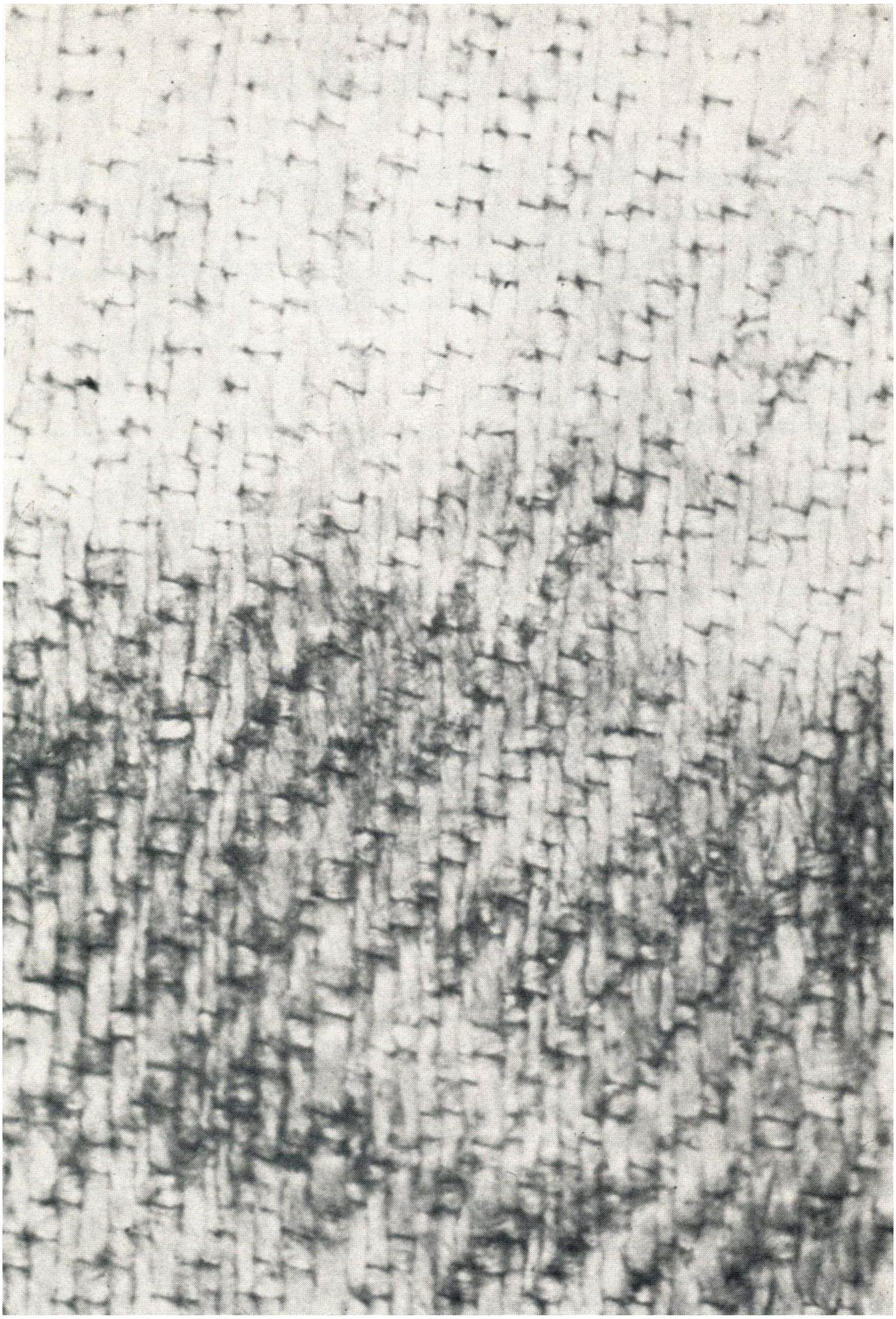

Blood on the dorsal area. Photo courtesy of STURP.

