The Shroud of Turin's 'Blood' Images:
Blood, or Paint? A History of Science Inquiry

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"It is the essence of scientific investigation to seek to conform thought to the nature of its object, as encountered in its interaction with us."
-- John Polkinghorne[1]

Introduction

According to the New Testament's book of John, Roman soldiers "flogged" Jesus of Nazareth, "twisted together a crown of thorns and put it on his head," "struck him in the face," and, along with two others, "crucified him."[2] Because the next day was unsuitable for the display of crucified individuals, a request that those crucified have their "legs broken" and their "bodies taken down" was made and granted.[3] (With their legs broken, victims of crucifixion could no longer push up their bodies to inhale, and death by suffocation quickly ensued.[4]) Because the soldiers found Jesus "already dead" they "did not break his legs," and one soldier "instead... pierced Jesus' side with a spear, bringing a sudden flow of blood and water."[5] John states that the body was "wrapped in strips of linen," while Luke says "in linen cloth," Mark writes "linen cloth," and Matthew states "a clean linen cloth," though John later speaks of both "strips of linen" and "the burial cloth that had been around Jesus' head."[6]

Incredible as it may seem, Jesus' burial cloth has been alleged to have survived to the present and be the object known as the Shroud of Turin (hereafter Shroud). The Shroud is an approximately 4.3 by 1.1 meters (14 feet 3 inches by 3 feet 7 inches) strip of linen cloth having burn marks from a 1532 fire, and most significantly, bearing the faint front and back images of an apparently scourged and crucified male. Close similarities exist between the image and the biblical accounts of Jesus' crucifixion: over 100 marks are visible on the chest and back side as if from a flogging,[7] 'blood' marks at the back of the head, to the sides of the face, and on the brow are suggestive of a crown of thorns,[8] the face appears beaten and wounded,[9] wounds appear in the visible wrist and the clearly-outlined foot as if from nails, a dark ellipsis resides in the side in a region having much 'blood' and a clear fluid as if from a lance wound, and seemingly unbroken legs.[10] Because of this close similarity, the image is universally believed to depict Jesus,[11] yet much controversy remains about whether the Shroud is Jesus' actual burial shroud or merely a forgery. A 'strong-authenticity' view holds that the body image was produced by supernatural means involving Jesus' body, while a 'weak-authenticity' view holds that the body image was produced by Jesus' body via unusual natural processes. In both the strong- and weak- authenticity views, the 'blood' images arose via contact of the cloth with a bloody Jesus.

A point of argument against the Shroud of Turin being Jesus' actual burial cloth is that it can be traced with certainty only from about AD 1355. Before then, existence and provenance is much more uncertain. According to some traditions, a disciple of Jesus brought from Jerusalem to Edessa a cloth miraculously imprinted with the likeness of Jesus.[12] Shroud historian Ian Wilson speculates that this cloth was the Shroud of Turin, and that it was hidden in a wall to be later rediscovered during the 500s.[13] In fact, a circa 593 account states that a 544 siege of Edessa was repulsed by "the divinely wrought likeness which human hands have not made" and which was discovered in the throes of the city's distress.[14] In 943, the 'cloth of Edessa' was moved from Edessa to Constantinople. The year thereafter, this cloth was described as bearing "blood and water from his [Jesus'] very side," and in a circa 1130 sermon borrowing from a 769 discussion, the cloth of Edessa was described as having "the glorious features of [Jesus'] face, and the majestic form of his whole body... supernaturally transferred,"[15] indicating the presence of more than simply a face. An official history of the cloth of Edessa characterized in 945 the imprint as "a moist secretion without pigment or the painter's art," and "due to sweat, not pigments,"[16] descriptions that conceivably could have been of the Shroud. The cloth of Edessa disappeared around the time of the 1204 ransacking of Constantinople.[17] Assuming that the cloth of Edessa is identical with the Shroud of Turin, the cloth of Edessa reappeared in

circa 1355, and has been known ever since as the Shroud of Turin.

An early charge of forgery appears in a 1389 letter by a bishop alleging that his predecessor had investigated the Shroud's origin in about 1355, and discovered it to be a painting:

> Eventually, after diligent inquiry and examination, he [the preceding bishop] discovered the fraud and how the said cloth had been cunningly painted, the truth being attested by the artist who had painted it, to wit, that it was a work of human skill and not miraculously wrought or bestowed.[18]

This letter, as well as the Shroud's seeming lack of historical mention prior to the 1350s, was proclaimed by scholars in 1900-1902 to constitute proof that the Shroud was a forgery.[19] The scholars had had their interest in the Shroud recently awakened by an 1898 discovery. On the night of 28 May 1898, upon developing his photographic plates of the Shroud, the Italian semi-professional photographer Seconda Pia found that the body image appeared much more realistic and lifelike when viewed in negative. Pia inferred that the body image on the Shroud had the qualities of a negative, so that when one obtained a negative of that negative, one saw a quite lifelike positive.[20]

Besides scholars, scientists were intrigued by the lifelike image. Working under the direction of the renowned agnostic zoologist Yves Delage, the Catholic artist and biologist Paul Vignon and others conducted experiments in an attempt to discover the mechanism responsible for the body image's formation. On 21 April 1902, Delage read his and Vignon's paper to the French Academy of Sciences describing the Shroud's properties and the research and experimentation done, and concluded that the Shroud was medically accurate, was not a painting, was not a forgery, and did wrap Jesus' body.[21] In 1931 and 1932, the French surgeon Peirre Barbet performed experiments on cadavers to learn more about crucifixion in relation to what is seen on the Shroud.[22] Barbet discovered that nails driven through the palms of the hands cannot support a body; in contrast, nails driven through the wrists *would* support a body, and furthermore, would damage nerves in the wrists, causing thumbs to retract into the palms.[23] On the Shroud, a wound appears in the visible wrist, and no thumb is apparent.

Vignon (in the 1930s) and the American Robert Wuenschel (by 1954) found at least 15 peculiarities shared by 1) the Shroud face and 2) many Byzantine portraits of Jesus from the 6th-12th centuries,[24] suggesting that the Shroud was in existence well before the 1988 carbon-dating date of between AD 1260 and 1390.[25] In 1969, a group of individuals examined and photographed the Shroud, but did not perform any testing.[26] A few years later, a 1973 Italian Commission largely composed of scientists examined the Shroud, and those samples of 'blood' removed were tested for the presence of blood, yet only negative results were obtained.[27] On 19 February 1976, upon placing a transparency of the Shroud into a device called a VP-8 Image Analyzer, two American scientists viewed a 3-D rendition of the body image, thereby discovering that the body image encodes 3-D information and posing a severe challenge to attempts at reproducing the body image.[28]

Beginning in October 1978, about forty American scientists intensely studied the Shroud before concluding that the body image was not some type of painting.[29] On the basis of their extensive testing of fibers and particulate matter taken from the Shroud, biophysicist John Heller (d. 13 December 1995) and chemist Alan Adler (d. 11 June 2000) concluded that the body image consisted simply of prematurely-aged linen.[30] The body image is, like a newspaper picture, a halftone, since the higher the density of yellowed fibers, the darker is the body image area.[31] In contrast, microscopist Walter McCrone claimed that the body image resulted from the application of simply iron-oxide (Fe_2O_3) particles, a claim he later altered to say that the body image resulted from the application of iron-oxide particles in a proteinaceous medium (i.e., liquid iron-oxide paint).

Regarding the 'blood,' Heller and Adler (hereafter H&A) concluded that it was actual blood material on the basis of physics-based and chemistry-based testing, most tests of which will be discussed, specifically the following: detection of higher-than-elsewhere levels of iron in 'blood' areas via X-ray fluorescence, indicative spectra obtained by microspectrophotometry, generation with chemicals and ultraviolet light of characteristic porphyrin fluorescence, positive tests for hemochromagen using hydrazine, positive tests for cyanmethemoglobin using a neutralized cyanide solution, positive tests for the bile pigment bilirubin, positive tests for protein, and use of proteolytic enzymes on 'blood' material, leaving no residues. The tests and data not discussed

are the reflection spectra indicative of bilirubin's[32] and blood's presence,[33] chemical detection of the specific protein albumin,[34] the presence of serum halos around various 'blood' marks when viewed under ultraviolet light,[35] the immunological determination that the 'blood' is of primate origin,[36] and the forensic judgement that the various blood and wound marks appear extremely realistic.[37]

Besides determining that blood was present, H&A also concluded that the 1532 fire burned blood to result in iron oxide residing at the Shroud's burned-'blood' areas. Contrary to McCrone's allegation that iron oxide cannot under any circumstances arise from hemoglobin, it was discovered in 1747 that burned-blood contains iron oxide.[38] H&A also discovered that "retting" (i.e. soaking in water) of the flax plants used in manufacturing the Shroud linen resulted in the uptake of iron, iron that in 1532 was 1) liberated by water splashed on the Shroud to douse the flames and 2) traveled to the watermargin areas, where it became iron oxide.[39]

In contrast to H&A, McCrone does not mention the burned-'blood' and watermargin iron-oxide, and has alleged at various times that the 'blood' images are 1) simply iron oxide particles, 2) simply post-1800s iron oxide particles, 3) iron oxide particles of a form derived from the earth and available for tens of thousands of years, all in a proteinaceous medium, i.e. liquid earthy iron-oxide paint, and 4) liquid earthy iron-oxide and liquid mercury-sulfide (HgS) paint.

This paper will be restricted to an examination of the conflicting claims regarding the presence or absence of actual blood. More specifically, the historical problem here under consideration is the problem of which claims about the actual identity of the 'blood,' whether McCrone's or H&A's, are most likely to be correct given the evidence that the two parties have produced, and which erroneous. To answer that question, we must travel back twenty years and scrutinize what was seen, what experiments done, what assumptions made, and what conclusions drawn. I conclude that contrary to McCrone's claims, neither iron-oxide nor mercury-sulfide contributes to the red coloration of the 'blood' images. Furthermore, H&A correctly concluded on the basis of their extensive, peer-reviewed testing that the 'blood' is indeed blood, even as not-peer-reviewed criticism of their testing is found to lack merit. Special note will be made of McCrone's repeated failure to appear at conferences and his failure to publish his three Shroud papers in the peer-reviewed scientific literature.

Since a finding that the 'blood' is paint would, if correct, constitute evidence for the Shroud being a forgery, while conversely, a demonstration that the 'blood' is blood would mean the Shroud is less likely to be a forgery, the paper's conclusion that the 'blood' is not paint and is blood sheds light on the question of forgery.

