

Fig. 1: Shroud Image, frontal and dorsal, positive and negative.

IS THE IMAGE ON THE SHROUD DUE TO A PROCESS HERETOFORE UNKNOWN TO MODERN SCIENCE?

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Common sense is the deposit of prejudice laid down in the mind before the age of eighteen. Albert Einstein

I. Introduction

What impresses and challenges me the most about the Shroud image is its resistance against explanation. Attempts to explain it as an artistic creation or the result of a natural transfer process (Refs. 1-3), such as diffusion or direct contact, remain unconvincing. Included are my own attempts over the past fifteen years to understand the image structure in terms of such mechanisms (Ref. 4).

To put this problem in perspective, consider the following set of image characteristics which must be explained simultaneously by any successful theory of image formation:

1. The body image is well resolved; features as detailed as the lips can be discerned (Ref. 4; see Figure 1).
2. The body image penetrates into the cloth to a depth of no more than a few fibrils and is restricted to crowns of the threads. The body image fibrils are individually colored and the coloring does not follow the bends or crevices associated with the intersecting threads of the weave. In addition, there is no cementation of fibrils or added pigment responsible for the macroscopic image color (Refs. 1, 2, 4, 5).
3. The intensity of the frontal body image correlates globally with expected separation distances between an assumed body and enveloping cloth. This correlation is independent of implied body surface composition (e.g., skin, hair, etc.) (Ref. 4); see 3-D representation of Shroud image in Figure 2.
4. There are no obvious side images surrounding the frontal and dorsal body images, including the region between the two heads (Ref. 1); see also photograph of Shroud, Figure 1.

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Fig. 2: Representation of Shroud Image where image intensity is converted to relief. The reasonable three-dimensional appearance of this relief implies that image intensity on the Shroud correlates with cloth-body distance (Ref. 4).

5. The body image is due chemically to a molecular change of the cloth cellulose, in particular a conjugated carbonyl structure associated with dehydration (Refs. 1-3).
6. The red image stains are composed of blood and/or blood derived substances (Refs. 2, 3).
7. If the Shroud is draped naturally over a body shape lying in the supine position, the frontal body image aligns vertically over corresponding features on that body (Ref. 6).
8. The maximum intensities of the frontal and dorsal images are nearly equal (Ref. 1, 4); see Figure 1.

The list is not complete, but it does serve to illustrate the difficulty in explaining the production mechanism of the Shroud image. For example, artist hypotheses which involve direct eye/ brain/hand coordination to artificially create an image are inconsistent with Items 2, 3, 5, 6, and 7 in the list (Refs. 1-4, 6). Diffusion and radiation, defined as those processes which involve particle transfer via random walk or straight line propagation through space from a body to the enveloping Shroud, do not explain Items 1, 2, 4, 5, and 7 (for diffusion) and 1, 4, and 7 (for radiation) (Refs.

1, 4, 6). Direct Contact, defined as those processes which generate intensity only where cloth-body contact occurs, fail on Items 3, 4, 7, and 8 (Refs. 1, 4, 6, 7).

Conceptually, certain image characteristics seem to be in opposition to one another. For example, it is difficult to come up with a mechanism that transfers body surface information to an enveloping cloth in such a way that the resulting image is both resolved (Item 1) and has an intensity structure that correlates with cloth-body distance (Item 3). The problem is that most projective mechanisms (e.g., diffusion or radiation) tend to have body-to-cloth point spread functions that blur with distance.

Clearly, finding a satisfactory mechanism for the origin of the Shroud image has shown itself to be a complex and difficult problem. Perhaps the reason why a satisfactory hypothesis has not been found is not so much due to a lack of image characterization but to an *overcharacterization*. That is, we seem to have a situation where the set of observables is so restrictive that all hypotheses posed thus far must be excluded, or at least be considered highly questionable, often on the basis of multiple objections.

Therefore, perhaps the time has come to ask if we ought to start thinking about the Shroud in categories quite different from those that have been considered in the past. In particular, perhaps we need to be more flexible in our scientific approach and consider hypotheses that might not be found readily in conventional modern science, for it is conceivable that the Shroud image presents, if you will, some type of "new physics" that ultimately requires an extension or even revision of current concepts.

