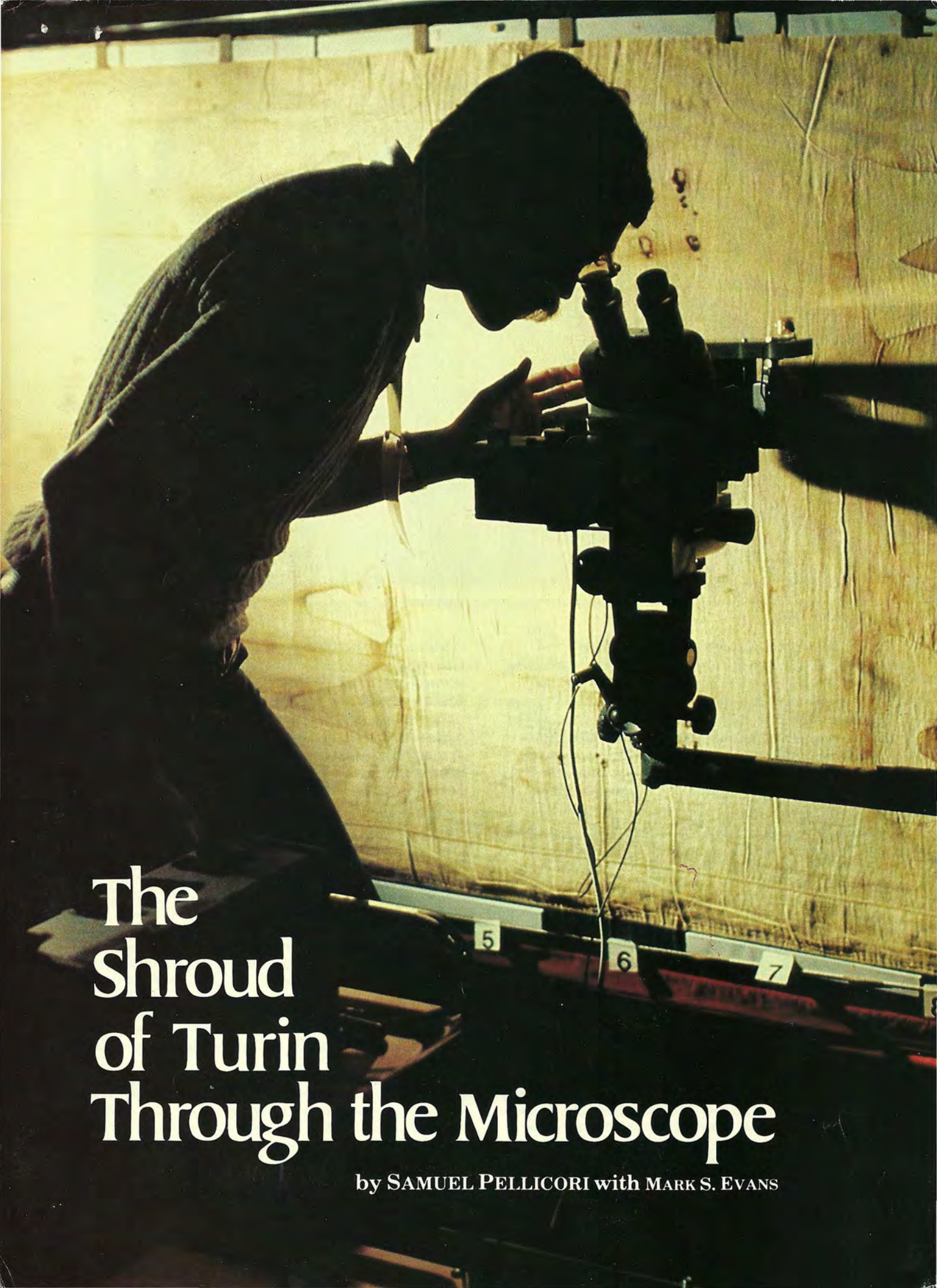


The Shroud of Turin Through the Microscope

by SAMUEL PELLICORI with MARK S. EVANS

(Left) *Mark Evans examines the carefully mounted Shroud of Turin with a photomicroscope.*

(Above) *A procession of scholars and clergy transfers the Shroud from the exhibition in the cathedral to the makeshift laboratory in the palace.*

(Right) *John Jackson* (front), *one of the team organizers, and author Samuel Pellicori performing high magnification visual examination.*

For more than four centuries, one of the most exalted and baffling religious relics in history —the purported burial shroud of Jesus Christ —has lain as an object of almost untouchable sanctity in the northwest Italian city of Turin's Cathedral of St. John the Baptist. It arrived there after at least two centuries of adoring veneration, near destruction and bitter controversy in the royal houses of France—and one unverified theory says by way of the Fourth Crusade to Constantinople in A.D. 1203. Even in the relic-worshipping Middle Ages, it is easy to understand that controversy should surround this object: the terrible liability of making a single item an article of supreme religious faith and indeed ultimate evidence for the existence and death of Jesus of Nazareth was so obvious, the implications of fraud so awesome, that many ecclesiastics wanted no part of the Shroud from the beginning. Some don't even now.

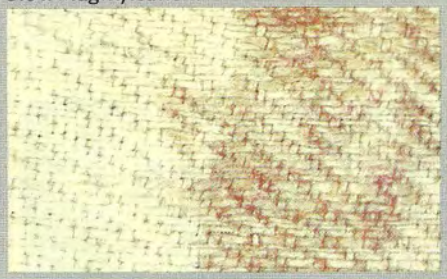
What makes this piece of linen so extraordinary is the fact that it bears the imprint of a body, the full front and back images of a man who has undergone what appears to be the tortures of repeated scourging and death by crucifixion. The scourge marks covering the body and the blood stains on the wrists, feet, side and head all correspond remarkably to the descriptions given in the scriptures concerning the crucifixion of Christ. No other relic has been known to display such photographically detailed imagery of the human form. Throughout the ages, no other relic has been more revered.

