithm to help identify the different layers in the scan, a step they called segmentation. In the case of the En-Gedi scroll, this was especially tricky because it had been burned and crushed, making it almost impossible in some areas to tell one layer from another. Part of the solution to this problem was to look at small segments of the scroll at a time, the authors said.

Once the individual layers of the scroll had been identified and modeled, the team began their search for readable print, a process they dubbed "texturing." In a CT scan, more dense areas appear brighter.

By looking at these bright regions of dense material and darker areas of less dense material on each layer in their scan, the researchers were able to determine where the ink had been placed on each layer of the scroll.

But they weren't done yet. Although they now had a digital model with text, their virtual scroll was still in a rolled-up position, making it difficult to read the words. This led them to invent a flattening process that is similar to the physical act of unwrapping a scroll.

Because all this work was done on small sections of the rolled-up parchment, the final step was to merge these flattened pieces together.

In the end, Seales and his team revealed that this hunk of burnt animal skin contained text on five complete wraps of the scroll, and thanks to their computational wizardry, it was readable.

"When he finally sent it to us, we almost dropped off our chairs," Shor said. "The scan we sent him looked like charcoal. When this came back as a written piece of flattened material that looked like a poem, you can't imagine the joy in the lab. It was unbelievable."

The digital reconstruction was so successful that biblical scholars were able to confirm the scroll contained the Book of Leviticus, making it the earliest copy of one of the five books of Moses to be discovered in a Holy Ark.

Michael Segal, a professor of biblical studies at Hebrew University in Jerusalem, who is analyzing the virtually unfurled scroll, said it offers important evidence of the state of biblical texts between the time of the Dead Sea Scrolls and those discovered several centuries later.

In particular, he said he was struck that the passages revealed in the En-Gedi scroll are identical in all of their details to the Masoretic text, which is still the authoritative Jewish text used today.

Since carbon dating and other archaeological evidence date the scrolls to the 3rd or 4th centuries, this analysis suggests that the text has not changed in almost 2,000 years.

The authors note that they are not the first to peer into the interior of a burnt scroll.

In 2015, Italian scientists were able to reveal a few words and letters embedded in a charred scroll that survived the catastrophic eruption of Mt. Vesuvius nearly two millenniums ago. However, the new work represents the first time a text has been reproduced in full from such a damaged artifact.

"It's incredibly impressive," said Greg Bearman, a former JPL researcher and consultant for the Leon Levy Dead Sea Scrolls digital library who was not involved in the work. "It's a real technical tour de force."

The tools the team used will become available as open-source software next year, Seales said, and he expects that new technologies will continue to improve at each step in their system.

Virtual unwrapping might also be used in other contexts, he said. For example, the intelligence world could be interested in the new technique to extract information noninvasively from materials.

"I believe there are more discoveries to come," Seales said. "Damage and decay is the natural order of things, but you can see that sometimes you can absolutely pull a text back from the brink of loss."

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