Reading Between The Lines

A THIN BEAM OF X-RAYS scans the writings of the legendary Greek scientist and mathematician Archimedes, a hidden text that may be the most important ancient scientific document discovered since the Renaissance. As faint lines emerge on a large computer monitor at Stanford's Synchrotron Radiation Laboratory, I can just barely make out the ghostly image of the Greek letter lambda.

As a Webcast producer for the Exploratorium science museum in San Francisco, I have been documenting this experimental use of one of the most sophisticated tools of modern science, to decipher a 1,000-year-old book made of goatskin. Known as the Archimedes Palimpsest, dubbed Archie for short, it looks terribly fragile. The edges of most of the book's 174 pages are burned, and tears, holes and spots of purple mold dot their surface. The parchment is smaller than I thought it would be, not much larger than a hardback novel.

I want simply to gawk, but the hum of machinery reminds me that I have work to do. Since I've been spending so much time around Archie, the imaging team has given me the job of shift supervisor this afternoon. I check the intensity of the X-ray scanner, note the time, and record the temperature and humidity from the environmental monitors near the document. In its pages is the only known surviving record of two of Archimedes' works, and the only version of another one in the original Greek. In addition, there are 14 pages of rare commentaries on Aristotle's treatise on the logic of categorization and another 10 pages that record two previously unknown speeches of Hyperides, an Athenian orator and politician from the fourth century B.C. Most of these are invisible to the naked eye—they've been obscured by mold, written over by a medieval priest or almost destroyed by a modern forger who didn't recognize, or care about, their true value.

ARCHIMEDES MAY BE BEST known for rising from his bath and running naked through the streets of Syracuse, a Greek city-state on what is now the island of Sicily, shouting "Eureka." ("I have found it.") According to legend—and it is more likely legend than fact—the third-century B.C. mathematician had just discovered that he could determine the purity of gold in part by measuring the volume of water it displaces. Archimedes was celebrated in his own time, as well as ours, for his practical applications of mathematics and physics. The screw that he invented still moves water uphill, and the catapults and other weapons he designed defended Syracuse from Roman invaders. (Syracuse eventually fell under the Roman siege, and Archimedes was killed by an enemy soldier at the age of 75—supposedly after drawing geometric figures in the sand and snapping: "Don't disturb my circles!") He also estimated the value of pi. "Archimedes was the greatest mathematician in the ancient world," says William Noel, a curator of ancient manuscripts at the Walters Art Museum in Baltimore and the person most responsible for the care and reading of the palimpsest. "He was the first scientist to apply abstract mathematical principles to the world around him."

Archimedes wrote his treatises on papyrus rolls, the originals of which have been lost. But his works were faithfully copied by generations of scribes and made the leap onto bound goatskin parchment by sometime late in the fifth century probably in Constantinople. That city's great libraries were sacked by Crusaders in 1204, but one parchment, penned in the 900s, somehow survived and was secreted away to a Christian monastery near Bethlehem. In 1229, a Greek priest who needed parchment for a prayer book took apart the Archimedes manuscript, scraped and washed off the pages and copied liturgical text on top of Archimedes' writings in a process known as palimpsesting (from the Greek word palimpsestos, meaning "scraped again"). Horrifying as that seems now, the original text probably would not have survived had the scribe not recycled it and subsequent monks not preserved the prayer book—unaware of what lay beneath the scriptures.

These Archimedes treatises were essentially lost to history until 1906, when a Danish classics scholar, Johan Ludwig Heiberg, discovered the thousand-year-old manuscript in a library in a Greek Orthodox monastery in Constantinople. Heiberg recognized that the faint writings underneath the prayers came from the mind of Archimedes. Heiberg was allowed to photograph many of the pages, and he published scholarly articles on those writings he was able to decipher. But Heiberg couldn't read some pages, and he ignored the diagrams. Then, sometime after World War I, the palimpsest disappeared again, removed from the library under mysterious circumstances—possibly stolen from the monastery—and is believed to have been in the hands of a French family for much of the 20th century It resurfaced again in 1998, when an anonymous private collector in the United States bought the document at auction for $2 million.

The palimpsest might have remained out of public view— and the hands of scholars—had the Walters Art Museum's Noel not managed to contact the new owner, through the selling agent, and request access to it. To the curator's delighted surprise, the owner (who remains anonymous) personally delivered it to Noel and his colleagues for conservation and study at the Walters.