THE 1978 SCIENTIFIC STUDY OF THE SHROUD OF TURIN

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ABSTRACT

The image on The Shroud of Turin consists of linen fibrils that are colored by substances produced through a cellulose oxidation - degradation process. No evidence was found to suggest that pigmented or dye materials were applied to the cloth. Iron, calcium, and strontium are present in the cloth. The "blood" areas give positive test results for proteinaceous material and contain blood. The blood regions show the largest concentrations of iron.

I. Introduction

The Holy Shroud is a rectangular cloth (approximately 435-cm long by 110-cm wide) kept locked in the chapel of the Royal Palace of the House of Savoy in Turin (Torino) Italy. It is owned by the House of Savoy whose titular head, Umberto II, lives in Portugal as the exiled King of Italy. The care of The Shroud is entrusted to the Archbishop of Turin. Impressed upon one surface of the cloth is a faint head-to-head double image of a man approximately 175-cm tall and 77kg in mass who has been badly mistreated.

Without doubt, The Shroud is an enigma. Millions believe this relic is the burial cloth of Jesus of Nazareth. Others are sure it is a forgery or at least not what the proponents claim. The authenticity of The Shroud is a subject of much debate. Its documented history[1, 2] dates only from the 14th century. In 1389 the bishop of Troyes in France (Pierre D'Arcis) pronounced the cloth a fraud and said the artist who painted the image was known. No specific details were handed down by His Excellency to substantiate the claim, however. There are various other traditions - about as well-supported - that place its first appearance close to the beginning of the Christian era.

Since The Shroud is a material object, it can be made subject to the rigors of a physical-scientific investigation. In this it differs from other equally controversial subjects such as UFOs, spooks, Bigfoots, etc. Unfortunately, the situation is complicated by the fact that, except on relatively few special occasions, The Shroud is unavailable for any type of viewing, and opportunities for examination of the cloth are quite rare. For example, there have been only five in the past hundred years.

In 1898 The Shroud was exposed in honor of the 50th anniversary of the Italian constitution. It was at this viewing that a talented amateur photographer named Secondo Pia took pictures that showed the image on its surface was a negative; i.e., the image on Pia's photographic plate was not a negative, as usual, but a positive. Just after the turn of the century, Paul Vignon, Professor of Biology at the Institut Catholique in Paris, put forth his "vaporograph" theory of Shroud-image formation[3,4]. Subsequently disproved, Vignon's mechanism involved chemical reaction of burial spices on the cloth with urea/ammonia from the sweat that covered the body wrapped in the cloth. During these same years Yves Delage, Professor of Comparative Anatomy at the Sorbonne, studied Pia's photographs and reported on 21 April 1902 to the Paris Academy of Sciences that the image on the cloth was indeed a negative and not a painting. A doctor of medicine, Delage described in great detail the side wound, scourges, etc. In May 1931, Giuseppi Enrie took excellent photographs that have been used as the main resource material over the last 50 years by sindonologists. They also have been the most popular and widely disseminated pictures of The Shroud. A few years later Pierre Barbet, Surgeon-General at St. Joseph's Hospital in Paris, studied pictures of The Shroud and made experiments with cadavers[5]. He established that in crucifixion nails must penetrate wrists - not palms of the hands - in order to support the weight of a human body. It is interesting to note that the discovery a few years ago of the remains of a man crucified during the first years of the Christian era show that this requirement was also known at that time. Evidently the knowledge was forgotten after the prohibition of crucifixion for the tradition that comes down through the centuries has nail holes in the palms of hands. Barbet's experiments also showed that the action of nailing through the wrist brings about median nerve injury that causes palm-ward contraction of the thumb. This, too, must have been observed in ancient crucifixions. In contrast, this effect was remembered for it appears in iconography at least as early as the 9th century.