But the Shroud, a 4.3 by 1.1 meter swath of handloomed, herringbone-patterned and folded linen, also bears aberrant markings that ironically now turn out to have a special significance for scientists examining the age-old mystery. In 1532, after the Duke of Savoy had a special church, Sainte Chapelle, built for the Shroud in Chambéry, France, a fire in the sacristy nearly destroyed the relic. To this day, scorch marks left by the smoldering fire started by drops of molten silver from its casket and water stains from efforts to douse the fire are clearly visible on the Shroud. Although repairs had to be made in the form of a reinforced backing cloth and patches sewn on by the nuns of the Poor Clare in 1532 and 1534, the lasting parallel burn lines and symmetrically patched areas and water stains now testify, four-and-one-half centuries later, to the original folds in the garment. They also set important and sometimes controversial benchmarks for evaluating the integrity of the original image.

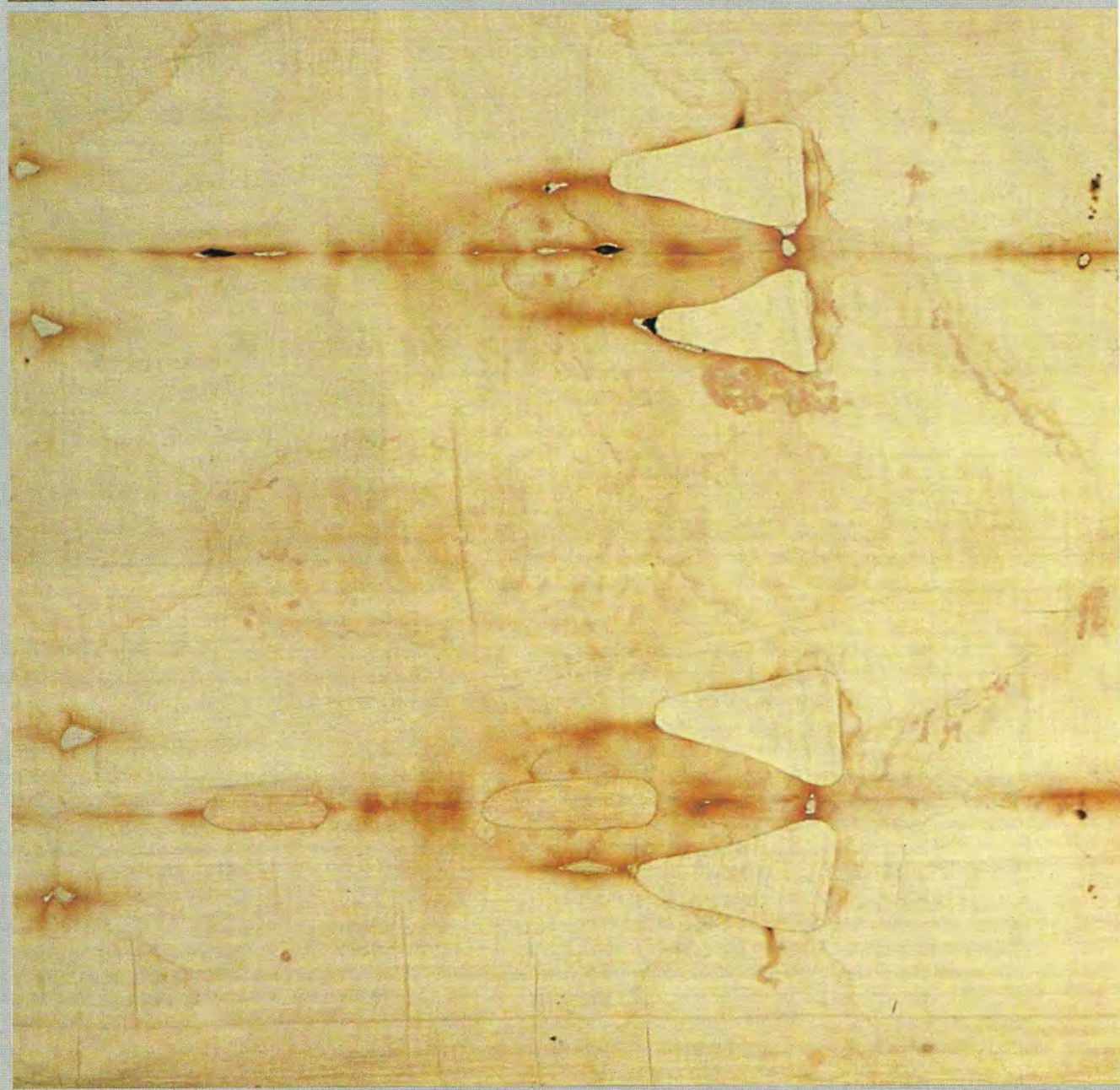
That image possesses several curious characteristics. Although it has been covetously guarded over the years—the Shroud has only been on public display twice in this century—an Italian photogra-

Close-up view of the blood area of small of the back at 18 x magnification.

Blood stain in the small of the back area showing average degree of blood density at 3.6 x magnification.

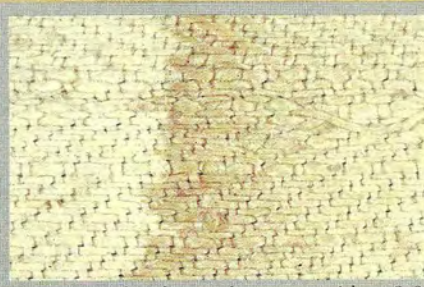


The dorsal foot image area including a dirty brown circular area within a blood stain a 3.6 x magnification.