The palimpsest had deteriorated significantly in the century since Heiberg first examined it in Turkey Humidity had spurred the growth of mold, and there were even more holes in the pages than before. Worst of all, four of them had been covered with gold-leaf paintings. Apparently, in a misguided attempt to make the book more valuable, a previous owner had used palimpsest pages to forge an illuminated Byzantine manuscript.

Before they could begin deciphering Archie's secrets, the Walters' conservators, led by Abigail Quandt, began the painstaking job of halting the damage. It took four years to take the book apart and clean it. Meanwhile, using ultraviolet light and various techniques to enhance images, scientists from Johns Hopkins University, the Rochester Institute of Technology and other institutions were able to reveal about 80 percent of the manuscript. According to Reviel Netz, a professor of classics at Stanford University, this work added substantially to Heiberg's efforts.

The document's most important treatise is called "The Method of Mechanical Theorems." In it, Archimedes uses the way an object can be balanced to derive its geometrical and physical properties. Even more important is the method's description of infinity, a concept long considered too problematic for ancient Greek mathematicians to grasp. Our modern understanding of it was refined by Issac Newton and Gottfried Wilhelm von Leibniz when they independently invented calculus. From the palimpsest, scholars now know that infinity was understood by Archimedes 20 centuries earlier.

Another unique text is the "Stomachion," arguably the first treatise on combinatorics, the branch of mathematics concerned with the organization of elements within sets. In this passage, Archimedes describes a puzzle in which a square is cut into 14 irregular pieces. The puzzle's solution lies in determining the number of ways the pieces can be arranged back into a square. It is not known if Archimedes solved the puzzle—those pages have been lost—but modern mathematicians have determined the answer: 17,152.

NOEL'S WALTERS ART MUSEUM team deciphered most of the palimpsest, but couldn't read through the forger's gold-leaf painting. That's where the Stanford Synchrotron Radiation Lab (SSRL) came into the picture. The lab generates X-rays from powerful beams of electrons that race around a 260-foot-diameter ring in the windowless, doughnut-shaped building at nearly the speed of light. A couple of years ago, while working on an unrelated Exploratorium project, I was getting a tour of the SSRL when Uwe Bergmann, a German-born physicist, stopped my group in the curved hallway. He told us he was working on an experiment that involved exposing inked parchment to the SSRL's X-ray beam. Bergmann had read about the palimpsest in a German magazine and had deduced that the SSRL would be able to image iron in the ink underneath the gold paintings. The experiment Bergmann showed me that day had convinced him that his technique could work on parchment—and he was practically jumping up and down in excitement.

To reveal the hidden ink, X-rays that form a beam no thicker than a human hair strike ink on the parchment. Their energy causes certain elements in the ink to fluoresce, or glow. Detectors pick up each element's distinctive wavelength of fluorescence, and a computer converts the data into computer images. "The X-rays just care about the element on the parchment," says Bergmann. "You can observe the iron in the ink no matter what is above or below it."

In the past two years, SSRL's imaging experiments have provided some exciting new results, including the signature of the scribe who first copied the liturgical texts and the date he did it (Ioannes Myronas, on April 29,1229).

NOW WE'RE AT THE END of the ten-day run. We've been scanning one of the most difficult pages in the book, the introduction to Archimedes' "Method of Mechanical Theorems," which is covered by a gold-leaf forgery of a seated saint (see p. 62). A diagram on the page contains critical information about how Archimedes thought about geometric proofs, information Heiberg ignored. This is the second run of this page; to extract more faint lines from underneath the painting, the detectors have been tuned to image calcium, rather than iron.

We've already had some success. Stanford's Reviel Netz told us earlier in the week that he was able to see clearly for the first time one of the labels for a drawing that accompanies Archimedes' "Method of Mechanical Theorems." The label, Netz says, decided a longstanding dispute among scholars about what they considered an error in the diagram.

After Stanford, the palimpsest will be hand-carried by conservator Abigail Quandt back to the Walters Art Museum in Baltimore, where it will undergo additional imaging work to reveal more of the text from Hyperides, the Athenian orator, which is expected to contain new information about the foundations of Greek democracy, Athenian law and social history The team expects to wrap up its work sometime in 2008, then the document will go on display for three months at the Walters and later at other museums. Its text will be published for scholars and students to pore over. "What we've been finding with the Archimedes Palimpsest is that this book never ceases to give up its secrets," says Noel. "It's like working with a great mind; you're made to think of things in new ways--from the nuts and bolts of medieval history to the roots of calculus and physics."