In 1969 and 1973 venerable and rather parochial groups of scientific experts examined the cloth. Photographic and microscopic investigations were accompanied (in 1973) by removal of a number of thread samples and two swatches from carefully selected areas. Included were several threads from "blood" areas as well as from non-blood/off-image regions for textile analysis. These are now known as the "Raes' samples"[1]. It was during the 1973 television exposition and scientific study that Max Frei, forensic expert from Zurich, Switzerland, removed samples of surface material from many places on the cloth that permitted his now well-known pollen study[6]. His results stated the finding of pollens indigenous to each part of the world in which The Shroud had been thought to reside during its centuries-long history. It is unfortunate that his work has been mistaken for a dating of the cloth, something Frei himself vigorously denies but is unable to stamp out. The general conclusion of the teams that worked during these years was that the cloth could be authentic but that more work was highly desirable[7]. This recommendation was fulfilled 8-13 October 1978 by the scientific investigation known as Operation STURP: The Shroud of Turin Research Project.

The first phase of STURP actually began before The Shroud was examined, although this was unrecognized at the time. In 1976 it was convincingly demonstrated that the density of the Enrie-filmed image varied inversely with the probable distance of cloth to body, was Lambertian in nature, and had a one-to-one global mapping function. Films of paintings of The Shroud did not show these characteristics. Three-dimensional relief figures and life-sized statues were constructed from The Shroud data[8].

In the late summer of 1978 (August 26) a public exposition of The Holy Shroud began. It was held in the Cathedral of St. John the Baptist in Turin, Italy, and celebrated the 400th anniversary of the relic's transfer from Chambéry in France to Turin. At the end of the six-week viewing, our team of American scientists was allowed to make non-destructive scientific measurements on the cloth. For 5 days (over 100 hours) data were collected.

II. Test Results

Both popular and technical accounts of the experiments with discussion of results have been published by various team members[9-18]. In addition, some of the data have been publicly reviewed by nonproject persons along with ideas and theories as to what the measurements mean[19-23]. The current understanding and interpretation by STURP personnel of all available evidence taken together has been set forth in its report entitled "Physics and Chemistry of the Shroud of Turin: Summary of the 1978 Investigation."[*] It is probably safe to say that no one of us would strongly disagree with any part of the group summary. This article reviews the data and conclusions of that report.

A. Cloth

The Shroud material basically is vegetable fiber or flax, commonly called linen. There are easily visible discontinuities in the color shade of the threads. This suggests that the material was hand-processed in hanks, and the discontinuities represent the changing from one bundle of yarn to another. The linen threads are about 0.15 mm in diameter and have a "Z" twist, as do very old samples of cotton. Each thread is composed of fibrils 10-15 pm in diameter. The cloth is woven as a twill in the herringbone pattern. The weave of The Shroud is tight but extremely resilient to an applied force. The fabric thickness at three widely separated points averages 345 ± 22 µm. The Holland backing cloth thickness is 270 ± 51 µm.

Although the weave structures and cloth-density variations are easily visible, radiography does not show any cloth-density discontinuities that correspond to the visible image. The total areal

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[*]Copies of either the detailed complete report and/or a simplified shorter[12] version are available from The Holy Shroud Guild, Box 336, Ephrata, PA 17522.

density was measured[13] as between 30 and 40 mg /cm^2 for the Shroud plus the backing cloth and an average Shroud-density value of 25 mg/cm^2 is estimated.

None of the data, however, provides any substantial clues as to the actual age of the cloth which has the impressed human image. A universally accepted technique for obtaining a satisfactory age for objects of this sort is the ^{14}C method. This procedure determines the time that has elapsed since the material left an equilibrium state with its environment by measuring the radioactive ^{14}C and stable ^{12}C concentrations. Knowledge of the rate at which ^{14}C disintegrates into ^{14}N allows an "object age" to be calculated. Until recently much too large amounts of The Shroud cloth would have been required to obtain a date in this manner. In the middle 70's, however, new techniques[24] in carbon-dating methods were developed that decreased the amount of cloth necessary by at least a factor of 10, from a square meter to only several square centimeters in area. Measurements[25] on old Egyptian mummy cloth have given accurate results and demonstrate that this technique could be readily applied to similar samples from The Shroud.