Some time ago, I decided to pursue such an approach to see where it might lead, having first spent many years trying to understand the Shroud image strictly in terms of conventional science (Refs. 2, 4). But given the apparent failure, or difficulty, of conventional transfer mechanisms to explain the image, I wondered if I could conceive of a principle by which the image might have been formed, even if such a principle contradicted current concepts of science. The result was a simple theory that I think accounts for the entire set of diverse image characteristics described above and, further, makes certain new predictions which could be tested during a future scientific examination of the Shroud. As will be seen, this theory clearly contains certain aspects which do not fall within categories of modern science, but nevertheless is scientifically well-posed and internally consistent. Finally, because this paper deals strictly with image formation, the conclusions contained herein are independent of the recent radiocarbon date and it is to be further noted that there is no attempt here to presuppose anything concerning the identity of the "Man of the Shroud". The hypothesis will be developed and argued strictly from considerations of image properties and no support will be derived from extraneous speculations.

II. Development of the Hypothesis

A. Critical Inferences concerning the Shroud Image

Let us now develop the hypothesis. It is useful to begin with three basic inferences concerning the image formation process which I think can be deduced from observations made directly from the Shroud image. These inferences, when considered collectively, lead naturally, if not compellingly, to the hypothesis proposed in this paper. This hypothesis can then be tested against all image properties as per the Scientific Method.

INFERENCE 1. The body and blood images were formed directly from a human body that was enveloped in the Shroud. This assumption certainly is the implication of Items 3, 6, and 7 in the above list of image characteristics. In particular, the fact that in Item 3 image intensity can be described consistently between two complex surfaces, one corresponding to an anatomically reasonable body shape and the other to a cloth draping over that shape, by a *simple* and global mathematical relationship (Refs. 4, 6), is compelling evidence that a cloth-covered body was directly responsible for the image. This conclusion is further strengthened by various characteristics associated with the blood patterns. For example, the blood trickle off the dorsal foot aligns with a similar stain off the frontal foot when a volunteer subject is wrapped head to foot in a cloth model of the Shroud (Refs. 8, 9). In addition, Lavoie has shown that the bloodstain off the elbow was likely generated with the Shroud wrapped around a human arm (Ref. 7). In general, forensic opinion regards the blood patterns as representing authentic flows from a human corpse, owing to their flow characteristics and general appearance on the Shroud (Refs. 2, 3, 10-13). Even at the microscopic level, there is no evidence of pigment that can be associated at any statistical significance with the macroscopic body image (Refs. 1-3). As noted in Item 6, the alleged bloodstains are composed of blood or blood-derived substances (Refs. 1-3). It is difficult to see how these various image subtleties and characteristics of the Shroud could be the work of human craftsmanship. Hence, it is reasonable to conclude that the image on the Shroud was generated directly from a cloth-covered human body by some process (Ref. 9).

INFERENCE 2. Gravity was a significant factor in the production of the image. Once the above conclusion that the Shroud covered a body is granted, then certain questions may be asked concerning the image which would be meaningless if one were to assume that the Shroud had its origin, for example, in an artist's studio. One such question concerns the spatial position of image features on the Shroud relative to the corresponding anatomy of an underlying body. In Item 7, we noted that if the Shroud drapes over a body lying in a horizontal or supine position, image features align more or less vertically above the corresponding body part (Ref. 6). That this

should occur is not immediately obvious because it is conceivable that image features could have been mapped, for example, perpendicular to either the body or draping cloth surfaces rather than strictly vertical. The significance of this result is that whatever mechanism was involved in producing the Shroud image, it must have had the property of transferring body surface information in the vertical-only direction. But how could such a thing have happened? It would appear that, somehow, the image formation process must "know" the vertical direction at each point on the body. If the body was lying in a horizontal, supine position, then it is not unreasonable to suspect that gravity, because it naturally manifests a vertical symmetry, was responsible for the observed near-vertical alignment of image features with respect to associated body features. Without further information, it is not clear how gravity could have achieved is, but I am proposing its involvement in the image formation process because (1) it possesses the required symmetry to account for the vertical alignment observed in the Shroud image, and (2) because gravity is a natural physical phenomenon that unarguably must have been present during the time of image formation.