* * *

Heller received a doctorate in medicine from Case Western Reserve University School of Medicine, and after teaching medical physics and internal medicine at Yale University, helped establish and worked at the New England Institute for Medical Research, which did basic research in the common areas of biology, physics, and chemistry.[40] Partial to basic research, Heller undertook projects he considered challenging explorations of the unknown.[41] Around the week of 21 July 1978, Heller's interest in the Shroud was kindled by reading a Barbara J. Culliton news story, "The Mystery of the Shroud of Turin Challenges 20th-Century Science."[42] For several days he entertained the possibility of becoming involved in the potentially-challenging upcoming scientific investigation that Culliton had mentioned.[43]

Heller finally contacted a project leader, theoretical physicist John Jackson of the Air Force Weapons Laboratory in Albuquerque, New Mexico.[44] Jackson had enlisted the help of Weapons Laboratory engineer Eric Jumper in doing analysis of the Shroud image and experimentation, and the project thereafter took off as Jackson recruited more individuals.[45] In response to a question about the identity of the 'blood,' Jackson directed Heller to a book by Shroud historian Ian Wilson for details about the 1973 Italian Commission's 'blood' testing.[46] Wilson had begun part-time study of the Shroud in about 1965, became convinced it was authentic, and published a book to that effect in 1978.[47]

In that book, Heller read, "Attempts to dissolve the granules during chemical treatment with acetic acid, oxygenated water, and glycerin of potassium were all unsuccessful."[48] The actual report states, "the pigmented encrustations did not pass into solution in the solvents, acids and the alkalies we used."[49] Heller informed Jackson that the

negative test results were meaningless, explaining at the time, "If you don't do the right tests in the right way, you can never get old blood into solution. If it's not in solution, you can't obtain a positive test."[50]

H&A reiterated this point in their first paper, stating that "false negative conclusions can be drawn if the material [to be tested] cannot be adequately solubilized, as can occur with a very aged strongly denatured sample."[51] (Denaturation constitutes the modification of a protein's or DNA strand's structure by heat, ultraviolet radiation, acid, etc., thereby diminishing or destroying its biological activity, the classic example of which is denaturation of an egg's protein by cooking.) Having received his PhD from Cornell University, and interested in microscopy, crystallography, and analysis of very small particles, McCrone started the research laboratory McCrone Associates Inc. in 1956, and started McCrone Research Institute in 1960 for teaching and research. Despite acknowledging the Italians' failure to solubilize, Shroud skeptic Joe Nickell writes that "those conducting the tests on the blood were... internationally known forensic serologists, a fact that underscored the credibility of the [negative] results."[52] Since McCrone terms the 1973 testing "impossible to fault" and "good forensic science"[53] despite the failure to solubilize, it is with a skeptical eye that we examine McCrone's claim of obtaining negative test results on 'blood.'

McCrone did two of the tests done in 1973, and he either did or did not get the 'blood' into solution before proceeding with the benzidine and sulfuric acid tests; if he got the 'blood' into solution, even as the Italians did not, then McCrone could not have honestly said "I find it impossible to fault the [1973] work." I conclude that the other possibility is the correct one: McCrone *did not* get the 'blood' into solution, in which case, his negative results with the two tests, like the 1973 results, are meaningless.

McCrone performed the phenolphthalein test, which is much more difficult to do than the benzidine test.[54] Since McCrone could not even properly handle the benzidine test, I conclude that he could not have properly done the much more complicated phenolphthalein test, in which case his obtaining negative result(s) with the latter is worthless. The Takayama and Teichman tests yielded McCrone negative results, yet since they are so insensitive, negative results with them does not mean blood is absent.[55]

McCrone states that when sodium azide in an iodine solution is applied to blood, nitrogen gas bubble production indicates the presence of sulfur-containing amino acids, which blood has. When he applied the solution to 'blood' fibers and to red Shroud particles, "little or no nitrogen gas is released," which he interprets as indicating that the red material is not actual blood.[56] However, since he apparently failed to perform controls with artificially-aged blood, he failed to check the possibility that nitrogen gas will not be produced by very aged, strongly denatured blood samples.

The sticky tapes from which McCrone obtained his samples for testing had originally been promised to Heller for doing blood testing.[57] In anticipation of receiving samples, Heller placed some blood and plasma "in different ways" on an old Spanish linen cloth (blood is composed of mostly red cells, with some white cells and platelets, all in a plasma suspension).[58] After applying sticky tape to the cloth, Heller carefully studied the resulting tapes, so much so that he began dreaming about fibrils.[59] In a similar manner, during the Shroud of Turin Research Project, Inc. (hereafter STURP) 8 - 13 October 1978 period of data collection on the Shroud, team members Ray Rogers and Robert Dinegar applied to the Shroud and removed 32 sticky tapes, each approximately 5 cm^2 in area.[60] Rogers was a chemist that worked with explosives at New Mexico's Los Alamos National Laboratory and a part-time archeologist, while Dinegar worked at Los Alamos making bombs and was an assistant Episcopal pastor.[61]

A month after the data collection group's return, Heller inquired as to the whereabouts of the samples he had been promised. Rogers informed Heller that McCrone had borrowed the tapes with instructions, saying "I told Walter to send you any that might have blood on them."[62] Following the arrival of 1979, Heller told Rogers he had received no slides, to which Rogers suggested he phone McCrone, yet McCrone "was never available."[63] McCrone eventually returned Heller's calls:

> "I'll send you a slide that's supposed to have some blood on it, but it's so small, I don't think you'll be able to do anything with it."
> I asked incredulously, "Is that all you're sending?"
> "What more do you need?"
> "I should have at least a couple of other slides to orient me. At this point, I don't have a clue to what anything looks like."

"All right, I'll see what I can do."[64]

McCrone sent four microscope slides labeled Blank, Scorch, Nonimage, and Blood, on each of which a sticky tape had been attached.[65] On the Blood slide, McCrone had circled a minuscule speck and written "Good Luck," yet the speck was so small that even using a high magnification light microscope viewing technique, Heller thought it impossible to determine what was being examined: "It could have been blood, dirt, a fragment of a linen fiber--anything."[66]

Heller had better luck elsewhere, thinking to himself upon finding a red-coated fiber on the Nonimage slide, "That sure looks as though it *might* be blood."[67] He eventually found on the slide a total of 7 fibers partly-coated with red stains, plus a glob he dubbed "biltong" after the sun-dried meat some African tribes produce.[68] Disregarding biltong, Heller calculated he had about 700 picograms of hemoglobin, assuming the red stains were blood. He considered attempting to measure that little blood absurd, telling readers, "I am reasonably sure that no one in the history of science ever tried or even fantasized about it."[69]

This unique problem was precipitated by McCrone. Despite Rogers's directive that Heller be sent slides with material that might be blood, McCrone's Blood slide was *no* such slide; to reiterate from above, the circled 'blood' speck was so small that by its appearance under a light microscope, "it could have been blood, dirt, a fragment of a linen fiber--anything." I infer that McCrone attempted to see to it that Heller could not do any testing for blood. McCrone's attempt is hardly surprising considering that he long delayed sending Shroud slides for electron microscope examination to people in his *own* company: writes McCrone,

> By January 1980 [i.e., by about 1 year after receiving Shroud slides], I had prepared two technical papers for publication.... Only then, did I allow the electron optics group at McCrone Associates to examine the "Shroud" fibers and tapes. I prevented them from doing this earlier because I (selfishly) wished to see polarized light microscopy solve the "Shroud" problem without assistance.[70]

His explanation of this self-described selfishness toward his own coworkers is that he "was hurt by" the fact that "an instrument I still found very useful... became the dinosaur of the research and development world," and thus, "wanted to show 'them' [i.e., the world at large] the light microscope is still important."[71] In short, McCrone had a "hope" that a successful use of the polarized light microscope on the Shroud "would reassert its once strong position in chemical research."[72] He was and remains a devoted crusader for the importance of the light microscope, despite its being made obsolete long ago by physics-based instruments.

Even though Heller had suggested to Jackson that one could use a physics-based instrument to determine the identity of the 'blood,' Heller began work on the red material through a chemistry approach.[73] The chemical structure that Heller wanted to detect is a component of hemoglobin (red blood cells mostly consist of hemoglobin). As its name suggests, hemoglobin consists of globin (a protein) and a heme molecule. A porphyrin has a single metal atom in its center; hemoglobin's heme molecule is a heme porphyrin, and its center metal atom is an iron atom. Heme porphyrin can be detected by applying hydrazine and formic acid to displace a (suspected) heme molecule's iron atom, followed by illumination under long-wavelength ultraviolet light to produce a red fluorescence that can be detected by a human eye adapted to the dark.[74]

Using bloody Spanish linen fibrils, Heller performed the chemical treatments, adapted his eyes, turned on the UV, and looked at the samples. He says he

> swore for thirty seconds without repeating myself. The adhesive used on the Mylar [sticky tape] was supposed to be inert. I growled, "Inert adhesive, my foot. It is damn well ert!" It fluoresced blue-white. I knew I would never be able to see red dots against that bright background.[75]

With additional experimentation, Heller was finally able to obtain a positive result with bloody Spanish linen fibers, yet even then, it required much more heme porphyrin than existed on the 7 Shroud fibers.[76]

Heller left a message for McCrone, requesting any additional slides that might have blood. Heller phoned a day later, and was told by a woman that the answer was no,[77] yet unbeknownst to Heller, in reality the answer to his question was yes. Heller then thought of Western Connecticut State College professor Alan Adler,[78] with whom he had collaborated on different projects, and who he describes as a physical chemist, thermodynamicist,

and "porphyrin nut."[79] Heller approached Adler in a roundabout way:

> "Al," I said enthusiastically, "how would you like to get involved in a real fun project? It even involves porphyrins."
> "Oh yeah? Did you say fun project?"
> "Yup. It might turn out to be the most fun you've ever had on a problem."
> "Sounds interesting. Are you guaranteeing it will be fun?"
> "Definitely."[80]

At a later meeting, Heller informed Adler what the Shroud of Turin was ("The what of where?"), what STURP was doing, and what Heller was up to. Adler had a "predatory light gleaming in his eye" when requesting to see some of the red fibers. Upon viewing one, he exclaimed, "John, that's blood!," to which Heller responded, "I think so too. But what I haven't figured out is how to prove it."[81] Noteworthy is Heller's refusal to call the 'blood''s similarity in appearance to actual blood definitive proof that the red stains were blood.