The dark brown color of the heel image shows up clearly at 36 x magnification.

Right eye at 18 x magnification consists of a light sepia color with the darkest coloration on the thread tops.

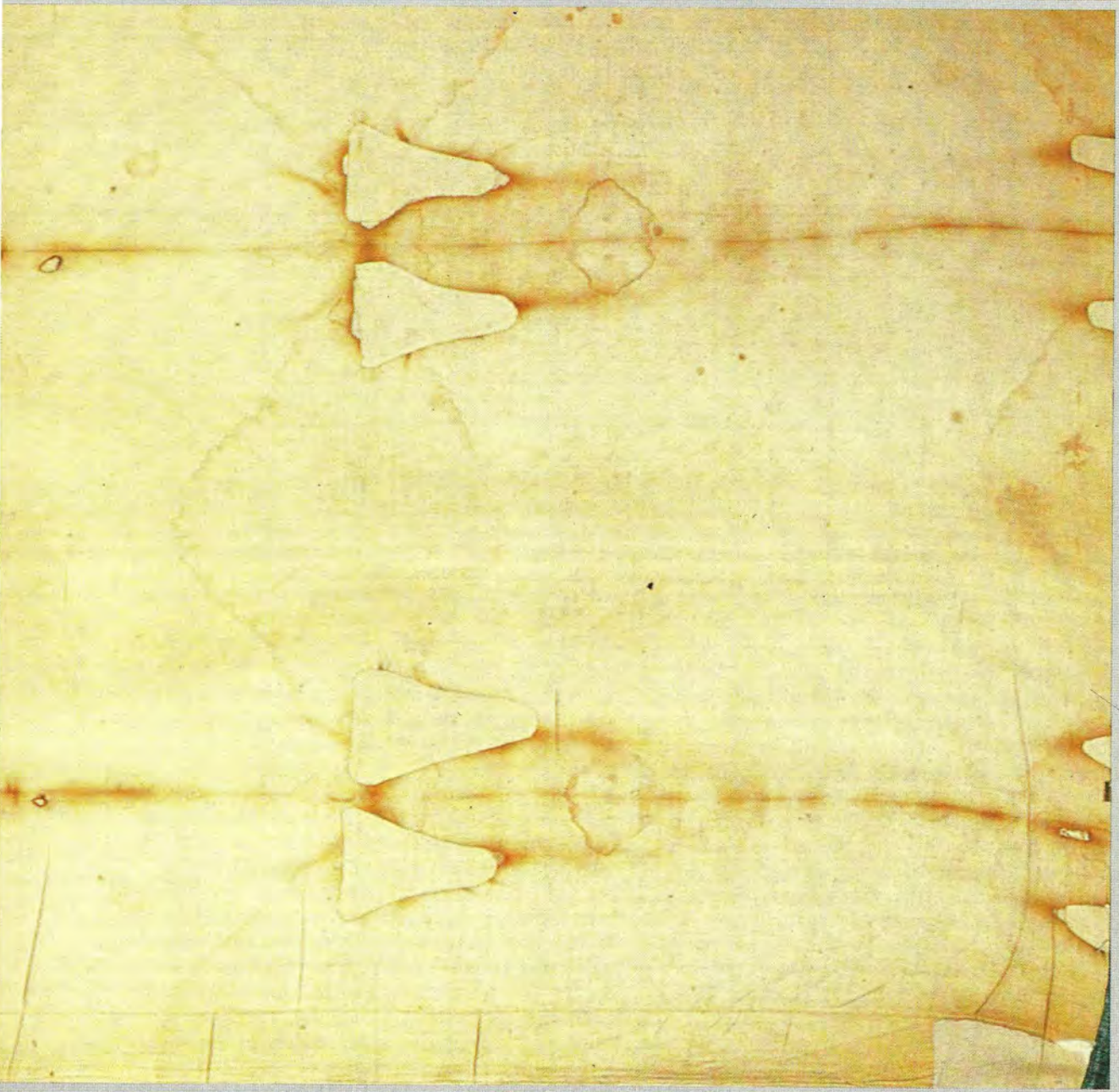


Water stain border on the reverse side at 3.6 x its normal size indicates that the darkest coloration occurs on the border.

One of the front lance wounds at 3.6 x magnification showing red particulate matter in the fibrils.

The dorsal heel area at 30 x magnification.