INFERENCE 3. The Shroud was in two different draping configurations when the body and blood images were formed. Recently, Lavoie and Adler have identified a location on the Shroud where body image features and associated bloodstains are in significant misregister (Ref. 14). In particular, consider the bloodstains that appear in the hair regions along either side of the face. If we ignore the body image for a moment and ask where these bloodstains came from, we would find, by a simple draping experiment of a cloth over a face, that these bloodstains originated from the sides of the face. However, the sides of the face are visible in the body image and appear several centimeters *inside* the pattern denoted by the bloodstains. That is, the bloodstains and the locations where, according to the body image, they must have come from by direct contact do not coincide spatially on the Shroud. Therefore, if the body image and bloodstains were produced from the same body shape,* it follows that the Shroud must have been in *two* distinct draping configurations when the body image and bloodstains were generated. The initial draping configuration must have been the one by which the bloodstains were transferred (because an independent observation

* In a previous paper (Ref. 15), I pointed out several bloodstains that appear to have recorded impressions on the Shroud both by direct transfer of blood material *and* as a direct discoloration of the cloth, like the body image, for the *same* bloodclot feature. If this observation can be confirmed by direct examination, then this would show that the body image and bloodstains originated from the same body. That is, we would have an example where the Shroud image contains an "image" in degraded cellulose of a blood feature that also recorded its presence by normal contact transfer of blood material.

pertaining to halos around the blood indicates that blood preceded the body image discolorations onto the Shroud; Refs. 1, 2). As can be seen in Lavoie's experimental photographs and discussion (Ref. 14), this draping configuration corresponds to the way in which a cloth would drape naturally over a human face. Subsequently, when the body image was generated, the Shroud apparently deformed, for some reason, to a somewhat flatter draping configuration, the result of which laterally positioned the images of the sides of the face several centimeters inside the bloodstain pattern. These bloodstains now happen to be coincident with the hair images due to the geometrically induced shift of the bloodstains relative to the body image (note that the hair has nothing to do with the argument, other than being a convenient way to describe the position of the bloodstains in question). The above arguments leading to Inference 3 are described more fully in Appendix A.

B. Synthesis of Critical Inferences

The foregoing three statements concerning the Shroud image are logical inferences from certain empirical observations of image structure and layout. To my mind, their significance is not what they represent individually, but rather what they imply collectively. For I think a specific picture of the image formation process is indicated. The problem, as I see it, is now to construct an image formation hypothesis that unites these three inferences and then test that hypothesis against all specific observations pertaining to the Shroud image.

How to achieve such unification, however, is not immediately obvious, because, at first thought, Inferences 1-3 seem mutually contradictory. For example, according to the third inference, we apparently must require that the Shroud flattened or straightened subsequent to the time when the bloodstains were formed. This flattening must have been significant in order to account for the several centimeter misregister between the locations of the bloodstains appearing in the hair image and those of the sides of the face where the bloodstains must have originated. Now, the second inference proposes that gravity was involved in the image formation process. Since obviously something must have caused the flattening or straightening of the Shroud, and gravity must apparently be incorporated into the image formation mechanism, it is logical to propose that the flattening was due to gravity. However, when considering the first inference that the formation of the body image involved an underlying, real human body, we encounter a logical difficulty in that the body structure would prevent the cloth from flattening under its own weight.*

* German (Refs. 1, 4) proposed a mechanism that the Shroud, under its own weight, settled and conformed onto the underlying body structure, whereby the image was formed by direct contact and/or diffusion at close range.

Thus, it would appear as though the three inferences contain ideas that are not easy to reconcile. Yet, I think each one of them taken separately is a reasonable interpretation of certain documented characteristics of the Shroud image. If that is granted, then the problem still remains as to what hypothesis of image formation is consistent simultaneously with all three inferences. It might be tempting to discard the concept of a cloth being flattened by gravity because of the apparent contradiction that the body prevents the collapse. Nevertheless, it seems to me that the collapse idea is a reasonable and natural synthesis of the two very different ideas contained in Inferences 2 and 3. If we retain the proposition of a collapsing cloth, then it seems to me that we are left with only one alternative in order to unify all three inferences. We must assume that, according to Inference 1, the Shroud initially covered a body shape, but, for some reason, that body did not impede the collapse of the Shroud during the time of image formation.

Now, such a conclusion can be interpreted in two very different ways. On one hand, it might mean that the observational data or logic taken to arrive at this point are defective, for a violation of common sense appears to be required to reconcile the three inferences. On the other hand, it might mean that "common sense" or, more properly, currently accepted laws of physics, may be inadequate to explain the image on the Shroud.