Adler became "hooked," and together they repeated Heller's experiments and went beyond them. However, in spite of their best efforts, they were unable to increase the sensitivity of the testing, and consequently, it seemed they would never be able to measure the fibers' 700 picograms of possibly-hemoglobin.[82] Heller and Adler suspended their investigation for the first post-Turin STURP meeting, held on 24-5 March 1979 in Santa Barbara, California.[83]

The X-ray fluorescence team consisted of Schwalbe and two nondestructive-testing coworkers at Los Alamos National Laboratory, Roger Morris and J. Ronald London.[84] Morris presented the results from the X-ray fluorescence testing, which permitted identification of the elements present in the Shroud areas sampled. When Heller heard that the group had found uniform iron levels throughout the Shroud except in the 'blood' areas, where there appeared higher iron levels than elsewhere, he thought,

> Well, well. That's presumptive evidence that the 'blood' may be real blood. The iron atoms in heme porphyrins would account for the extra iron in those areas. I *have* to figure out a way to test the garnet-red spots.[85]

In their published paper, Morris et al. write that while their findings "do not prove that the stains are blood, they are generally consistent with this hypothesis," concluding, "we can say no more than that either blood or some iron-based pigment was used to produce the ['blood'] stains."[86] Only in the presence of additional indications can the higher-than-elsewhere iron levels in 'blood' regions constitute evidence for H&A's contention that the 'blood' is blood.

In their control runs using whole blood, Morris et al. detected both iron and potassium, with the potassium levels usually being at-least ten times smaller than the iron levels.[87] In contrast to the control runs, no indications of potassium appeared in the Shroud data; Morris et al. add, "poor signal-to-noise ratios may preclude definite conclusions on this point," but this does not stop McCrone from asserting, "If they [STURP] don't find potassium with iron and calcium--t'aint blood!"[88]

At the time of Rogers's talk, McCrone believed the 'blood' to be artist's iron-oxide particles. His identification of iron-oxide was based on neither chemical testing nor physics-based testing, but consisted simply of looking through his microscope and seeing particles that seemed to have the appearance and crystalline characteristics of iron-oxide. In his first Shroud paper, McCrone characterized the red particles in the following manner:

> This material, when examined on the tapes with higher magnification and transmitted polarized light, is identical in appearance and properties (color, pleochroism, shape, size, crystallinity, refractive indices, and birefringence) to the particles of hydrous and anhydrous iron oxide particles, collectively known as iron earth pigment, used since the days of the caveman.[89]

McCrone's statements about the size and shape of the red particles changed several times, and are discussed in the course of this paper. We turn now to the questions of color and supposed crystalline characteristics, beginning with the latter.

"Pleochroism" is a crystal's property of displaying different colors when viewed by a particular form of light. The higher a material's "refractive index," the more the material will bend light that enters and goes through it; in "birefringence," light is refracted/ bent in two slightly different directions, forming two rays. Birefringence is only exhibited by "anisotropic" molecules, while by way of contrast, "isotropic" molecules do not exhibit

birefringence.[90] Such things as topaz, calcite, and iron-oxide are birefringent, while blood is not.[91]

After later determining that the 'blood' was blood, lacked pleochroism, and lacked birefringence,[92] Heller suspected that McCrone had attributed birefringence to Shroud particles by checking for the property while they were on the Mylar sticky tape:

> The only way that someone [i.e. McCrone] could have been misled into thinking that the blood particles on the Shroud were birefringent is if he had examined them for this property while they were still on the Mylar tape. Mylar is optically active, and *any* red particle looks birefringent when the light has to pass through the tape and particle. The particles had to be removed from the tape if one was to determine which were blood and which were not.[93]

The suspicion was confirmed by McCrone's first paper, where Heller read "This material, when examined on the tapes with higher magnification and transmitted polarized light, is identical in appearance and properties...." Oddly enough, McCrone's first paper acknowledges that Mylar is anisotropic (and by extension, birefringent),[94] yet McCrone still went ahead with identifying the particles as birefringent while they were on the Mylar.

In 1996, McCrone obliquely admitted having made the mistake in attributing crystalline characteristics-- including birefringence and pleochroism-- to red Shroud particles they do not possess: "The particles are isotropic hence not pure hematite but they match red ochre in size, shape and color."[95] Compare the 1980 "This material... is identical in appearance and properties (color, pleochroism, shape, size, crystallinity, refractive indices, and birefringence) to the particles of hydrous and anhydrous iron oxide particles...."; gone is any mention of pleochroism, crystallinity, refractive indices, and birefringence.

In short, McCrone made a large mistake in saying 'blood' particles possess certain crystalline characteristics when in fact they do not, thereby contributing to his misidentification of 'blood' as iron-oxide.

We turn now to a discussion of the unusually red color of the 'blood.' In a 26 December 1978 lab notebook entry, McCrone wrote that the 'blood' seemed too red to be blood:

> Starting with 3-CB, a heavy ['blood'] image area, blood from lance wound--Using low magnification (10x and 10x obj.) I could see heavy encrustations (of blood?)--too red! I've never seen dried blood look like this. The sample we used for the Particle Atlas is spray dried but is yellow to black depending on thickness of the particles.[96]

The oddity of the red color of the 'blood' was noted as long ago as 1937 by Vignon. Vignon writes that during the three-week-long 1931 exhibition of the Shroud, he and others "saw the Shroud repeatedly in different conditions of light, for long periods at a time, and on several occasions were allowed to handle it."[97] After discussing the major blood flows, Vignon states, "But the color of all this blood raises a new problem. It is a sort of dull carmine, whereas very old blood becomes brown. Here, then, is another riddle, but not an objection."[98] Vignon failed to explain why the redness is not, as McCrone believes to be the case, an objection to the claim that the 'blood' is blood.

Adler and others answer Vignon's question and McCrone's objection in the following manner. For one thing, not all the 'blood' material is red, for its color ranges from yellow to orange to red to brown. Also, the 'blood' is not whole blood, but exudate from a blood clot (when a blood clot dries, it contracts, exuding liquid blood material). The 'blood' moreover is blood clot exudate from a beaten, traumatized individual. A traumatic beating would destroy red blood cells, and the red cell debris would go to the liver, which in turn would take the debris's hemoglobin and convert it to the bile pigment bilirubin. Bilirubin levels in the blood would rapidly rise, meaning that should a cut form, the resulting blood clot's exudate will contain serum albumin (a protein found in blood serum), and that albumin will bring with it bilirubin. The clot exudate's hemoglobin oxidizes to become "methemoglobin," which is reddish-brown/ brown; this reddish-brown/ brown + the yellow-orange bilirubin = red. (Malaria can produce red cell destruction, but severe malaria cases are rare.)[99] Ancient DNA specialist Thomas Loy agrees with Adler's explanation for the seemingly too-red color of much of the 'blood,' himself having found 300,000 year-old blood with the same vivid red color.[100]

Following the Santa Barbara meeting, Heller and Adler moved from chemistry to physics, specifically, microspectrophotometry (mi-cro-

spec-tro-fuh-tah'-mu-tree). A spectrophotometer shines a range of wavelengths of light at a material, and determines which wavelengths made it through the material and with what intensities. A microspectrophotometer is simply a spectrophotometer altered for use on very small specimens.[101] When showing Yale University's Joseph Gall the slide, Heller said, "We're going to have to take the spectrum through glass, stickum, any miscellaneous dirt on the surface of the fibrils, the garnet-red stuff, and the linen fibril itself, not to mention the Mylar."[102] Gall thought they would be unable to see fine structure in the midst of that conglomeration, "fine structure" being the many little valleys and peaks that make up a molecule's "fingerprint" when its spectrum is plotted.[103] Regarding hemoglobin's various fingerprints, H&A note that there exists

> no specific spectrum for blood *per se*; what is seen depends on the chemical state of the hemoglobin (e.g., reduced, methemoglobin [which would be oxidized hemoglobin], denatured) and on its state of aggregation (e.g., film, crystal, solution).[104]

Heller and Gall were looking for the Soret band, which is extremely strong absorption at about four hundred ten nanometers wavelength because of the heme porphyrin.[105] In response to Gall's question about the absorption's specificity, Heller replied, "It's specific. There's nothing in nature which absorbs light at four hundred... ten nanometers that strongly. The porphyrins... should give a peak that looks like Mount Everest."[106]

Using a *Zeiss* microspectrophotometer, they began the readings of biltong at 700 nanometers, and initially went down in increments of 10 nanometers. Heller recalls that

> When we reached 450 nanometers, my pulse rate began to go up. Very unscientific. At 430 nanometers, we shortened the gap between readings to 5 nanometers. At 425, the peak was still climbing. At 420 and 415, it was still rising. The crucial reading was 410. If the graph peaked here and began to fall away, we were onto something big. If, however, it continued to rise, the experiment had fallen through and was useless. At 405, there seemed to be a flattening-out. My pulse was racing.
>
> "Calm down," I said to myself. "This is an experiment--nothing more, nothing less. The data are the data!" When we hit four hundred, the peak began to fall. At 395--more so. At 390, it was sharply down. "Oh, my God," I said aloud, "it really is blood!" The hair stood up on the nape of my neck. Exhilaration shot through me. This was *blood*, not iron oxide. I let out my breath with a huge whoosh, and Gall turned to me and smiled. "I guess we did it, John. Now, let's try a fibril."[107]

Following biltong, they found the Soret band on the fibril. Gall left to keep an appointment, and Heller "floated out" to his car: "'It's blood!' ran the refrain through my head. This is a project, not a boondoggle. It is an abso-bloody-lutely first-class, interesting project. My veins felt too full."