In October 1978 The Second International Sindonological Symposium held in Turin was told that Church authorities would consider releasing Shroud material when at least 2 universities agreed on which of the several available ^{14}C procedures should be used. The Shroud of Turin Research Project has studied the capabilities of the radiocarbon-measuring scientific community. A detailed report has been written. It concludes: 1) there are now 5 laboratories in the United States and overseas that agree on the procedures; 2) fresh, well-documented samples should be used, and these can be taken from areas of the cloth that will leave the Shroud visually untouched; 3) sample-preparation procedures can insure no error in date due to foreign contamination accreted over the centuries; and 4) the calibration curve that relates radiocarbon time to chronological time has been refined and probably will give an error of less than ± 150 years in the final date.

B. Image

The image is probably the most intriguing aspect of The Shroud. The joined frontal and dorsal likenesses appear at first glance to be the work of human hands. If the image were produced by a skillful artist, he would probably have either added colored substances to the cloth or changed the chemical structure of parts of the cloth so that they absorb certain wavelengths of visible light.

Microscopic observations show that the image is caused by a discontinuous distribution of translucent yellowish fibrils. For pure image the colored fibrils appear only on the topmost surfaces of the threads, and the coloration extends only 2 or 3 fibrils deep. The color density of a fibril varies by less than a factor of two. The number of fibrils per unit area appears to determine the darkness of an image portion. Both the frontal and dorsal images show this effect. Color does not saturate the cloth in any image area. There is an absence of liquid capillary flow into the image threads.

The image is best (most vividly) seen at a distance. It fades as the observer approaches and is difficult to locate under magnification. There is nothing mysterious about this property; it is a well-known phenomenon. In diffuse-image situations, the human eye discriminates better when more area of the image can be seen at one time.

Portions of the image that intersect areas scorched in the fire of 1532 show no change in color or density. It is questionable whether either organic dyes and stains or inorganic pigments and painting media could have survived unaltered temperatures that must have reached at least 800ºC. No evidence for scorched paint can be seen. There is also no evidence that any part of the image is water soluble. The flow of the water used to extinguish the fire of 1532 was not impeded by the image, hence the probability of the presence of nonsoluble or hydrophobic paints is slight. Slight retardation does seem to exist in the "blood" area of the side wound.

There is no appearance of brush marks, angular dependence of image density, nor non-uniform image fading. The abrupt, obvious change in facial image density is not a chin band as sometimes has been suggested. Variations in image density occur where the material used to weave the cloth changes and threads overlap. An argument can be made, however, from other aspects of the image, that a chin band is indeed around the head.

X-ray fluorescence examination revealed iron, calcium, and strontium in all areas tested[13]. Within the sensitivity and precision limits of the experiment, there does not appear to be any discontinuity in elemental composition between the image and non-image areas. The scan across the facial image area gave an average iron concentration of 12 ± 2 µg/cm^2, while that across the dorsal foot region recorded 38 ± 3 µg/cm^2. One can only speculate why the amount of iron is significantly larger in the latter—excess dirt or more blood could explain the facts. In any event this region seems to be an anomaly, and the background concentration of iron appears to be of the order of 10 µg/cm^2. Relatively large amounts (200 ± 50 µg/cm^2) of calcium and a very small quantity (2.5 ± 1.0 µg/cm^2) of strontium were found. Examination of threads removed in the 1973 investigation (Raes' samples) gave the same identification plus smaller trace amounts of potassium, chlorine, and lead. No concentration of arsenic characteristic of the yellow pigments available in the 14th century was found in the image fibrils.

Ultraviolet and visible reflectance and fluorescence measurements on the image, scorch, "bloodstain," and clear areas were made[17]. The reflectance background data are consistent with that associated with old linen material containing carboxyl, carbonyl, and double bonds of varying degrees of conjugation; i.e., cloth yellowed through chemical changes in the cellulose molecules.