In the remainder of this paper, I would like to develop the thesis that the second interpretation is correct; specifically, that in the case of the Shroud image, the cloth did collapse into and through the underlying body structure. As a physicist, I admit to having my own difficulties with this concept, but I also know that scientists must be ready to overturn even their most hallowed principles if observation warrants. The real test of any hypothesis is not so much the logic by which it was deduced, but its ability to explain observations, make predictions, and provide insight into how reality is constructed. And, let us keep in mind that, to date, no "conventional" hypothesis has been advanced which successfully explains the Shroud image. To this end, I would like to ask the reader to put aside, for the moment, any reservations he or she might have concerning the "unconventional" nature of this concept and consider it merely as a hypothesis to be evaluated critically using the well established principles of the Scientific Method.

Despite the problems in explaining equal contact intensities for the frontal and dorsal images (Item 8) (Refs. 1, 4), this mechanism would position the image of the sides of the face *at* or *outside* the bloodstains in the hair (in order for the cloth to conform to the face), rather than *inside* as reasoned by Lavoie and Adler (Ref. 14); that is, the German model in essence requires the cloth to become less flat than the initial draping configuration as opposed to Inference 3.

III. Comparison of Hypothesis with Shroud Characteristics

A. Points of Logic

Let us turn our discussion to the problem of comparing the hypothesis of a collapsing Shroud into a body with currently known image characteristics. However, before this is done, it is appropriate to discuss some points of logic. In proposing an "unorthodox" theory of image formation, we are tacitly assuming that there is a hidden side of nature which has heretofore not been observed or studied by modern science, but, for some reason, manifested itself when the Shroud image was formed. Of course, one could always posit that the image on the Shroud is due to a singular, unrepeatably process; perhaps it was. But that would remove the discussion from any possible scientific inquiry because science is predicated on the notion of empirical repeatability. Science should always be on the lookout for any observation that points to a phenomenon which is not accounted for by current theories. On the other hand, science should not be "too ready" to assume that a given observation signals an inadequacy of currently accepted scientific theory; every attempt should be made to first understand the observation in terms of currently accepted scientific principles. In the case of the Shroud image, we must continue to determine if it might be explained by a "conventional" process. Indeed, if this can be done, then any attempt to explain the image by some "unconventional" process, including the one described in the present paper, should recognize the logical priority of such a successful, "conventional" explanation.

But given the absence of an accepted "conventional" theory of image formation for the Shroud (Refs. 1-4), particularly in view of the widespread attention the Shroud has received in recent decades, I feel it is no longer inappropriate to venture a theory that falls in the "unconventional" category, as long as that theory explains all image characteristics and, in the appropriate limit, blends with familiar scientific principles and laws. In addition, the theory should have a certain predictive value in that it can account for, or predict, image characteristics which were not used specifically to define the hypothesis in the first place. Science does not look for mere phenomenological descriptions of observations.

B. Constraints on Parameters of Theory

With these caveats, let us consider the hypothesis of the present paper as a possible explanation of the Shroud image. In particular, I would like to use a subset of the image characteristics discussed at the beginning of this paper to define the parameters of the theory, and then show how the remainder of the characteristics in the list are predicted. Further, I would like to use the theory to make predictions of other image characteristics which can only be tested by another examination of the Shroud which specifically looks for them.

The concept of a cloth falling into the underlying body region and receiving an image, in essence, requires that two separate assumptions be made. First, we must assume that the body becomes mechanically "transparent" to its physical surroundings and, second, that a stimulus is generated that records the passage of the cloth through the body region onto the cloth as an image. With regard to the latter assumption, it is unclear in an *a priori* sense what to assume for the physical nature of the stimulus. However, we at least know that it was able to interact physically with cloth; otherwise, image discolorations would not have been formed. Because certain selective discolorations or almost "shadow-like" effects are reported to exist in the image discoloration at the fibril level (Item 2; i.e., image discolorations reside only on the crown of the threads and do not wrap around into the intervening weave structure: Refs. 1, 2, 5), it is reasonable to propose a stimulus that is radiative in character, and we will proceed on that basis.