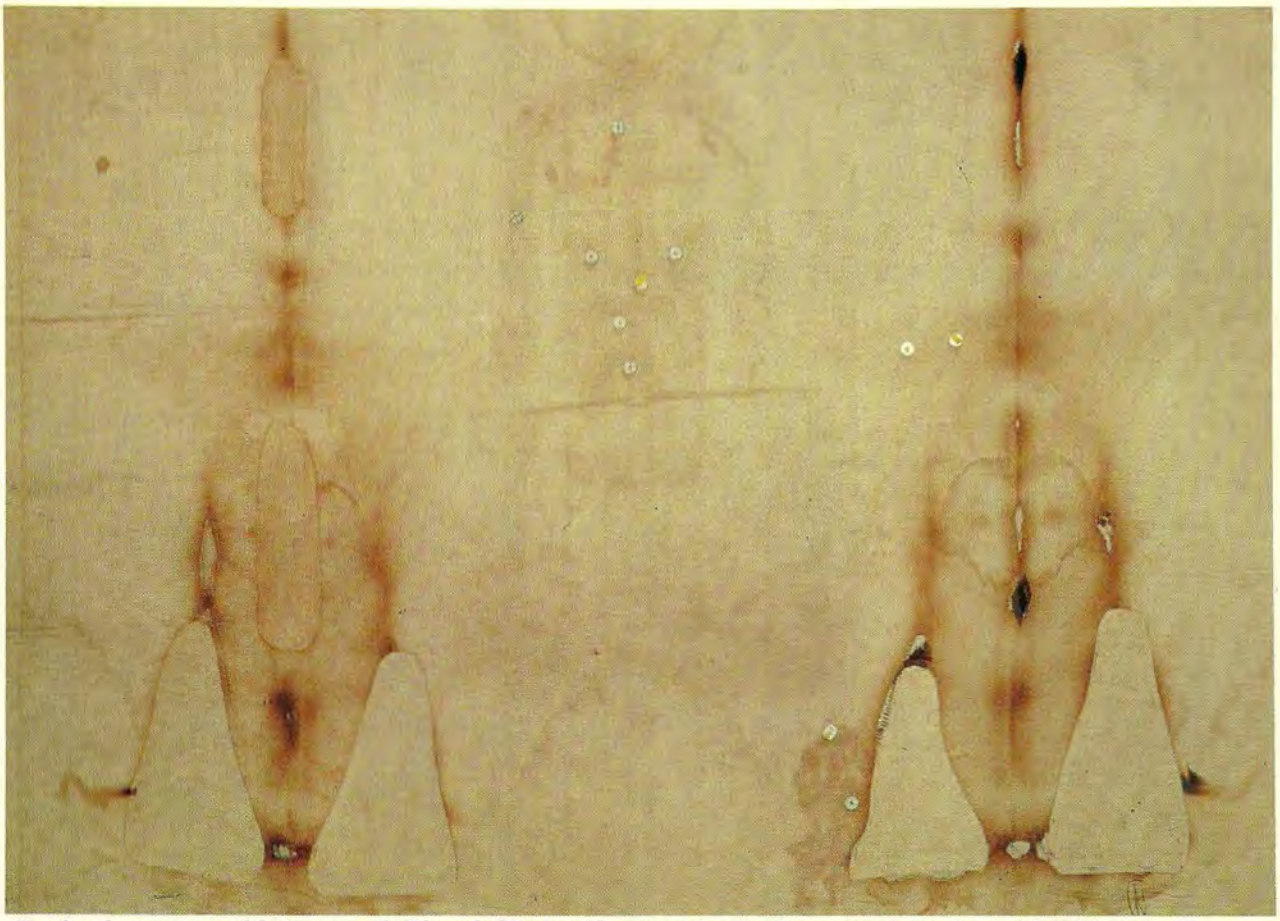
Tip of the nose at 36 x magnification.



These dark brown nearly monocolored threads represent a water stain.

A scorch mark at 18 x magnification is dark brown in color.

An obviously heavy burn area seen at 18 x magnification.



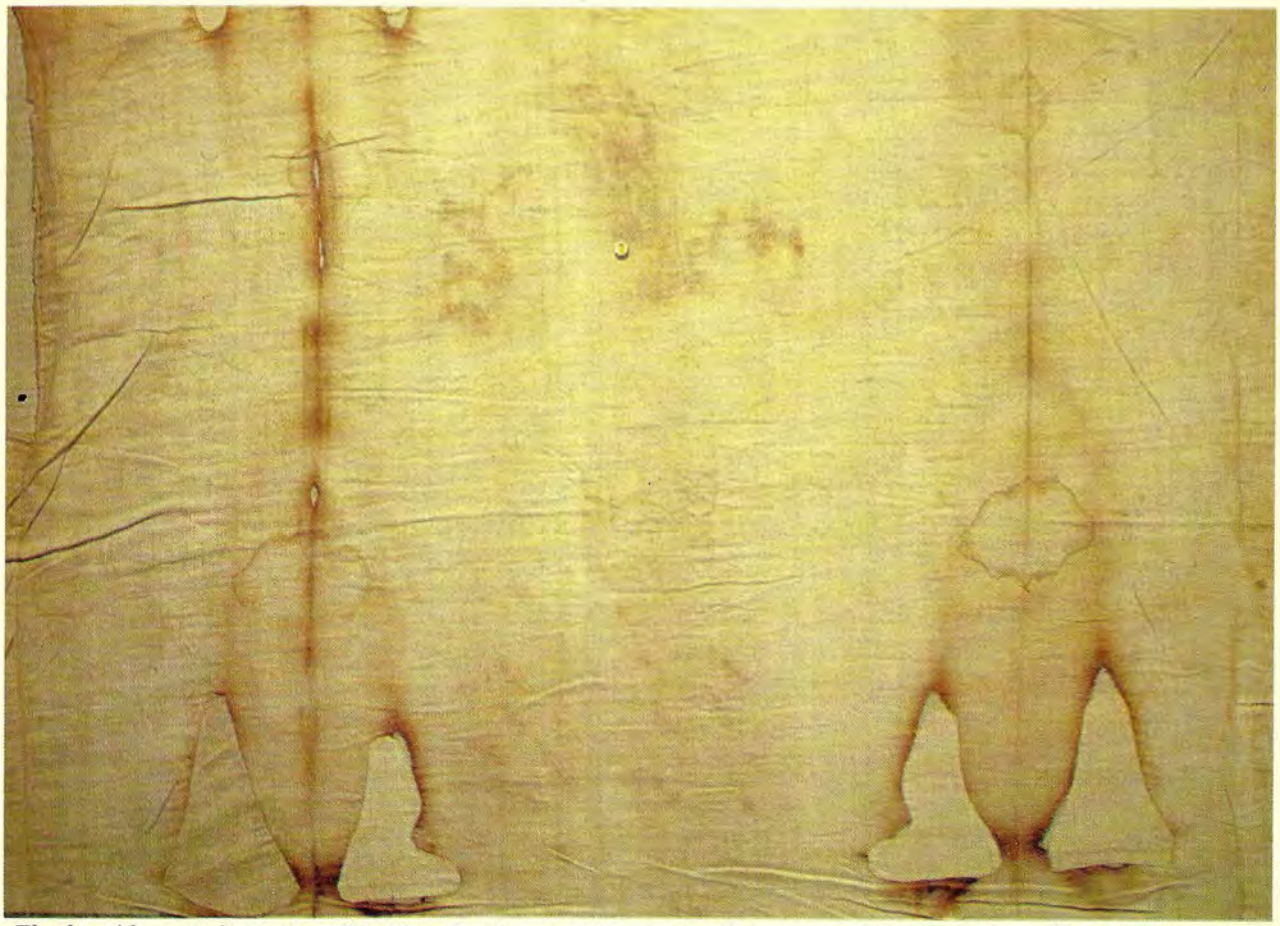
Head and upper torso of the image on the Shroud of Turin with magnets locating lance wound, scorches and facial features. The eyes were also examined and photomicrographs taken. The heavy vertical lines are creases which were scorched in the fire of 1532 when the Shroud was folded through the center of the face. Water used to douse that fire left outlined stains. The patches were added after 1534 to cover the burn holes.