Upon returning to the New England Institute, Heller ran in and seized Adler. After the coordinates had been plotted on graph paper, Adler observed, "John, this is hemoglobin. It's the acid methemoglobin form, and it's denatured and very old." Heller "beamed" before noting, "But Al. We don't have the requisite fine structure," to which Adler replied, "Fine structure, my foot! Do you think this is the spectrum of sauteed artichoke hearts? Don't be ridiculous." Suggested Heller, "Let's check with at least two other top hemoglobin hotshots and see if they are as sure as we are. Pick anyone you want." Adler's choice gave the answer of old acid methemoglobin. They then spoke via speakerphone to Bruce Cameron, "whose double-doctorate is dedicated to hemoglobin in all its many forms," and upon receiving and plotting the numbers, Cameron said, "You both should know what it is. It's old acid methemoglobin. I don't know why you wanted to bother me with something you know as well as I do... Hey, wait a minute. Are you two idiots working on the Shroud of Turin?" At this point, Heller and Adler shook hands after smiling at each other.[108]

In their first Shroud paper, H&A state that the Shroud fibrils' spectra were "indicative" of "the spectrum of a fully oxidized denatured met-hemoglobin, i.e., a so-called perturbed acid met-hemoglobin"; such a spectrum is "thermodynamically... expected" considering the age of at-least 600 years. However, as previously noted, there was a lack of fine structure: "the high degree of scattering from these solid samples makes the visible band shape features less distinct and does produce peak shifts.... Therefore, this identification is much less positive than desired."[109] Heller must have returned to Yale, for H&A write that all the red fibrils

were tested, as well as controls from the Spanish linen.[110] The 'bloody' Shroud and Spanish linen control fibers "all... showed intense Soret (400-450-nm) absorption indicative of a regular porphyrinic material."[111] The finding of a Soret band for biltong found mention in the summary paper of Larry Schwalbe and Ray Rogers,[112] but neither of H&A's papers. For a living, Schwalbe performed nondestructive testing/ analysis at Los Alamos National Laboratory.[113]

Six months after Santa Barbara (i.e., around September 1979), a meeting was held in Los Alamos, at which time McCrone said the iron oxide he saw was a post-1800s iron-oxide.[114] The appearance of the "iron oxide" apparently changed, prompting McCrone to drop the post-1800s claim in February 1980, when he wrote,

> I thought at first that only a synthetic iron oxide, Jeweler's rouge, available only after about 1800, was present on the Shroud. However, I now see evidence for older forms of iron oxide, especially, natural iron oxide pigments that have been used for many hundreds of years; in fact, were used by Stone Age man in decorating cave walls many thousands of years ago.[115]

With the Santa Barbara and Los Alamos conferences behind them, John Jackson and Eric Jumper called for a third conference, this time at Colorado Springs sometime around Easter Sunday, 6 April 1980, to discuss the Shroud's chemistry. Since the schedule of McCrone made a particular spring break week inconvenient, the rest of the group altered plans for a meeting the following week. Jumper informed McCrone that anything needed would be available, including laboratories, and suggested that they discuss the respective findings and resolve any differences, or at least agree about the sources and bases of the disagreements. McCrone agreed with the concept of discussing differences face-to-face and was ready to appear at the meeting, yet on the opening day of the conference, Jumper informed the others that McCrone had just communicated that he was unable to attend.[116]

Heller introduced Adler, who suggested they do some chemistry, whereupon Jackson noted that they had right there the requisite facilities and the slides. That news pleasantly surprised Heller:

> "What!" I yelped. "We have slides?" "Oh, sure. Didn't I tell you? Eric [Jumper], Ray [Rogers], and I [Jackson] made a special trip to Chicago to McCrone's lab to get them back."[117]

Heller was "positively salivating." After assembling needed equipment, publications, and chemicals, they commenced working. When Jumper pointed to a particular *Zeiss* microscope and commented, "I have one of the slides from a blood area under there," Heller

> pounced on the microscope. "Wow!" I exclaimed. "We've got a whole jungle of stuff here. Good grief, there are microacres of what looks like blood." "Move over," rasped Adler. He looked. "If that isn't blood, I'll eat this microscope."[118]

Adler performed a hydrazine + formic acid test on Spanish linen blood, and obtained a positive result. Adler then tested a 'bloody' fibril via the hydrazine + formic acid method:

> ....Adler asked me [Heller] for a Shroud fibril covered with what we both believed to be blood. I picked one that had a huge amount of red coating compared to the 700-picogram amount we had had before. He put on the reagents. Out went the lights. On went the ultraviolet. The red fluorescence could be seen with the naked eye. "Great," cheered Larry Schwalbe. "Neat," said Jackson.[119]

During further testing that day, 'blood' fibrils continued to be positive for blood. When a 'blood' area was tested for protein, it was positive, as is to be expected of real blood, for as Heller notes, "blood is loaded with different types of protein, such as albumins and globulins."[120]

The next morning, Jackson made a comment about the lack of red particles on at-least a third of the body image fibers. Heller says he himself "had been looking at the red dots and blobs in image and nonimage fibrils, and, increasingly, they looked like blood." After fibers having red dots were collected, and their red dots harvested, Adler explained how the test would proceed: "I'm about to add hydrazine. If the red particle goes into solution, it's got to be blood protein. It can't be iron oxide." In response to Jumper's question of why iron oxide fails to dissolve in hydrazine, Heller responded with a question:

> "If you placed a horseshoe in a bowl of water, would it dissolve in five minutes?" "Of course not!" "That's your answer. Iron has a very low solubility."

When Adler added the hydrazine, the red particles started to dissolve:

> "And," crowed Al, "they're producing the typical hemochromagen color. This, lady and gentlemen, is *not* iron oxide; it is blood!"[121]

In short, on the basis of the conference's protein testing, hydrazine + formic acid testing, and hydrazine testing, there existed an amount of data adequate for forming a preliminary conclusion that the 'blood' was actual blood.[122]

Following the Colorado Springs conference, Heller and Adler did additional work to solidify the preliminary conclusion about the 'blood' using 22 sticky tapes, Jumper having placed tapes "in Adler's hands with the imperative 'Go do chemistry.'"[123] Adler agreed with Heller's desire to start over, as if they had not done any testing in Colorado.[124]

They started by investigating the specificity and sensitivity of various protein tests, including the ninhydrin, Amido black, Coomassie Brilliant Blue, Bromthymol Blue, Biuret-Lowry, Bromcresol Green, and fluorescamine tests, and the latter was found to be the most suitable.[125] H&A used fluorescamine on a Shroud 'serum' fibril-- "which should have been laden with blood proteins"-- put out the lights and turned on the UV light, and the "erstwhile honey-yellow fibrils glowed with a positive test like a bright green fluorescent beacon." They continued with one 'serum' fibril "after another from every sample that contained such fibrils."[126] Not just serum but also 'blood' fibrils and shards tested positive for protein: "Positive fluorescamine tests were obtained on both the red and golden yellow coated fibrils, on the shards, and on both the orange and brown globs."[127]

The "shards" were half-tubular, elongated 'blood' fragments that had resulted when dried 'blood' cracked off Shroud fibrils. Shards were tested not only for protein, but for blood as well during the post-Colorado testing. Write H&A, "If the shards are barely covered, i.e., microspotted with a film of hydrazine, they slowly dissolve and give a characteristic pink hemochromagen-like color."[128] Not just the shards, but also the 'bloody' fibrils produced such results.[129] In sharp contrast to Heller's account of Colorado and H&A's paper's remarks, McCrone flatly says "*None* of the red image-area particles are soluble in hydrazine."[130] Other than possibly this remark, as far as I know McCrone does not mention actually applying hydrazine to Shroud particles.

Shroud skeptics Joe Nickell, John Fischer, and Marvin Mueller disagree with the validity of H&A's blood testing. After studying art and teaching English at the University of Kentucky, debunker of the paranormal Joe Nickell became a senior research fellow with the Committee for the Scientific Investigation of Claims of the Paranormal (CSICOP).[131] Forensic analyst John Fischer works at a county sheriff office in Florida, has expertise in chemical analyses and developing spot tests, and has testified in court about blood tests. Affiliated with the Los Alamos National Laboratory, Marvin Mueller does work in experimental and theoretical physics.[132]

Fischer, writing with the assistance of Nickell and Mueller, alleges that they found that hydrazine also dissolves "tempera paint composed of the pigments and medium identified by McCrone" and produces a pink hemochromagen-like color, thereby suggesting that H&A's hydrazine test is given to false positives.[133] I strongly suspect that the medium referred to is a proteinaceous tempera made from animal collagen (the sources being muscle, skin, tendons, bones, cartilage, etc.),[134] and that the pigments referred to are iron oxide, vermilion/ mercury-sulfide, and rose madder. Since McCrone believes he saw merely "a few particles" of rose madder pigment,[135] since he thinks that "nearly all of the colored particles on the [Shroud] tapes are red ochre,"[136] and since McCrone's writings give scant mention to rose madder, I fail to see the basis for Fisher et al.'s viewing rose madder as being somehow significant to discussions of what the 'blood' is. Parenthetically, the color "madder" was derived from the root of the field plant *Rubea tinctorum*; a chemical substance in the root called "alizarine" is responsible for the red color of madder.[137]

I could accept that hydrazine 'dissolves' collagen. On the grounds that hydrazine is a *base*[138] while iron oxide is only soluble in concentrated *acid*,[139] I reject the possibility that hydrazine dissolves iron oxide (Fe_2O_3), and the possibility that hydrazine dissolves iron oxide to produce a pink color. I have difficulty accepting the following possibilities: a) hydrazine dissolves collagen, producing a pink color, b) hydrazine dissolves vermilion (HgS), c) hydrazine dissolves vermilion, producing a pink color, d) hydrazine dissolves alizarine ($C_{14}H_8O_4$), and e) hydrazine dissolves alizarine, producing a pink color.

Note also that their data and claims in this regard have not been published in the peer-reviewed literature.

H&A executed the familiar hydrazine + formic acid test (which had been done on the slide having biltong, and in Colorado) on the new slides' "larger, redder orange globs," once again with positive results.[140] In a letter to or article in McCrone's magazine *The Microscope*, Fischer suggests that these were either false positives or perhaps positives for rose madder:

> Since many kinds of porphyrins are present in common plant and animal substances, even a fragment of a leaf, for example, could produce similar fluorescence. Most interesting in this regard is the fact that a trace of rose madder pigment (identified by McCrone)--bound in a matrix of a red-ochre collagen tempera paint--can give a similar result.[141]

By way of reply to Fischer, Adler counters that H&A's porphyrin fluorescence generating test "is a very sensitive and very specific test."[142] He continues by stating that the 'blood' material "did not fluoresce to begin with, so it is not a plant material such as chlorophyll, as some people have claimed."[143] I do not know whether Adler is saying 'so it is not plant materials similar in nature to chlorophyll,' or saying the more broad 'so it is not a plant material.' In the specific case of chlorophyll, while being a porphyrin (its central atom is an atom of magnesium) and while it does fluoresce, "its fluorescence does not have to be generated."[144] I suspect that in order to detect whether material to be tested fluoresces on its own, one would have to look at it in a darkened room, under UV light, and before application of the reagents, and suspect that by his statement that the 'blood' material "did not fluoresce to begin with," Adler was referring to the UV fluorescence results: the "Ultraviolet fluorescence photography of the Shroud of Turin" paper describes the 'blood' features in a table as "Highly absorbing. No color," and states, "Laboratory data for whole blood displayed total absorption, which is in agreement with the Shroud data."[145]

If Fischer et al. obtained a positive result with the hydrazine + formic acid test on a mix of root (or leaf) material + red-ochre tempera paint, and if that mix fails to fluoresce at the outset, it would be helpful were they to make that clear. As matters stand, their data and claims have not been published in the peer-reviewed literature.