In order to account for the high resolution of the body image (Item 1), we must require that the hypothetical radiation be highly absorbing in air. Otherwise, radiation emerging from closely spaced body features would overlap, resulting in a blurred image during the collapse process. The next issue to be decided is whether to assume if the hypothetical radiation is emitted only from the surface of the body or volumetrically from within. But in order to account for the observation that the contact intensities of the frontal and dorsal images are essentially equal (Item 8), it is clear that we cannot assume the body to be a surface-only radiator. For if it were, the passage of the cloth through the frontal body surface would halt the action of the stimulus on the cloth, whereas on the dorsal side the effect of the stimulus would continue to integrate since the cloth there does not pass through the body but merely remains in contact with the body surface. This would result in a marked difference in the contact intensities of the frontal and dorsal images, which is not observed. Hence, we can only assume that the hypothetical radiation is emitted volumetrically throughout the inside of the body region.

As far as the time scale for the hypothesized radiation/collapse event, we can at this point only make qualitative statements. On one hand, the time scale must not be too short; otherwise the presumed inrush of the surrounding air into the mechanically transparent body region (which logically must occur if the cloth can move into the body region) would overwhelm gravity in directing the collapse of the cloth and this would preclude the observed vertical symmetry from occurring in the Shroud image (Item 7). On the other hand, the time scale for the radiation event cannot be so long as to be operative well after the frontal half of the Shroud has passed through the upper body surface. Such a circumstance would, in essence, destroy the signal-to-noise ratio of the image by

creating a background discoloration that would "wash out" variations of image structure that correlate with body surface topography.

These constraints might seem somewhat contrived, but it should be noted that these are but after-the-fact considerations concerning an image that already exists and must be explained. Different characteristics and constraints would have been required if the Shroud image had different characteristics. Note that in the above development, there was no need to assume that the cloth and physical environment behaved according to any principle other than standard physics (i.e., cloth collapses under gravity, air hydrodynamically flows into the body region, cellulose is chemically modified by radiation, etc.), and the apparent "violation" of accepted physics is assumed to be associated only with the body itself.

Thus far, we have invoked image characteristics as defined in Items 1, 2, 7, and 8 to deduce the character of the collapse process and stimulus. The picture that results is that of a cloth-covered body that for some reason became mechanically transparent to its physical surroundings and, as it did so, emitted radiation from all points within and on the surface of the body. This radiation was highly absorbed in air. As the top part of the Shroud fell into the mechanically transparent body, the radiation began to interact with the cloth so as to produce a time integrated record of the cloth's passage through the body region. This time record is what is commonly referred to as the "body image". A diagram of this concept is shown and discussed in Appendix B.

C. Specific Predictions of Image Characteristics

Let us now show how this concept explains each of the image characteristics of the Shroud listed at the beginning of this paper. If we consider that Items 1, 2, 7, and 8 define the hypothesis, as discussed above, then we can consider that the remaining items in the list are independent tests of the hypothesis.

1. *High Resolution.* As various points on the Shroud intersect different topographical features on the body surface during the collapse process, radiation dose on the cloth begins to accumulate. Because the radiation is assumed to be strongly absorbed in air, radiation effects on the cloth cannot begin until virtual intersection with the body surface occurs. Thus, a one-to-one mapping between a given point on the body to a unique point on the cloth is achieved for all points on the Shroud, which is equivalent to stating that the image is well resolved. This effect is described in Appendix B.

2. *Superficial Penetration of Image.* Once the cloth enters the body region, radiation interacts with each cloth fibril throughout the bulk of the cloth from all directions. However, fibrils on both surfaces of the cloth receive a greater dose than those inside because they are unobstructed by adjacent fibrils. These fibrils would probably be highly absorbing to the radiation because the air, which is

less dense by nearly three orders of magnitude than cellulose, is assumed to be highly absorbing to account for image resolution. (See also discussion in Item 5 below pertaining to absorption in cellulose.) The net result is an exaggerated dose accumulation of the surface fibrils over those inside the cloth leading to a superficial body image. This argument is diagrammed and discussed in Appendix B. In addition, side shadowing by adjacent fibrils lying on the surface of the threads could lead to the observed selectivity of fibril coloration. A given surface fibril would brown (after normal aging; see Item 5 below) to a near asymptotic value depending upon the initial dose received, but the overall dose on a given fibril depends in part upon the degree of shadowing by neighboring surface fibrils. The greater the average dose in a given region of the cloth, the greater would be the relative number of fibrils that would overcome the effects of adjacent fibril shadowing and eventually brown with age. It might also be that different fibrils have different tolerances to browning for a given radiation dose, and this could also contribute to the observed selectivity of fibril browning. Finally, shadowing by the weave structure itself would prevent discolorations from wrapping around a given thread into the interstitial regions of the weave pattern (Refs. 1, 2, 5). An interesting study would be to correlate fibril browning at the microscopic level with degree of shadowing by neighboring fibrils and average image intensity in the given region of cloth.