pher named Secondo Pia was allowed to take pictures as early as 1898. His results were altogether startling because, unexpectedly, the photographic negatives revealed an image that was far more distinct than that on the Shroud itself. Suddenly the figure on the cloth, estimated to be that of a man about 5'10" tall and weighing 170-175 pounds, was brought to life more vividly than ever before. Even more startling was the fact that the subtle gradations in the density of light, reflected from across different body features on the cloth, appeared on the photographic plates in such a way as to suggest physical contouring—in other words, *three-dimensionality*. This finding, confirmed again in 1931 by the French photographer Guiseppe Enrie, put proponents of the deliberate forgery theory over an impossible barrel: to suggest that a Mediaeval artist would have the foresight to conceive of a rendition having the qualities of a photographic negative encoded with three-dimensional information is preposterous.

Science would not get a first-hand look at the Shroud until 1969, and then once more in 1973, when church authorities permitted a group of Italian researchers to investigate it for purposes of preservation. Although they concentrated on textile studies and only briefly commented on the image itself, the Italian scientists detected no evidence—even under magnification—of paints or pigments in the image which their findings showed appeared only on the upper crowns of the woven threads. Thus the Italian work, unable to conclusively characterize the "blood" stains, intensified rather than settled compelling questions about the Shroud for scientists and ecclesiastics alike.

Could the nature of and cause for the strange, almost three-dimensional body image and elusive blood stains be determined? Could that and other information be obtained to date the relic once and for all and thus address the ultimate question of authenticity head-on? Intrigued by the mystery and challenge of the Shroud, a small group of

(Center spread, previous page) *The Shroud of Turin mounted on a frame for study in the fifteenth-century palace joining the chapel. The color differences between the scorches, water marks, blood stains and body image are obvious. A team of scientists examined this remarkable relic and performed a battery of tests including the photomicroscopy which brought out the details of the Shroud so clearly.*