If Fischer et al. generated fluorescence with root material using another test, then that result has no bearing on H&A's work. Should Fischer et al. have used another test, that test probably was one of the "usual forensic tests for blood" H&A wrote about as being given to false positives, while by way of contrast, H&A termed their hydrazine + formic acid test "a more specific test."[146] Forensic analyst Paul Kirk writes that the substances giving those usual tests difficulty appear in such things as horseradishes, radishes, grass as well as other green leaves, green onion bulbs, carrots, dandelion root, potatoes, and watermelons, among other places.[147] The rooty plants are reminiscent of the root from which rose madder is derived (just as "grass and other green leaves" is reminiscent of Fischer's talk of a leaf fragment).

Importantly, Kirk observes that the plant substances producing the false positives are "unstable and can be readily destroyed by heating or by complete drying," and another person notes that of the plants he studied (which Kirk lists), their false-positive-producing substances are readily destroyed by boiling, by drying, and on standing.[148] Since the Shroud's at-least 600 year-old age a) presents a long standing-time, and b) is more than adequate for complete drying of the 'blood' images, Kirk's observation means that any positives on Shroud 'blood' with the "usual forensic tests for blood" cannot be false-positives from plant material.

In short, if as appears likely, Fischer used on root (or leaf) material a test other than H&A's hydrazine + formic acid test, Fischer's test is irrelevant as a criticism of H&A's work, was probably less specific, was probably providing false positives with *fresh* root (or leaf), and in addition, those false positives probably would not have appeared had the root (or leaf) material been completely dried.

In addition to the hydrazine and hydrazine + formic acid tests, H&A performed a blood test involving a cyanide solution. With the addition of a neutralized cyanide solution to methemoglobin (which is brown), one gets "cyanmethemoglobin" (which is bright red).[149] Upon microspotting of the Shroud shards, "a characteristic cyanmethemoglobin type color slowly develops on the surface."[150] Not just the shards, but also the 'bloody' fibrils produced such

cyanmethemoglobin-like color results.[151] Fischer et al. respond by alleging that use of H&A's solution on tempera paint produces the same sort of color.[152]

In short, writing in not-peer-reviewed forums, Fischer et al. allege that H&A's hydrazine, hydrazine + formic acid, and neutralized cyanide tests are not specific for blood, and allege that false-positives involving paint could account for the results. By way of contrast, H&A write in their second peer-reviewed article that the positive results with the three tests "demonstrate, in our opinion, that the shards and red coated fibrils contain heme derivatives, thus corroborating our earlier [i.e. first paper's] results in concluding that the 'blood' marks were in fact composed of blood."[153] We turn now to H&A's azobilirubin and proteolytic enzyme testing.

Some shards had a greenish-brown/ olive color, indicating that "they might contain bile pigments" (e.g., bilirubin and biliverdin), which are "among the decay products of hemoglobin."[154] After microspotting with the test reagent, "characteristic blue azobilirubin colors could be positively detected in reflected light on the surfaces of the olive colored shards, the orange globs, and, also, weakly on the more orange colored red coated fibrils."[155] Addition of acid made the color become a paler purple that was discharged with 10 minutes of shortwave UV light, "giving still one more positive test for blood."[156]

Nickell et al. suggest that the two positive results for bilirubin were actually positive for something else. Specifically, Fisher, Nickell, and Mueller allege that in using H&A's azobilirubin test on a {Lombard gold + vermilion} + tempera mix, they "obtained similar results" to what H&A found.[157] Fischer and Nickell equate Lombard gold with fish-bile yellow, stating "Fish-bile yellow (known as 'Lombard gold') and yellows from saffron and walnut bark were extracted [by us], since yellows were often used in medieval times to 'warm' vermilion."[158] The reference cited shortly thereafter mentions neither Lombard gold nor fish-bile yellow, and I do not know what "fish-bile yellow" is.

We do learn from the source Fischer and Nickell referenced that the hues/ shades of 'warmed' vermilions have "an inclination to orange,"[159] information that finds corroboration in the everyday fact that red + yellow = orange. Regarding the suggestion that fish-bile yellow was added to a forger's 'blood' mix for painted application, it appears to me that the 'warming' of vermilion (which is red) with Lombard gold/ fish-bile yellow (which would seem to be yellow) would produce an orangey-red hue. However, when viewed from afar, the Shroud's 'blood' is red, and is not orangey-red (there are of course orange globs, and orange-red 'blood' fibrils). Should Nickell et al. come back with saying that perhaps the supposed forger mixed only a small amount of fish-bile yellow in with vermilion, the question for them would be, For what reason would an artist have added to vermilion so little an amount of yellow as to have an unnoticeable effect on the final color when viewed from afar?

Furthermore, it strikes me as being unlikely for an artist to have painted 'blood' with an orangey-red paint: it would make much more sense to paint 'blood' with a red pigment, say straight mercury-sulfide/ vermilion. Or as the 1400s book *The Craftsman's Handbook* advises in the section How to Paint Wounds, "To do, that is, to paint, a wounded man, or rather a wound, take straight vermilion; get it laid in wherever you want to do blood."[160]

H&A also did a another set of experiments that involved proteolytic enzymes, which attack and destroy proteins, and which are found in meat tenderizers.[161] A proteolytic enzyme solution totally "'dissolved'" in 30 minutes the "non-birefringent red particulate coated fibrils coatings, leaving no particulate residues."[162] H&A interpreted this dissolving as a "further indicat[ion] that these particulates are blood and not Fe_2O_3 impregnated protein binder."[163] Enzymes also dissolved the orange globs, the brown globs, and the shards.[164] Had the 'blood' material been some combination of iron-oxide particles or mercury-sulfide particles, all in a proteinaceous medium, the particles would have remained following the enzyme treatment. (Being "partially charred blood materials," the brown globs left their "small dark embedded particulates, probably carbonized material, as residue" following protease treatment.[165]) H&A additionally found that the proteases "had no effect on the birefringent red particulates coating fibrils,"[166] which would have been located at the water margins, a result that "further confirms that these birefringent red particulates are definitely different from those in the blood areas."[167]

In short, Nickell et al. state in a not-peer-reviewed forum that H&A's positive azobilirubin test could have been detecting an additive to paint, and do not have a response to H&A's work in which 'blood' material was 'dissolved' by proteolytic enzymes.

The reader may have noticed the repeated references to be absence of peer-review for Fisher et al.'s claims. Standards for publication in the scientific literature are much higher than for publication in books, magazines, college essays, etc., or as Heller succinctly puts it, "In science, anybody can say anything he wants to, but it is not until it is openly published in a respected scientific journal that it becomes official." Heller explains that to be published in a respected scientific journal, a process called peer-review must be gone through:

> There is a tough screening mechanism that is used universally by all major scientific journals. When an author submits a paper for publication, the editor sends copies to eminent scientists in the field. These scientific peers study the article closely. They evaluate whether the experimental methods and techniques are up to their own standards. The data and the conclusions are appraised, and even the bibliography is studied. The critiques of each of these peer reviewers are sent to the author, who must do whatever is required to conform to their suggestions. This may mean carrying out more experiments, trying different methods, setting up more rigorous statistical standards, and so on.[168]

Heller recalls that STURP had concluded at the outset that on account of the potentially disputatious nature of their work, all of STURP's papers "should be sent to the major journals so that the work could be critically vetted before publication."[169] Out of this awareness that "because of the nature of this entire project, sufficient was not good enough," and probably out of an awareness that its work "would be scrutinized hypercritically by any peer-review board," STURP established its own review group to scrutinize papers before there were sent to a scientific journal whose own reviewers "would have the last word."[170] In Heller's opinion, "STURP's reviewers were uncompromisingly and painfully tough and thorough," particularly Jumper, Schwalbe, Rogers, and two others.[171]

When McCrone submitted two papers for review, Heller says that "the reviews were, as always, rigorous, and they pulled no punches."[172] The first was submitted around December 1979, and the response dated 10 April 1980 was signed by Jumper.[173] The letter reads in part, "In short, your data is misrepresented, your observations are highly questionable, and your conclusions are pontifications rather than scientific logic; I cannot permit this paper to carry the Shroud of Turin Research Project's seal of approval."[174] The second paper received a "similar" response.[175]

Heller attributes McCrone's resignation from STURP to McCrone "feeling insulted" at the reception of the two papers.[176] One indication that McCrone had the capacity to be insulted to the point that he consequently resigned appears in this 1996 comment:

> I expected the world to agree with my conclusions [about the Shroud]. I've been spoiled. I'm used having everyone agree with me (sometimes even when I've been wrong). Now, to find out they don't believe me when I'm right is difficult to take.[177]

Perhaps so difficult to take that McCrone could no longer bear being a member of a group of individuals disagreeing "to a man"[178] with his conclusion that the Shroud body and 'blood' images are paintings. On the basis of the 'spoiled' remark, I could easily believe that McCrone was insulted at the comments on his two papers, and that the feeling of insult contributed to his move to resign.

McCrone certainly had the capacity to insult, for he wrote to Wilson, "Adler is an *ass* and you *may* quote me,"[179] and stated in his book, "The variance between their [the STURP scientists'] conclusions and the truth concerning the Shroud image is due to incompetence, deceit, or a combination of the two."[180] McCrone thinks deceit was a factor, and alleges that H&A fabricated positive wet-chemistry results for blood:

> Some evidence supporting authenticity was manufactured because they [STURP] were so certain the Shroud is authentic they felt confident in finding what would be there if the Shroud was authentic. In particular, there is no blood on the "Shroud" yet they reported positive forensic tests for blood.... Their [STURP's] publication of more than 30 pseudoscientific papers in a variety of learned scientific journals is also "sad and disturbing." The basis for sadness is obvious--the use of deceit to prove a falsehood.[181]

McCrone's "last effort to convince STURP was published in their February 1980 Newsletter," an effort that was also his "first, last, and only" contribution to the newsletter.[182]

A possibly additional factor in McCrone's resignation appears in his statement, "I had also been told by STURP that I'd never be able to publish my papers because one of them would be asked to review them by any Journal Editor."[183] McCrone's resignation occurred in June 1980,[184] and it would be useful to know when he was told his papers would not clear any peer-review panel: was it before or after his resignation? If before, then McCrone's being told they would never clear almost certainly contributed to his desire to resign. If it was after he resigned, then the 'this won't get published' conveyance could have been in the form 'These papers need serious work. You resigned from STURP and so cannot do additional testing on the slides, testing that is necessary to make your papers publishable. And without those experiments, we are not going to permit these papers to be published.'