3. *Correlation of Image Intensity with Cloth-Body Distance.* The initial draping configuration of the Shroud over a body establishes the initial cloth-body distances. If, then, the Shroud overlying the body falls into the body region, different points on the cloth will intersect the body surface at different times depending upon how far that point was originally away from the body. Thus, each cloth point will receive a radiation dose in proportion to the time that the point is inside the emitting body region. Since that time is inversely proportional to the initial cloth-body distance, it follows that the radiation dose, and hence image intensity, is likewise inversely proportional to the initial cloth-body distance. See also the discussion in Appendix B.

4. *Absence of Side Images.* As the cloth collapses into the body region, internal stresses within the cloth cause it to bulge away from the sides of the body and at the top of the head. Because the radiation is strongly absorbed in air, very little dose is accumulated in the side and upper head regions of the cloth and, hence, no image is visible there. See also Appendix B.

5. *Chemical Nature of the Image.* Electromagnetic radiation that is absorbed strongly in air consists of photons in the ultraviolet or soft x-ray region that are sufficiently energetic to photochemically modify cellulose (Ref. 16). Such photons are also strongly absorbed

in cellulose over fibril-like distances (Ref. 17). Experiments performed by the author have shown that subsequent aging in an oven of photosensitized (bleached) cloth by shortwave ultraviolet radiation produces a browned pattern like the Shroud body image composed of chemically altered cellulose. Thus, we imagine that radiation from the body initially photosensitized the body image onto the Shroud. This pattern would have appeared, if the radiation was ultraviolet, as a white (bleached) image on a less white cloth. With time, natural aging would have reversed the relative shading of the image to its presently observed state where it appears darker than the surrounding cloth (which also aged or darkened with time, but not as fast). This mechanism is consistent with (1) the observed lack of pyrolytic products expected from a high-temperature cellulose degradation (Refs. 2, 3) (in this case image browning occurs by natural aging at ambient temperatures over a long period of time) and (2) the absence of substances in the image areas that might have chemically browned the cloth (Refs. 1, 2, 3) (in this case image discoloration is set onto the cloth only by photolysis and subsequent aging). Direct chemical or spectroscopic testing of the Shroud would probably be required to determine if the image cellulose was modified by a radiation event similar to the kind envisioned here or by some other type of stimulus. Appendix C describes the effects of ultraviolet radiation on linen in more detail and compares laboratory studies with what is observed spectrally on the Shroud.

6. *Blood on the Shroud.* As the Shroud is initially draped over a body covered with blood, that blood is transferred naturally to the Shroud by direct contact.

7. *Vertical Alignment of Image and Associated Body Features.* As the Shroud collapses into the body region, each cloth point falls vertically downwards. Thus, relative to the initial draping configuration of the Shroud over the body, image features tend to align vertically over their corresponding body part. The only exception to this rule would be where tangential stresses in the cloth are sufficient to perturb the otherwise vertical motion. Such stresses would probably be significant mostly near the sides of the body image due to the flattening of the cloth and bulging away from the body as explained above. See Appendix B for diagram and discussion.

8. *Equivalence of Maximum Intensities of Frontal and Dorsal Images.* Image intensity is determined solely by contact time of the cloth with the body region. Thus, assuming the radiation event is operative on a time scale less than the time for the upper part of the Shroud to fall completely through the body region, as discussed above, it follows that the interaction times for cloth points, whether initially in contact with the frontal or dorsal surfaces of the body, are equal. Hence, the doses, or image intensities, at those

initial contact points should be equal. See Appendix B for diagram and discussion.

Thus, the hypothesis of the Shroud collapsing into a radiating body explains all the above characteristics of the Shroud image, something that other image formation hypotheses posed thus far fail to do.