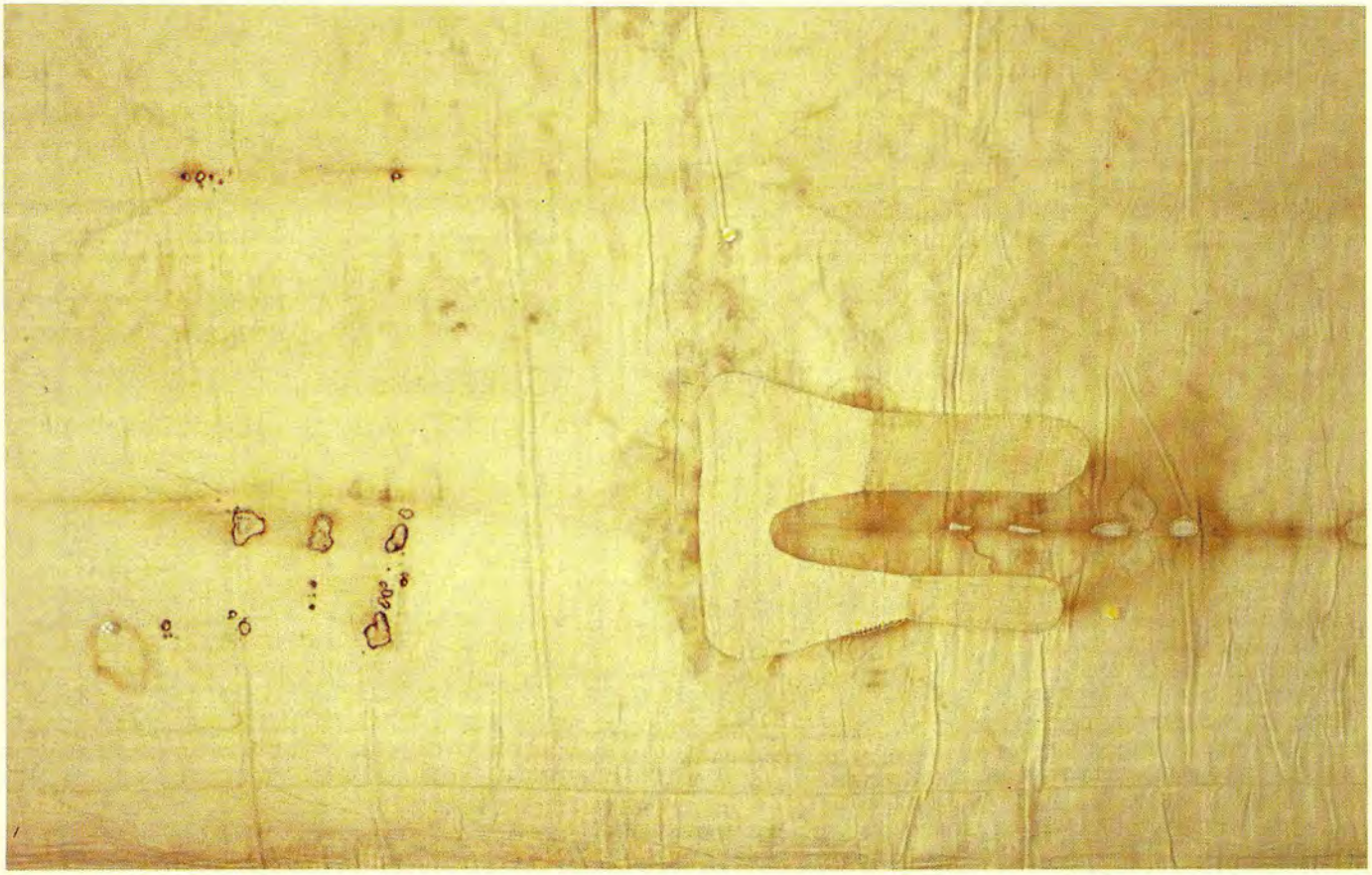


The dorsal knees-to-feet section of the Shroud with magnets locating the heel image and blood stain areas. The folding geometry existing during the fire is evident from the water stain and burn mark symmetry.

American scientists, headed by John Jackson and Eric Jumper of the U.S. Air Force Academy, proposed in 1976 to undertake an in-depth program of non-destructive research. With the help of lobbying by Shroud scholars in Italy and fortuitous timing, the ecclesiastical custodians of the relic and Umberto II, the deposed King of Italy and its legal owner as reigning head of the House of Savoy, agreed to grant permission. In celebration of its 400th year in Turin, the Shroud was put on public display for only the second time in this century at the end of the summer of 1978. In six weeks it drew well over three million visitors from around the world. On the last night of the exhibition, October 8, 1978, it drew the immediate attention of the newly-formed Shroud of Turin Research Project Inc.—25 American specialists in physics, organic chemistry, computer technology, x-ray analysis, hematology and spectroscopy.

Perhaps no work of art or archaeology has ever been so intensively studied as the Shroud was about to be. To probe the very atoms of the Shroud's identity, a battery of the most sophisticated techniques available were brought to the task, many of them used in hair-splitting research on art forgeries and forensic problems: microchemical analysis, fluorescence, radiography, infrared radiometry, optical microscopy, ultraviolet fluorescence photography, visible, ultraviolet and infrared spectroscopy, and multispectral narrowband photography. A common object of these tests was to identify the elements present in the image to finally settle the question of whether it stemmed from man-made artistry or a more provocative and unknown natural origin. Thus x-ray fluorescence, for example, which involves subjecting an object to a beam of x-rays and then measuring the specific ways in which a secondary stream of x-rays are scattered, can reveal exactly which elements are present, and consequently whether they are constituents of modern pigments or readily available organic substances. At the same time, detecting the presence of iron, potassium and phosphorous, elements found in blood, would be particularly important. Visible light and ultraviolet spectral analysis are used to detect reflection characteristics for later matching in the laboratory with known substances. Microchemical analysis of tiny linen fibrils could at the same time be used to determine whether the blood-colored areas contained any hemoglobin products or artificially applied paint.

Our own work, color photomicroscopy, which had never been done on the Shroud before, involved photographing chosen details of particular importance through a microscope to record and later intensively study the image in ways that had been



The dorsal image on the Shroud excluding the head and feet. Many scourge marks are present. Magnet locates blood stain in the small of the back, a water stain and a scorched area near one patch. The small circular burned outlines are presumed to be from a time preceding the 1532 fire for which historical records are vague. The backing cloth to which patches were sewn shows through these holes.

invisible to all previous observers. From the minutia of texture, color and density changes over sampled areas of body image, suspected blood stains, water marks, scorches and burns, we would seek a definitive profile of this most elusive object. The photomicrographs were made with sophisticated but standard equipment: a Wild M400 Photomakroscope using Ektachrome pro-64 film and 500 British Candle Power flash units under control of an electronic exposure device. Under the best of conditions, photomicroscopy involves difficulties beyond the normal photographic problem; image resolution is blurred by motion in proportion to the amount of magnification provided by the microscope. These were not the best of conditions. Our experimental "laboratory" was a room in the fifteenth-century royal palace of Umberto with wooden floors that fairly heaved at the slightest footfall. This meant that for fear of blurriness we could only work with magnification up to 20 times. An inappropriately timed step could produce vibrations that would be exaggerated 20-fold on film. Mysterious drafts coursing through the Mediaeval palace were similarly vexing, given the fact we were working with a virtual sail in the 14-foot cloth. To counter these set problems, we took two steps: securing the cloth to the backing support frame with a circle of extra magnets and attaching a "measuring rod" to the microscope to provide a fixed focal plane, and second, to caution both Italian and English speakers in the room, singing out the duet "*alto*-stop" just before making each exposure.

A second and more common problem was the lighting. We attempted to regulate this by using a 500 watt tungsten overhead lamp (in addition to the palace's ornate chandelier) and putting black plastic sheets over the window. The second precaution served the additional function of limiting the Shroud's exposure to the natural blue or ultraviolet in solar radiation that could damage the linen's (or canvas') cellulose fibers. We were able to prepare for some difficulties in advance. Extensive testing by Mark Evans, then a graduate student at the Brooks Institute of Photography in Santa Barbara, helped establish the required illumination, exposure time and film calibration on a replica of the Shroud before the trip to Turin. At the palace in Turin itself, we then extended the range of exposures to compensate for local exigencies and improve the chances of success. We also used a number of small magnets both to hold the Shroud in place on the mounting frame and to serve as markers in calibrating specific areas on which the different photomicrographs were most concentrated.