Whatever the factors prompting resignation, McCrone notes that at the time, he served as editor of the McCrone Institute's *The Microscope*, and his two papers appeared there in 1980.[185] Heller observes that this "did not meet our standards of a major peer-reviewed journal," and accurately notes that "these two curious documents" lacked "mention of any of the results of the physical findings or of the presence of blood -- all of which had been published in the standard scientific literature -- except to dismiss them."[186]

Such was also the case with McCrone's third *Microscope* paper, where McCrone changed his paint claims once again to say that the 'blood' was liquid earthy iron-oxide paint and liquid mercury-sulfide (HgS) paint. We continue now our look at the iron oxide claim before proceeding to examine the mercury-sulfide claim.

Heller recalls that upon reading McCrone's third paper, Adler "was speechless." Upon finding his voice, Adler asked,

> "Say, isn't red ocher almost always impure?" I mulled it over. "Yes. It seems to me that it's always contaminated with manganese, nickel, cobalt, or aluminum." "That's how I remember it. Let's test the iron oxide for impurities. If all the iron on the Shroud comes either from the retting process or from blood, it should be pure; if it comes from ground deposits, as red ocher does, it should have at least one of those contaminants in it."[187]

Jumper, Adler, et al. add that the contaminants would be present "unless pure hematite crystals were employed by the artist, which, although possible, is highly unlikely."[188] Heller considered it "really gilding the lily yet again" to check for contaminants, "but considering the nature of the project, we [H&A] decided not only to gild but to platinum-plate it."[189]

By researching books, H&A found that contaminants ought be present above the level of 1 percent,[190] after which came the testing. H&A write that in using wet chemistry tests with approximately 50 birefringent red-coated fibers, most if not all of which would have come from the watermargins, they found that manganese, cobalt, nickel, and aluminum "could only be present at a level of less than 1%."[191] Hence, the watermargin iron oxide very likely was not an artist's iron oxide, 'very likely' because of the small possibility that an artist used pure hematite crystals to paint 'watermargins.'

Adler was "delighted" with the wet chemistry results.[192] Not delighted, Heller desired to be certain that the contaminants were not present, and so did a followup test on iron oxide particles from various tapes.[193] Heller used an electron microprobe, which operates in a manner similar to an X-ray fluorescence device, and that similarly identifies elements present in a sample. The iron oxide tested was "pure,"[194] yet testing of watermargin iron oxide does not really speak to McCrone's claim that artist's iron oxide resides in 'blood' areas.

H&A later did additional microprobe testing of a broader variety of samples, including 'blood.' The earthy iron oxide contaminants cobalt, manganese, and nickel again failed to appear, and mercury was only found in a so-called 'track' area:

> Using a Kevex ISI 100B Energy Dispersive Spectrometer [i.e., an electron microprobe], we have examined 16 different globs and fibrils from blood image, body image, and non-image tape samples. The fibrils all show strong calcium and iron signals [this would be from the retting]. The globs all show sodium, magnesium, aluminum, silicon, phosphorus, sulfur, chlorine, potassium, calcium, and iron. Some also show copper and zinc. Fibrils and globs from the cinnabar "track" area on [the lance wound 'blood' tape] 6BF also show mercury. Most importantly, there is no cobalt, manganese, or nickel detected anywhere and the mercury is only detectable in "track" samples. Similar results were

> obtained by J. Jackson and W. Ercoline in their SEM [scanning electron microscope] studies.[195]

Regarding the 'track' area and its accompanying particle, H&A identified it as cinnabar (HgS), out of which artists' vermilion is made:

> As I [Heller] was harvesting red dots, I suddenly saw one that.... was an unusual particle compared with what I had been looking at, and was obviously a crystal. I turned to Adler and said, "Look at this." We traded places. He said, "Do you know what this looks like?" "Yup. Cinnabar."[196]

Heller hastens to explain to readers that he does not profess to have the identify-on-site ability McCrone claims to have:

> I must not give the impression that I can look through a microscope and reach geochemical conclusions by eye. I cannot. It just so happened that some years ago I was an expert witness in a case involving two countries and some purportedly stolen treasures. The key datum in the resolution was cinnabar....[197]

Adler responded to Heller's cinnabar proclamation with "Right. Let's test it."[198] While Adler obtained reagents, Heller scrutinized the slide:

> The piece of cinnabar was enormous compared with what we had been working with. I could actually pick it up with a microforceps. .... It was shaped like a pyramid with a broad base. After having measured the base, I began to manipulate the optics, the light sources, and I finally convinced myself that I could see a track across a corner of the slide where the crystal had been dragged. There were extremely tiny fragments that had abraded off the base.[199]

Use of the reagents on the particle provided a "strong, positive test for mercury," which, combined with its "crystalline structure, proclaimed it to be cinnabar."[200]

Having found the particle and track, H&A commenced, "like the hounds after the hare," on a "complete and exhaustive search for additional samples. On that tape, and on all the rest [i.e., the other 21], there was not another one."[201] H&A write that they considered the particle and track "clearly an 'accidental' artifact" for the reason that "we have seen nothing like it on any other slides, nor have any other red particulates even from this same tape away from this track given a positive test for Hg [mercury]."[202]

Noteworthy is H&A's doing a chemical test and refusing to rely on simply appearance in identifying the particle, even though Heller possessed familiarity with cinnabar's appearance. Note also that while Heller says he "finally convinced myself that I could see a track" using the microscope, that perception of a track was confirmed by the microprobe testing, which found mercury in the 'track.'

The McCrone Associates electron optics group did microprobe testing of 11 particles from tape 3-CB, and even they fail to claim finding manganese, cobalt, or nickel.[203] McCrone Associates do claim finding via microprobe the elements sodium, magnesium, aluminum, silicon, phosphorus, sulfur, chlorine, potassium, calcium, iron, and copper (all of which H&A reported finding in 'blood' globs-- see above-- and all of which H&A note are "found in whole blood."[204]) H&A wryly observe that "it would be a most peculiar mineralogical assemblage that would provide these elements and not the expected iron earth pigment impurities, i.e. manganese, cobalt, and nickel."[205]

McCrone says that the potassium, chlorine, phosphorus, silicon, aluminum, and sodium are "expected contaminants in earth pigments like red iron oxide and represent minerals such as limestone..., feldspar and quartz."[206] He does not mention manganese, cobalt, and nickel as being expected earth pigment contaminants, does not account for the three contaminants' absence, and does not present an explanation for his data's claimed presence of calcium and magnesium.

Of the Turin Polytechnic, Giovanni Riggi was an Italian scientist that had worked alongside STURP members during the October 1978 data collection period.[207] Riggi used an electron microprobe on Shroud particles that he had vacuumed from the Shroud, and H&A write that Riggi too failed to find "the expected impurity signals for mineralogically derived material."[208] I do not know whether aluminum, which is present in blood, is included in this remark. By way of controls, Riggi examined with microprobe both Renaissance and modern 'Venetian

red' (which is an iron earth pigment), and found "strong peaks of our four contaminants."[209]

To reiterate, McCrone believes that his coworkers' microprobe data regarding iron and mercury's presence indicates that a "mixture of iron earth and vermilion pigments" were used to create the Shroud's 'blood.'[210] Having discussed the significance of iron earth contaminants' absence for the iron oxide claim, we turn now to the vermilion claim.

The McCrone Associates electron optics group is the same group that reported finding large quantities of titanium dioxide in the Vinland Map's ink, yet when the Map was comprehensively retested via a microprobe-like technique in circa-1987, the claimed high levels were not found,[211] casting doubt on the group's Shroud microprobe data.

Schwalbe and Rogers dismiss the vermilion allegation by noting that the X-ray fluorescence data "suggest that mercury is present nowhere in amounts greater than about 10 [micro]g/ cm^2."[212] In response to the X-ray fluorescence data's upper limitation on *iron oxide* concentration in the body image, McCrone replied that iron oxide in body image areas was below that upper limit yet still visible. In response to the upper limitation on *mercury* concentrations, because of the 'blood' areas' large quantity of particulate matter (in sharp contrast to the body image areas), McCrone would have a much more difficult time replying that mercury is below the mercury upper limit yet still present in 'blood' areas to a worthy-of-note degree.

McCrone observes about his microprobe figures that "the major peaks for mercury (Hg) and sulfur (S)... coincide."[213] Specifically, the biggest peak of mercury's X-ray energies appears at 2.19 kilo-electron volts, while sulfur's peak appears close by, at 2.31 kilo-electron volts,[214] and consequently, given the horizontal scale of the patterns McCrone provides, it is impossible to determine whether the peaks McCrone labels "Hg/S" represent purely mercury, or purely sulfur, or both-- perhaps as a combination in the form of HgS. Thus, the numbers in the "Hg/S" column of McCrone's microprobe data table cannot be used to make a claim of detecting vermilion. For all we know, the "Hg/S" numbers are actually all from sulfur.

Should McCrone state that because of the closeness in mercury and sulfur's X-ray energies, the presence of both mercury and sulfur was detected in particle H via "wavelength dispersion using the electron microprobe" (whenever that test is), I would point out that this result does not say what the ratio of Hg to S is, nor does this particle H result mean that all the other particles' "Hg/S" peaks consist of both mercury and sulfur.

At this point, McCrone might point out that about half of the 11 microprobe patterns have little peaks to their far right that are labeled "Hg." However, he presents no control patterns for known vermilion and known {vermilion + iron oxide} particles. Nor is there any sign of a control run using blank filter paper so as to see what noise is being gotten; in contrast, the STURP X-ray fluorescence paper does: "we have included as Fig. 8(b) a spectrum taken from Whatman 42 filter paper. The purpose of this 'control run' was to help qualitatively identify spectral artifacts resulting from primary beam scatter."[215] Furthermore, McCrone's patterns presented[216] appear to have differing vertical scales: 9 of the 11 appear to have been scaled up or down-- by different counting times and/or by actual scaling-- so as to have their tallest peaks just barely fit in the respective boxes. This changing of scales, and the lack of control patterns, makes it impossible to determine whether the little "Hg" humps are indicative of mercury or something else entirely, say noise.

McCrone reveals being "embarrassed by the finding of vermilion by the McCrone Associates electron optics group" because he had not seen vermilion with his light microscope.[217] He looked again and, not surprisingly, began seeing what he believed to be vermilion that was "distinctively different from the submicron red ochre," the vermilion being "larger, elongated in shape, and about 1-2 x 5 microns [in size]."[218] Compare McCrone's 1980 statement that the Shroud's red particles were "identical" in shape and size to iron oxide particles.[219] Perhaps some of the Shroud particles change their shape and size from day to day.