D. Additional Predictions of the Theory

In addition, there are several other predictions of the theory which should be noted:

1. *Intensity Structure of the Frontal and Dorsal Images.* While the frontal image is predicted to be "three-dimensional", the dorsal image is predicted to be one of "direct contact". The reason for the difference is that the top part of the Shroud falls dynamically through the body region while the lower part remains statically in place. This means that image intensity should be generated on the lower part of the Shroud only where hard body contact with the cloth occurs, owing to the strong attenuation in air of the emitted radiation from the body. Although studies regarding the intensity structure of the dorsal image have been inconclusive (Ref. 4), it is the opinion of the author that certain anomalies in the dorsal image indicate that it manifests a direct contact-like character. As can be seen in Figure 3, perhaps the most obvious is at the base of the shoulders where image intensity abruptly *decreases* in spite of the fact that scourge marks, which imply close contact of the cloth with the body in order to be transferred, are continuous across the body image discontinuity. Experiments by the author show further that the shoulder region, where enhanced intensity occurs in the dorsal image, is a natural support, and therefore a hard contact region for a reclining human body. These empirically determined support regions are shown in Figure 4. There are other discontinuities in intensity in the dorsal image, such as around the buttocks region in Figure 3, which make the dorsal image appear as a mosaic of shading and dropout regions, consistent with the appearance of a direct contact image. A critical study should be made of the dorsal image to see whether or not it has a direct contact character as predicted by the collapse theory.

2. *Body and Blood Image Misregistrations.* In regions of the cloth which fell vertically downward, body and bloodstains should be in register. However, where the cloth is displaced laterally as well as vertically during the collapse, notably near the sides of the body, we could expect that the body and blood images should be in misregister. As discussed above, such appears to be the case for blood originating from the sides of the face but which have been shifted onto the hair images due, presumably, to a lateral movement

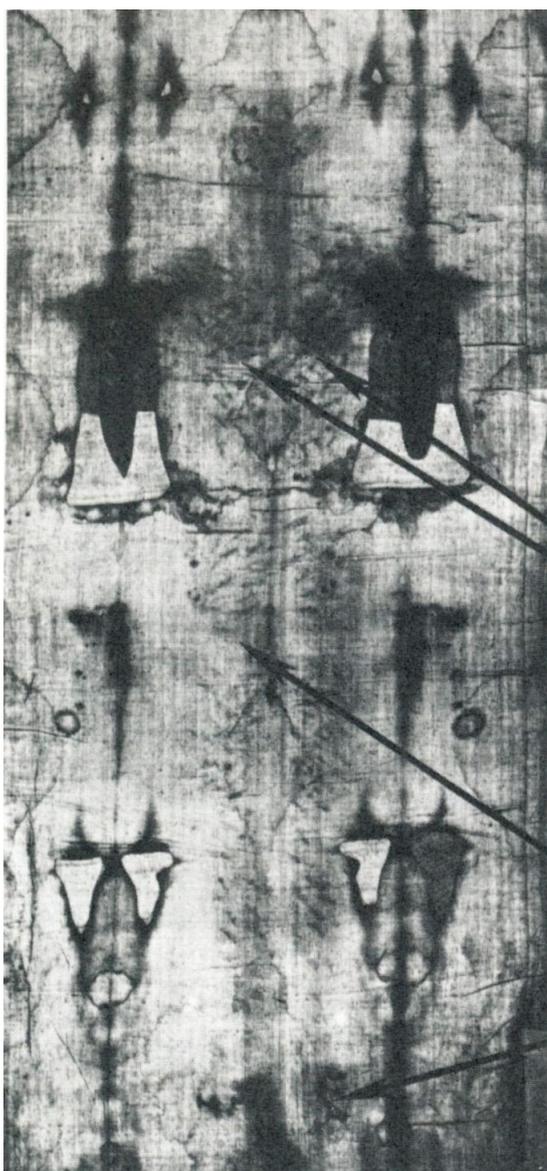


Fig. 3: Dorsal image of Shroud.

- A. Discontinuity in body image intensity. Note that scourge pattern runs continuously across the discontinuity, which implies that the cloth was in, or nearly in, contact with the body.
- B. Discontinuity drop-out in body image.
- C. Possible misregistration of blood and foot image.

of the cloth during the collapse. Another possible body/blood misregistration is at the dorsal foot where the body and blood imprints seem to be somewhat out of coincidence; see Figure 3. The Shroud image should be studied for possible misregistrations.