The actual photos were grouped into five categories of stain type: blood stain, body image, water

But there seems little doubt that these stains. . .are those of blood.

stain, scorch and clear background. At first glance, the coloring of the scorches and water marks from the 1532 fire and the body image itself all appear somewhat similar against the yellowed background linen. Even at the photomicrographic level the scorches and body image reflect light in approximately the same way. Closer examination, however, revealed that the water stains had some distinct characteristics, notably that they penetrated the linen's threads to all depths, including around bends and into crevices in the fiber, which made for a darkish brown saturated appearance. The water stains also have an abrupt boundary where the unwetted areas begin. The scorches, on the other hand, altered the coloring of the bulk of each fibril to a constant density—that is, also regardless of bends and crevices. But as might be expected from a scorch, these marks had a diffuse and gradual boundary. The body stains, however, appear lighter and straw yellow in tone and, significantly, are generally restricted to the top three or four fibrils of each thread crown. In other words, this shallower coloration does not usually follow the bends or crevices caused by intersecting threads of the weave—a distinction that proved to be of great importance.

The blood stained areas are particularly fascinating. Under magnification, they generally appear to be red-orange amorphous encrustations caught in the fibrils or in the crevices, suggesting direct contact with a viscous fluid, with most of the outer solidified material falling or being abraded away over time. Close-ups of particular areas such as the apparent lance wound on the figure's right front side demonstrated a surprising contrast between the brownish background coloring of the blood stain and the exceptionally reddish particulate material caught in the fibrils. The brownish color is as it should be—blood usually darkens through oxidization with age—but the red color is startlingly reminiscent of recent blood and not at all what one would expect after a minimum of 600 years. To address this problem, I contacted a number of museums in search of old blood samples for comparison only to find that except for the bloody sleeve of the assassinated Abraham Lincoln and a few samples from a nineteenth-century Indian massacre, nothing close to 600-year-old samples exists. There are brownish stained cloths from 2,000 to 3,000-year-old Egyptian and Coptic mummies, to be sure, but it is impossible to tell whether they are stained with actual blood or decayed body fluids. While it is possible that some property of the Turin cloth or even the blood itself preserved its reddish color, the question remains a mystery for now.

But there seems little doubt that these stains, which penetrate to the reverse side of the cloth, are those of blood. In areas where the particulate clumps have been removed, they have the distinctive and correct homogeneous reddish-orange coloration. It seems that these areas were probably soaked with a colored liquid less viscous or dense than whole blood—most likely blood serum which separates from whole blood at death. Optical spectrophotometry and microchemical analysis have since confirmed that the suspected blood stains do in fact contain hemoglobin.

The body image itself is a uniform, light sepia yellow color on the points of highest relief of the threads, or in other words, on the outermost surface of the Shroud. There is no indication of any artificial coating or pigments on the surface of these darkened fibrils. Some areas, presumably those where contact between the body and Shroud was more complete or direct, simply have more of the darkened fibrils. The images of the cheek, eyes and fingers are primarily registered on the upper crowns of the threads. Yet even in the darkest and atypical of areas—the heel and nose—the image stain does not penetrate to the reverse side of the cloth and shows no evidence of any mixture of blood. Visual observation of the heel area at 500 times magnification revealed the presence of very fine yellowish particles suggesting dirt; the nose area might also contain dirt or residual skin material. Laboratory examinations of the effects of human perspiration and skin oils subsequently showed similar properties. Under magnification, many Shroud body areas are distinguished by small bundles of exceptionally darkened fibrils resting slightly above the rest of the thread to produce a kind of striping effect. The explanation for this phenomenon might be related to the observation

made with the unaided eye that some sections of the weave did not imprint the body image. Most notable are the stripes along the sides of the face.

But how then was the image actually produced? Our photomicrographic observations on the linen's texture and subtle coloring, along with the laboratory experiments on perspiration and oils, suggested one possibility—such fluids simply accelerated the normal degradation and darkening of cellulose, the basic component of linen, which occurs through gradual oxidation and loss of water by exposure to heat and light. It is well known that cellulose, be it paper, linen or cotton, can be artificially darkened through the application of either heat or light energy in what amounts to a rapid simulation of the aging process. I decided to test the effect of various substances such as body oils, sweat and olive oil—which along with myrrh and aloes was used as a burial oil in ancient Palestine—by applying them to linen in very light coats and baking the cloth at high temperatures to reproduce the effects of slow extended aging. In each case the latent, formerly invisible image developed into a visible stain in a matter of hours. Under magnification the fibrils from this stained area appeared less smooth than the unwetted fibers, just as the unstained background on the actual Shroud shows a tighter, smoother weave than the body image area. The chemistry behind the events is quite sensible: the foreign substances simply absorb more energy than the untouched areas and thus promote the degradation and darkening. This strongly suggests that substances on the body once enclosed in the Shroud—either burial ointments, perspiration or skin secretions—transfigured the cloth through direct contact. Yet despite supportive findings by organic chemists on the image chemistry, not all scientists agree with our hypothesized mechanism of image transfer from body to cloth.

The scorches appear in all densities. . .

One alternate hypothesis, for example, maintains that the Shroud's image was produced perhaps deliberately through faintly singeing a linen cloth with a hot statue. That suggestion makes analysis of the scorches, attributed to the 1532 fire, particularly important. Under magnification, the scorches appear in all densities from obviously burned or carbonized material to lightly colored fibers. Because the clearly burned material is so obviously just that, only the latter are of interest in comparison with the image areas. The lightly scorched areas resemble the body image in both color and density shading, so visual observations alone could not resolve the issue. Ultraviolet fluorescence photography revealed that the body image does not fluoresce while the scorched fibrils do. In addition, the scorches are also subtly redder than the straw yellow body image.