The relative spectral reflectance of the image generally increases with the wavelength of the light used to examine it. There appears to be no fine structure in any of the spectra. The image areas showed none of the spectral characteristics expected from normal dyes, stains and pigments. The average image density exhibits a broad maximum near 300 nm which decreases monotonically to 750 nm. There is a decreasing image contrast from the near ultraviolet to the near infrared. The image decreases the reflectance, as do the scorches, "bloodstains," and cloth-mottling.

The cloth background fluoresces with a broad maximum near 435 nm[17]. Mottling diminishes the fluorescence, as do the scorches. The image and "bloodstains" are nonfluorescent. Animal gelatin is impure and fluoresces. Because the image does not fluoresce, it cannot contain this protein-type binder. The most sensitive protein test (fluorescamine) showed no protein whatsoever in the image.

An examination of the fibrils removed from the cloth by a "stickytape"[26] technique showed that the image has a distinct straw-yellow color. Non-image areas showed a very different pale-yellow color. Very small particles of iron oxide are found in those areas where the water-stain margin intersects other features. The image is not due to protein or iron oxide.

Chemical spot tests on the fibrils and the nature of the tests show that the image color is due to the presence of a cellulose degradation product - specifically, dehydrated acid oxidation with the formation of a conjugated carbonyl chromophore - and not due to paint pigment, dye, or stain. Microchemical staining techniques show unequivocally the presence of protein-like material only in the "blood"/image areas[18].

There are ways to alter the chemical composition of cellulose in linen cloth to produce an image. The first is simply scorching or burning the material. Light scorches that do not color the reverse side of a cloth can be made easily, either by direct contact or radiant energy transfer. They do not change the gross mechanical properties of the cloth and do not fade with time. Scorches are stable to further heating up to temperatures and times that will produce an equivalent scorch in the base material. Furthermore, scorches do not move as water percolates through them, nor do they impede water flow. The chemical components of scorches are not soluble in many solvents.

The image and the scorched regions of The Shroud have common physical and chemical properties. The fibrils in both areas are colored throughout their bulk, are translucent, and appear unaffected by known previous washings. The spectral reflectances of the image and the areas scorched 'in the fire of 1532 are quite similar. The mean reflected density of five image areas agrees within experimental error with the mean value of the light scorches. The fluorescence curves of the body image areas and the light scorch areas also are comparable. There is a pronounced maximum at about 450 nm, a value shifted slightly towards longer wavelengths from the non-image area maximum. Both the image and light scorches reduce the background fluorescence[17].

Despite the apparent correlation, the resemblance of the body image to the light scorches from the fire may be superficial[27, 28]. Subtle color differences do exist. The scorches on The Shroud appear to be visually redder than the body image and they also differ somewhat in the ultraviolet fluorescence characteristics. The discrepancies may be attributed to different surrounding conditions during the two formation processes. In the fire of 1532 The Shroud was scorched while inside a metal box, and we may surmise that oxygen was limited at that time. In this case, the temperature would be relatively high in the scorching zone, and several reactive pyrolysis products would be produced. Pure cellulose heated in an oxygen-depleted environment produced pyrolysis products that fluoresced in the same manner as those Shroud areas damaged in the medieval fire[28]. If the image is the result of a scorch, a temperature lower than that of a fire would be expected to have been operative and the oxygen concentration that of air, which is not an oxygen-deficient atmosphere.

A second way of altering the chemical composition of the cloth so that it can be seen visually includes mechanisms in which the underlying material is treated by an applied reagent which either produces an image immediately or sensitizes the area so that a latent image eventually is developed by aging and/or heat[15]. Concentrated sulfuric acid will do the first. Linen baked dry in air for 7.5 hrs. at 150ºC qualitatively reproduced the spectral reflectance and fluorescence characteristics of The Shroud background areas. In the same type of experiment, areas of linen treated with materials such as skin secretions (perspiration plus oils) or olive oil in very thin coatings, followed by baking in air at 140º for 3.5 hrs., became yellower than the discoloration associated with the untreated baked linen sample. The samples did not darken with continued baking's. Such an experiment involves a diffusion (liquid) process. A molecular transport phenomenon such as this demands contact throughout. This does not occur with all The Shroud image, particularly the face.