Evidently the color also changes from one moment to the next: first the 'blood' particles are "identical" in color to iron oxide,[220] and then later McCrone thinks he sees the color of vermilion: "Many loose particle aggregates, picked from the blood-image tapes, show red particles different in shape and color from red ochre..., but characteristic of the artist's pigment, vermilion (HgS)."[221] Then again, maybe the color and shape of both vermilion

and iron-oxide are actually the same: "Both red iron earth pigments and vermilion are deep orange to red... and [have] no obvious shape differences."[222] I leave it to the reader to decide which, if any, of McCrone's conflicting statements about the size, shape, and color of iron-oxide, mercury-sulfide, and Shroud particles are worthy of acceptance. Regarding size and shape, it is interesting to note that Heller says microscopic quantities of 'blood' appeared in the form of dots, blobs, flakes, and shards, while McCrone merely speaks of dots and blobs.

McCrone reports that "one small area on the 3-CB tape showed orange-red crystals,"[223] on which he performed a microchemical test to obtain "a faint mercury mirror."[224] Considering McCrone's poor blood-testing and identify-on-site abilities, I put little stock in this mercury mirror result. I do note that McCrone says he used a "pure copper surface,"[225] and that that allegedly-pure copper surface was a *penny* (these often appear quite dirty to me) having many mercury mirrors from practice runs.

Should I grant for the sake of argument that the electron optics group did indeed find mercury in 8 of about 13 microscopic particles tested, and grant the mercury-mirror claim, that does not amount to granting that the 'blood' images are composed to a noteworthy degree of vermilion. For one thing, there would remain the question of how representative that sample of about 14 was. Because of this question, even Mueller does not consider McCrone's mercury claims conclusive: "A crucial issue here is how representative of the speck population is McCrone's sample....? More work needs to be done on this."[226]

Also, according to Heller, McCrone's claimed finding of 8 microscopic partly-vermilion particles was not "enough... to account for one painted drop of blood, let alone all the gore on the Shroud."[227] Such a vermilion finding is necessary, but not sufficient for calling the 'blood' image partly-vermilion paint. Heller explains that in the world of science, there is a difference between 'necessary' and 'sufficient' evidence. Before calling an image a painting, it is 'necessary' to show that colorant resides in the image. However, such a demonstration is not 'sufficient' evidence that the image in question is a painting. To show that an image consists of paint, one must show that there is paint in the right locations and of a sufficiently visible quantity.[228] A finding of mercury in 9 of about 14 minuscule particles is a far cry from meeting the of-a-sufficiently-visible-quantity requirement. In short, a finding of a few, invisible-to-the-naked-eye particles of paint does not a painting make, nor a Shroud 'blood' image.

Such is particularly the case considering that there exists a high probability that when "sanctifying" their copies of the Shroud, artists inadvertently transferred paint from their copies to the Shroud. To illustrate such sanctifying, a document accompanying an 1822 copy states that the copy "was presented that it should be sanctified by contact with the Most Holy Relic; and which cloth was, by our hands, laid upon the Most Holy Shroud so that the two were perfectly fitted together in every part."[229]

Conclusion

By its appearance under a microscope, the 'blood' appeared to be blood to Heller and Adler, who should know based on their familiarity with blood and a control blood preparation. Heller's insistence that testing would be relied upon and not merely identification-by-sight resulted in H&A conducting extensive, even exhaustive, testing of Shroud material. Through their testing, Heller and Adler obtained positive wet-chemistry test results for blood material, results that included the detection of heme porphyrin, hemochromagen, cyanmethemoglobin, and bile pigments. In addition, the 'blood' tested positive for protein, and proteolytic enzymes completely dissolved 'blood' material. H&A presented several physics-based measurements indicating that blood material resides on the Shroud, including X-ray fluorescence data revealing higher-than-elsewhere iron levels in 'blood' areas, and indicative microspectrophotometry spectra.

In sharp contrast to H&A's attitude toward the usefulness of microscopy vs. actual testing, McCrone believed that his own identification-by- sight was sufficient to accurately determine with confidence the identity of the objects viewed, while his testing of red particles for blood and his forwarding of samples to the McCrone Associates electron optics group came merely as an afterthought. In short, H&A's and McCrone's very different attitudes toward the microscope and toward physics- and chemistry- based testing greatly affected the course of their respective investigations.

Trained on, familiar with, and devoted to the polarized light microscope, McCrone was reluctant to do wet-chemistry testing and loathe to accept the peer-reviewed results of the 1978 physics-based testing. Such a phenomenon is a common occurrence

in the world of science, where people often prefer to continue using machines and techniques they are familiar with rather than adopt and use newer and better techniques and instruments. In contrast to McCrone, Heller showed a willingness to experiment with change when he a) used newer techniques, for example the porphyrin fluorescence test, which had been developed at the New England Institute, and b) developed with Adler new testing procedures when working with the original slide.

McCrone's desire to see to it that the microscope solve the question of the nature of the Shroud resulted in his (temporarily) restricting H&A to only seven 'bloody' fibers plus biltong, a restriction that affected Heller's efforts by prompting him to seek the assistance of Adler, and affected H&A's work by making their initial chemistry testing more difficult, making weaker their conclusion from chemistry experiments that actual blood resided on their initial tape, and making weaker their extrapolation from that tapes's chemistry results to the Shroud's 'blood' areas. McCrone's returning of the slides to STURP affected both his 'blood' testing and the testing of the electron optics group by making them have minute amounts of Shroud material to perform tests on, thereby making correspondingly weaker the extrapolations made based on the supposed results of that testing.

Heller's personality trait of dogged pursuit of solid answers to challenging questions resulted in a firmer conclusion that the 'blood' was blood than otherwise would have been the case. Adler's interest in porphyrins and fun projects helped him become involved in Shroud study, to which he contributed at the time and in the years since. McCrone's devotion to the microscope prevented him from taking into account peer-reviewed data from physics-based instruments and wet-chemistry testing contrary to his painting conclusions. McCrone's failure to respond in print to contrary peer-reviewed data and conclusions, and his allegation that H&A and STURP fabricated data, were presaged by the fact that both before and after resigning from STURP, McCrone exhibited marked reluctance to defend his claims before other STURP scientists.

McCrone appealed to microscope appearance when making the conflicting statements that the 'blood' had the appearance of post-1800s iron oxide, and the appearance of a form of iron oxide existing for tens of thousands of years, and still later, the appearance of iron-oxide and mercury-sulfide. His contradictory statements cast much doubt upon his claimed ability to identify on sight material seen through a microscope, and makes highly questionable his largely-microscope-based claim that the 'blood' is paint. Further casting doubt on McCrone's microscope claims is the fact that he attributed crystalline characteristics, including birefringence, to red Shroud particles based on examination of the particles *on* the Mylar sticky tape, which makes *anything* appear birefringent.

McCrone called "good forensic science" testing of 'blood' that had proceeded despite a failure to first solubilize the material, a failure that makes meaningless the 1973 negative results. McCrone reports testing red Shroud particles with negative results for blood, yet he himself failed to solubilize the material before proceeding with at least two of his tests, casting doubt on the validity of his other blood tests' negatives. In addition, it is unclear whether McCrone's testing for blood was performed upon 'blood,' burned-'blood' iron-oxide, watermargin iron-oxide, or some combination thereof. The McCrone Associates electron optics group's iron-oxide and mercury-sulfide claims have problems and were not confirmed by peer-reviewed electron microprobe and X-ray fluorescence testing.

This paper's conclusion that, contrary to McCrone's adamant claims, the 'blood' does not consist to a significant degree of pigment particles has implications for McCrone's other claims about the physical nature of the Shroud image. For instance, considering that McCrone was so wrong about the identity of red particles on 'blood' tapes, it would be well to approach with great caution his claimed identification of *body-image* red particles as iron-oxide. Caution could also be useful in approaching his claim that simply iron-oxide particles account for the body image, and his later (contrary) claim that age-yellowed liquid iron-oxide paint accounts for the body image.

The decision that STURP's papers ought be peer-reviewed helped ensure that the group's published work would be of high quality, and probably contributed to McCrone's resignation from STURP. Though not peer-reviewed, McCrone's claims helped push H&A to do additional testing, including microprobe and proteolytic enzyme testing. Writing in not-peer-reviewed venues, Fischer et al. allege that most of H&A's positive wet-chemistry test results could be false positives. More specifically, Fischer et al. implausibly allege that hydrazine dissolves iron

oxide, vermilion, and a root extract called alizarine to produce a pink hemochromagen-like color, allege that adding a neutralized cyanide solution to 'blood' produces a bright red cyanmethemoglobin-like color, and allege that H&A's positive hydrazine + formic acid test results can be obtained with paint even while almost certainly speaking of another, less-specific test. In short, there exists reason to doubt that if obtained, Fischer's positives were obtained using the same methods that H&A used. Fischer et al. also allege that H&A's detection of bilirubin could have resulted from an additive to paint, yet adding yellow to red tended to make vermilion orangey-red, even as from a distance, the Shroud 'blood' images are red. Fischer et al. do not have a response to H&A's work in which 'blood' material was 'dissolved' by proteolytic enzymes.

The conclusion that the 'blood' is actual blood concurs with and meshes with the consensus of medical community members that have studied the image that 1) the body image is anatomically and medically realistic to an extraordinary degree, and 2) production of the body and 'blood' images involved an actual human body. The red color of much of the 'blood,' the high bilirubin levels detected therein, and the body image lend strong support to the view that the 'blood' came from a beaten individual. In light of the foregoing, forging the Shroud would have required the use of a body beaten and crucified precisely after the manner of Jesus' crucifixion. Such a requirement makes more unlikely the possibility that an individual went to the trouble of forging the Shroud. In short, it is highly likely that the 'blood' on the Shroud of Turin is not paint and is blood. Though this conclusion does *not* mean the Shroud of Turin is authentic, it does mean that the Shroud is less likely to be a forgery.