A more serious challenge, if only for the amount of publicity it has recently received, has been directed to our findings by a Chicago photomicroscopist, Walter McCrone of McCrone Associates. While not a participant at Turin, he analyzed some of the fibrils pulled off the surface by adhesive tape. In brief, McCrone says that he detected the presence of red ochre—a pigment containing iron oxide and as with all paints, a binder—on tiny fibrils of the Shroud. This would indicate that the image was painted on and, in other words, is a deliberate forgery. Forewarned of these charges, the Turin research team made extensive highly sophisticated microchemical tests conducted by Allan Adler of Western Connecticut State College that detected no pigments or binders for pigments of any kind to a level of less than millionths of a gram; the traces of iron oxide that were found, on the other hand, were so slight as to be invisible to the naked eye. Further, they were no more abundant in image areas than in non-image areas. But McCrone insists that tiny colored particles can be seen at magnifications of several hundred. The argument is almost beside the point. The particles can't be seen by the naked eye. But the body image on the Shroud is visible to the naked eye and paint pigment is clearly not the reason.

The Shroud image is far too subtle for such heavy-handed explanations as the red ochre or hot statue theories. When examined under a wide range of wavelengths from the near ultraviolet or blue light to the red visible, the Shroud body image consistently and exclusively reflects light of the same distinctive straw-yellow tone, with reflectance diminishing toward the shorter, blue wavelengths. When subjected to ultraviolet radiation,

The Shroud is not a product of a clever Mediaeval artist.

the body image neither reflects nor fluoresces: in significant contrast to the scorch marks. The resemblance of light scorches to the body image is therefore only superficial. Pyrolysis or chemical decomposition by fire brought about some surface degradation of the cellulose, and left some by-products apart from the burned and scorched areas, but these effects were undoubtedly the result of the 1532 fire.

The Shroud is not the product of a clever Mediaeval artist. And we now have some firm and generally agreed upon evidence about what caused this hauntingly mysterious image—the accelerated structural degeneration of cellulose fibrils as a result of natural, chemically induced molecular changes in the material. The hypothesis that these changes were catalyzed by natural skin secretions or preservative burial ointments is in no way diminished by the absence of these substances on the Shroud today—they could easily have evaporated or even been washed away over the centuries. To us, the idea that the image was transferred directly onto the cloth by skin contact remains the most plausible theory.

But the Shroud is nothing if not an enigma. Critics of our hypothesis, some members of the Turin research team itself, argue that an image produced by contact alone could not have the unique, three-dimensional contouring found on the Shroud. The trouble is that even after intensive scientific investigation, we still do not have the detailed understanding of the transfer mechanism necessary to either verify or invalidate that charge. On-going laboratory simulations might some day aid in our understanding. For now, we do know that the blood itself had to be transferred to the Shroud by direct contact and not some mysterious burst of energy. Similarly, the remarkably fine detailing of the scourge marks revealed by ultraviolet fluorescence photographs would be impossible to obtain by any other means than direct contact between the body and linen.

Further studies which unfortunately are not likely to be approved soon, might help answer some of these perplexing questions. Just the construction of a more stable platform, for example, would allow us to take photomicrographs at a magnification of 100, or 5 times more powerful than those taken in 1978. Higher resolution x-ray fluorescence might also finally identify the presence of potassium and chlorine, certain indications of human blood. On the basis of the recent work in Turin, many other tests could be vastly refined. For now, we know that the Shroud was not a product of any human chicanery. But was it the actual burial cloth of Christ? Our research has not been able to prove that weighty conclusion, nor perhaps will science ever be able to say. But at the same time, some of the most exhaustive research ever conducted on any relic, object of art or archaeological artifact in no way has eliminated that possibility.

For Further Reading on the scientific investigations of the Shroud of Turin: J.S. Accetta and J.S. Baumgart, "Infrared Reflectance Spectroscopy and Thermographic Investigations of the Shroud of Turin," *Applied Optics* 19 (June 15, 1980): 1921-29, a search for infrared signatures and emittance variations revealed no evidence of forgery or retouching; B.J. Culliton, "Science Investigates the Shroud of Turin," *Science* 201 (1978): 235, outlines the state of the knowledge and planned tests preceding the October 1978 investigation; R. Gilbert and M. Gilbert, "Ultraviolet-Visible Reflectance and Fluorescence Spectra of the Shroud of Turin," *Applied Optics* 19 (June 15, 1980): 1930-36, presents spectral measurements from the 1978 mission; John H. Heller and Allan D. Adler, "Blood on the Shroud of Turin," *Applied Optics* 19 (August 15, 1980): 2742-44, is a chemical and spectral confirmation of blood; R.A. Morris, L.A. Schwalbe and J.R. London, "X-Ray Fluorescence Investigation of the Shroud of Turin," *X-Ray Spectrometry* 9 (1980): 40-7, gives the x-ray measurements; S.F. Pellicori, "Spectral Properties of the Shroud of Turin," *Applied Optics* 19 (June 15, 1978): 1913-20, evaluates the spectrophotometric measurements made at Turin and subsequent laboratory simulations and their interpretations; Peter M. Rinaldi, *The Man in the Shroud* (Sidgwick and Jackson, Ltd., Britain 1974, revised): 40, describes earlier observations; Kenneth F. Weaver, "The Mystery of the Shroud," *National Geographic* 157 (June 1980): 730-53, reports on the 1978 mission to Turin; Ian Wilson, *The Shroud of Turin* (Doubleday and Co., New York 1978), presents the known history and hypothesizes a trace to the time of Christ. A research position summary and final report of the STURP team will be published in the near future.