A detailed mechanism for the formation of the image has not yet been formulated. Vapor diffusion of the sensitizing materials is unlikely because the image appears only on the thread crowns and not throughout the weave structure. In contrast to the face, however, direct contact transfer must have been operative on the torso for the scourge marks are transferred as blood. The general appearance of these scourge marks depends upon the wavelength of the illuminating light; in the near ultraviolet (335-375 nm) fine scratches also appear. Without intimate communication of the subject with the linen, the high resolution of the scratches could not have been preserved.

We have absolutely no indication that the image was produced by the hand of man. In fact, it appears we have evidence of its being "acheropoietos."

C. Bloodstains

One of the goals of the project was to characterize the stains which appear to be blood. In addition to any intrinsic importance of their own, "bloodstain" data might provide circumstantial evidence and supplemental clues that would shed light and understanding in other areas of the overall picture. For example, if blood is not identified, The Shroud is not what some claim it to be and probably not a burial cloth at all, while a positive hematic analysis could answer the question of which first went on the cloth, blood or image. Unfortunately, bloodstain data can say nothing positive about the origin of The Shroud—blood could be present equally well from both "painting" and natural cloth-marking processes. Finally, the emotional interest in this subject simply cannot be overlooked. All in all, stain characterization is important.

Under moderate magnification the "blood" looks as if it went on as a viscous fluid that flowed around the threads and soaked through to the opposite side of the cloth where it is also visible. The stain areas appear brownish-red in reflected white light and crimson in transmitted. Old blood can vary in color across the whole spectrum. It is thus to be expected that the color of the individual "bloodstained" fibrils is not strictly uniform[27, 28]. In some cases the "blood" appears to surround or coat the fibrils and in others it is lying free. Microspectrophotometry using visible light showed intense absorption near 410 nm (Soret peak), characteristic of porphyrinic material. Twelve tests for blood are positive, results that corroborate the findings of the spectral tests[29].

Chemical analysis confirmed the presence of porphyrinic material. The samples were treated with a strong reducing agent to change iron to the ferrous state and then with a concentrated strong acid to displace it. Under near ultraviolet radiation the treated sample of blood fibrils was seen to fluoresce in the red, confirming the presence of porphyrin and, therefore, also blood in the alleged "blood" areas".

Radiography revealed no high-density structures that might correspond to the visible blood stains. However, in the blood areas the x-ray fluorescence studies indicated 30-40 $\mu g/cm^2$ of iron concentrations above the measured or inferred background levels[11]. This is consistent with the presence of blood.

Bloodstains do not fluoresce—it is virtually totally absorbing in the ultraviolet. However, at the border of the scourge marks and around the periphery of the heavier blood flows, there is a white fluorescence, invisible in white light. When tested chemically this was identified as serum albumin. Blood degradation products in the form of bile pigments were also found.

There is no specific absorption spectrum for blood *per se*[18, 30]. The spectral characteristics depend upon the chemical state of the hemoglobin and also on its state of aggregation. The Shroud blood data are those for "perturbed" acid methemoglobin, the chemical state in which the iron in the hemoglobin is oxidized[29, 30]. Published absorption spectra (480-640 nm) for acid methemoglobin correspond to The Shroud curves and even include the small absorption structure in the near infrared (630 nm)[29, 31].

III. Conclusions

The combined evidence at this time makes it appear improbable that The Shroud image consists of pigmented material applied to the cloth. None of the findings suggest that the image is a direct result of printing, rubbing, spraying, or brush painting.

The fluorescence and reflectance characteristics of The Shroud as well as the apparent chemical nature and microscopic appearance of the image support the contention that the image is a cellulose degradation effect. How this came about is unknown. Also still unanswered is the extremely important question as to whether the image is the result of aided or unaided natural processes.

The evidence is sufficient to conclude that the "blood" areas on The Shroud are blood. The presence of protein, the optical absorption, microchemistry (including induced porphyrin fluorescence), and the iron concentrations determined by x-ray fluorescence all support this conclusion.

IV. Acknowledgements

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