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Notes

1. Polkinghorne (1989), 85.

2. The Bible, John 19:1-3, 17-18.

3. John 19:31.

4. Edwards et al., 1461.

5. John 19:33-4.

6. John 19:40, 20:6-7; Luke 23:53; Mark 15:46; Matthew 27:59.

7. Each mark has two parts, i.e. appears in the shape of a squeezed "V." See Bucklin, 36.

8. Not a circle of thorns, but a cap. See Heller (1983), 4; Bucklin, 38; Lavoie (1998), 104-11.

9. Murphy, 52; Barbet (1953), chapter "The Preliminary Sufferings"; Bucklin, 38.

10. Bucklin; Murphy, 57.

11. See, e.g., Schafersman, 41; McCrone (spring 1982), 36; McCrone (1981), 35.

12. Wilson (1998), 263.

13. Wilson (1998), 264, 266.

14. Cited in Wilson (1998), 266; Wilson (1998), 161, 266.

15. Cited in Wilson (1998), 270, Wilson's bracketing.

16. Cited in Wilson (1998), 268.

17. Wilson (1998), 272-3.

18. Cited in Wilson (1978), 230-1.

19. Meacham.

20. Humber (1977), 29-32; "Shroud chronology; Pia's discovery; Pray Manuscript" <http://www.deja.com/=dnc/threadmsg_md.xp?AN=703116016>.

21. Humber, 124; Fossati, "Remembrance."

22. Wilson (1998), 300.

23. Meacham; Bucklin, 37.

24. Wilson (1978), 84-5.

25. Wilson (1998), 309, 310; Damon et al.

26. Wilson (1998), 302.

27. McCrone (1996), 5-12.

28. Wilson (1978), 198-9; Heller (1983), 39-41; "The body image's encoding of 3-D information" <http://www.deja.com/=dnc/threadmsg_md.xp?AN=703116138>.

29. Murphy, 55.

30. Jumper et al., 456; Murphy, 65; Lavoie, 58-9; Heller (1983), 200.

31. Jumper et al., 451. Also, Schwalbe & Rogers, 11 (1982), Lavoie, 61.

32. Adler (1996), 223-8.

33. Heller & Adler (1980), 2743; Pellicori, 1916 (1980). See also Schwalbe & Rogers, 38-9.

34. Heller & Adler (1981), 90; Jumper et al., 461.

35. Miller & Pellicori (1981), 76, 79, 80, 81, 82, 83, 85; Schwalbe and Rogers, 39; Heller & Adler (1981), 96.

36. Jumper et al., 461-2. See also Heller (1983), 187-8, for a single test that was not published: cf. Heller (1983), 216 and Heller & Adler (1981), 92.

37. Heller & Adler (1981), 92.

38. Gove (1996), 52; Adler (1987), 58.

39. Heller & Adler (1981), 93; Heller (1983), 180; Adler (1987), 58.

40. Heller (1983), jacket, 9; Heller (1960), jacket, 41-2.

41. Heller (1960), 33, 51; 9-10, 12.

42. Culliton; Heller (1983), 5.

43. Heller (1983), 8-12.

44. Heller (1983), 20, 23.

45. Murphy, 60; Heller (1983), 25.

46. Heller (1983), 12-13.

47. Wilson (1998), 3, xi.

48. Wilson (1978), 58-9.

49. Cited in McCrone (1996), 11, who quotes from a translation.

50. Heller (1983), 13-14.

51. Heller & Adler (1980), 2743.

52. Nickell (1987), 128; Nickell (summer 1981), 29; Nickell (spring 1998), 49.

53. McCrone (1996), 12.

54. Kirk, 188.

55. McCrone (1996), 12; Kirk, 189, 190.

56. McCrone (1980), 122; McCrone (1996), 104.

57. Heller (1983), 83, 121-2.

58. Heller (1983), 120-1; Beck et al., 553, 555.

59. Heller (1983), 121.

60. Wilson (1998), 304; Schwalbe and Rogers, 11.

61. Murphy, 44, 64, 47.

62. Heller (1983), 121-2.

63. Heller (1983), 122-3.

64. Heller (1983), 124-5.

65. Heller (1983), 125.

66. Heller (1983), 125, 132.

67. Heller (1983), 126.

68. Heller (1983), 126-9.

69. Heller (1983), 129.

70. McCrone (1996), 116.

71. McCrone (1996), 117.

72. McCrone (1993), 4.

73. Heller (1983), 14, 130.

74. Heller (1983), 130.

75. Heller (1983), 130-1.

76. Heller (1983), 132.

77. Heller (1983), 132.

78. Heller & Adler (1981), 81.

79. Heller (1983), 132-3.

80. Heller (1983), 133.

81. Heller (1983), 133.

82. Heller (1983), 133-4.

83. Heller (1983), 134; Wilson (1998), 305.

84. Morris et al., 40; Murphy, 54.

85. Heller (1983), 136.

86. Morris et al., 46.

87. Morris et al., 46.

88. Morris et al., 46; McCrone (1996), 162.

89. McCrone & Skirius (1980), 107, 110.

90. *Merriam-Webster's*; Epstein, 58.

91. Heller (1983), 141, 177.

92. Heller & Adler (1981), 85.

93. Heller (1983), 177.

94. McCrone & Skirius (1980), 106.

95. McCrone (1996), 85.

96. McCrone (1996), 82.

97. Vignon, 162.

98. Vignon, 164.

99. Adler's comments in Case, 57-8; Adler (1987), 58-9; Jumper et al., 459.

100. Wilson (1998), 92.

101. *Merriam-Webster's*.

102. Heller (1983), 144.

103. Heller (1983), 144.

104. Heller & Adler (1980), 2742.

105. Heller (1983), 144.

106. Heller (1983), 144.

107. Heller (1983), 145-6.

108. Heller (1983), 147.

109. Heller & Adler (1980), 2743.

110. Heller & Adler (1980), 2742.

111. Heller & Adler (1980), 2742.

112. Schwalbe and Rogers, 37.

113. Murphy, 52, 54; Schwalbe and Rogers, 3.

114. Heller (1983), 148.

115. McCrone (1996), 114.

116. Heller (1983), 153-4.

117. Heller (1983), 156. Cf. McCrone (1996), 124.

118. Heller (1983), 157-8.

119. Heller (1983), 160.

120. Heller (1983), 163-4.

121. Heller (1983), 165, 164.

122. Heller (1983), 165.

123. Heller (1983), 166, 168.

124. Heller (1983), 181.

125. Heller (1983), 182; Heller & Adler (1981), 92.

126. Heller (1983), 182.

127. Heller & Adler (1981), 90.

128. Heller & Adler (1981), 89.

129. Heller & Adler (1981), 89.

130. McCrone (1996), 166.

131. Nickell (Jan/Feb 1978), 20; Nickell (1987), cover; Nickell (spring 1998), 48.

132. Nickell (1987), 3.

133. Nickell (1987), 160.

134. McCrone (1980), 122-3, 127.

135. McCrone & Skirius (1980), 111.

136. McCrone (1996), 85.

137. Thompson, 122; *Merriam-Webster's*.

138. *Merriam-Webster's*.

139. McCrone (1980), 127; Heller & Adler (1981), 92.

140. Heller & Adler (1981), 89.

141. Nickell (1987), 158. The first sentence has a reference to John F. Fischer, *The Microscope* (year 1981, vol 29), 69-70.

142. Adler (1987), 47.

143. Adler (1987), 57.

144. Adler (1987), 57; Beck et al., 227-8.

145. Miller and Pellicori, 84, 75. The serum halos did fluoresce.

146. Heller & Adler (1980), 2743.

147. Kirk, 186-7.

148. Kirk, 186, 187.

149. Fiori, 260-1.

150. Heller & Adler (1981), 89.

151. Heller & Adler (1981), 89.

152. Nickell (1987), 160.

153. Heller & Adler (1981), 89.

154. Heller (1983), 186; Heller & Adler (1981), 89.

155. Heller & Adler (1981), 89.

156. Heller (1983), 186; Heller & Adler (1981), 89.

157. Nickell (1987), 159.

158. Nickell (1987), 132.

159. Thompson, 108.

160. Cennini (1933), 95.

161. Heller (1983), 183.

162. Heller & Adler (1981), 91.

163. Heller & Adler (1981), 91.

164. Heller & Adler (1981), 91.

165. Heller & Adler (1981), 85, 89, 91.

166. Heller & Adler (1981), 91.

167. Heller & Adler (1981), 91.

168. Heller (1983), 167-8.

169. Heller (1983), 168.

170. Heller (1983), 183.

171. Heller (1983), 183.

172. Heller (1983), 184.

173. McCrone (1996), 151.

174. Cited in McCrone (1996), 151.

175. McCrone (1996), 151.

176. Heller (1983), 184.

177. McCrone (1996), 173.

178. Murphy, 55.

179. Cited in Wilson (1998), 82.

180. McCrone (1996), 169.

181. McCrone (1996), 321.

182. McCrone (1996), 173, 316.

183. Heller (1983), 151-2.

184. McCrone (1996), 151.

185. McCrone (1996), 152; 184.

186. Heller (1983), 184.

187. Heller (1983), 194.

188. Jumper et al., 465.

189. Heller (1983), 194.

190. Heller (1983), 194.

191. Heller & Adler (1981), 92.

192. Heller (1983), 195.

193. Heller (1983), 195.

194. Heller (1983), 196.

195. Heller & Adler (1981), 100. I have changed the chemical symbols into words.

196. Heller (1983), 191.

197. Heller (1983), 191-2.

198. Heller (1983), 192.

199. Heller (1983), 192.

200. Heller (1983), 192. Also, Heller & Adler (1981), 94.

201. Heller (1983), 193.

202. Heller & Adler (1981), 94.

203. McCrone (1981), 28.

204. McCrone (1981), 28; for copper, see labels in Figures 13, 14, 18, 20. Whole blood comment: Heller & Adler (1981), 100.

205. Heller & Adler (1981), 100. I have changed the chemical symbols into words.

206. McCrone (1981), 26.

207. Murphy, 51; Heller (1983), 111.

208. Heller & Adler (1981), 97.

209. Heller (1983), 196. See also Heller & Adler (1981), 97.

210. McCrone (1981), 26.

211. Cahill et al. McCrone replies in McCrone (1988).

212. Schwalbe and Rogers, 16.

213. McCrone (1996), 129.

214. McCrone (1981), 25.

215. Morris, 44.

216. McCrone (1981).

217. McCrone (1996), 136.

218. McCrone (1996), 136.

219. McCrone & Skirius (1980), 107-8.

220. McCrone & Skirius (1980), 107.

221. McCrone (1990). Figure 9 also appears on McCrone (1996), 145.

222. McCrone (1981), 27.

223. McCrone (1981), 35.

224. McCrone (1981), 35.

225. McCrone (1981), 35.

226. Mueller, 31.

227. Heller (1983), 194.

228. Heller (1983), 193; Heller & Adler (1981), 96-7.

229. Cited in Fossati (Sept 1984), 22. For more instances of sanctification, see also 9, 17, 18, 20; Fossati (Dec 1984), 23, 24, 29, 32, 36.