3. *Motion Blur*. Another effect associated with any lateral movement of the cloth during the hypothetical collapse event would be to induce a "motion blur" into the Shroud image. It is unclear if such effects occur on the frontal image because it is generally well resolved (Item 1); nevertheless, there are several candidates which should be considered:

- a. At approximately the location of the throat appears an image structure that is connected to the beard by an ill-defined series of streaks; see

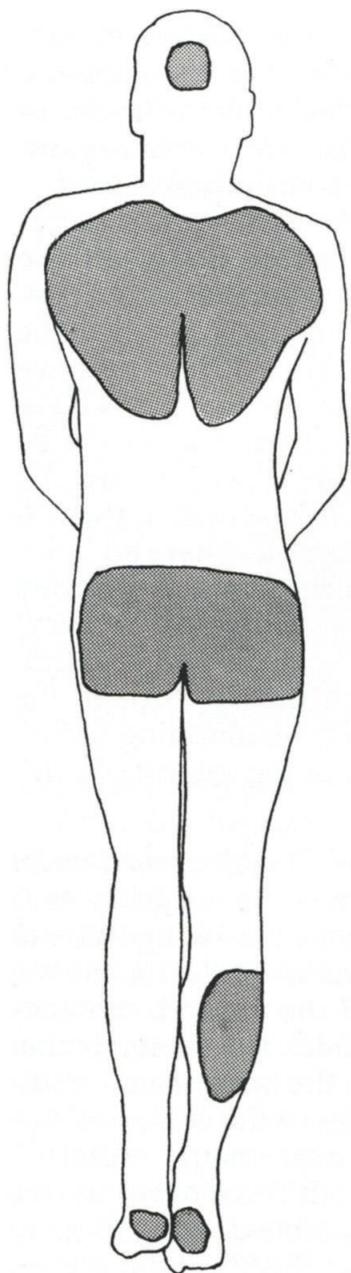


Fig. 4: Support regions of a human body on a perfectly flat surface. Compare with shading regions of dorsal image in Figure 3, keeping in mind that the support surface for Man of Shroud may not have been perfectly flat, and even somewhat contoured to the dorsal body.

Appendix A. This structure might have been generated by a lateral dragging of the cloth over the beard for a several centimeter distance during the postulated collapse of the Shroud.

- b. While the facial image is well resolved, the ankle region of the frontal image is not; see Figure 1. This might be explained on the basis of motion blur due to a complex wrapping of the foot region which in turn prevented a simple downward, vertical-only collapse of the cloth.
- c. The edges of the eye and cheek appear to "sweep" outward into the void between the face and hair with reduced intensity; see Appendix A. Since a misregistration of the body and bloodstains has apparently occurred in this region (Ref. 14), it is reasonable to ask if this image feature might be a motion blur effect associated with a lateral movement of the cloth during the postulated collapse.

4. *Possible Imaging of Internal Body Structures.* If the assumed radiation is homogeneously generated throughout the body region, then image intensity would be determined strictly by the length of time that a given part of the cloth is inside the body region. However, if the radiant emission varied with some physical parameter, such as initial mass density, then internal body structures might be convoluted into the general image picture along with the surface features of the body. However, the fact that the surface details of the body appear to dominate the image indicates that the assumed volumetric emission of radiation would have to have been nearly homogeneous. However, many researchers have noted the elongated fingers of the Man of the Shroud, as can be seen in Figure 1, and explained them in various ways (Refs. 16, 18, 19) including one by the author (Ref. 20). In the context of the collapse theory, the hand region might be an example where an internal body structure dominated the image which normally recorded body surface topography. In particular, the "elongated fingers" might actually be images of the internal bones of the hand extending into the palm region, which, as the cloth passed through the hand region, recorded a greater dose than the surrounding tissue. A similar suggestion was made by Carter but in the context of a different theory of image formation (Ref. 16).

5. *Surface Discolorations on Both Sides of the Shroud for the Frontal Image.* As noted above, the superficial nature of the image (Item 1) is explained by the theory. However, the above reasoning leads to one other prediction concerning the superficiality of the image; the frontal image should reside on *both* sides of the Shroud, whereas the dorsal image should reside on only *one* side. The reason is that when the upper part of the Shroud falls into the body region, radiation from the body impinges upon both sides of the cloth; see Appendix B. However, in the case of the dorsal image, radiation impinges from only one side because the cloth there never moves into the body. Unfortunately there are no suitable data available to test this prediction because the reverse side of the Shroud has been covered since 1534 with a backing cloth.* But if such a prediction could be confirmed by a future examination of the reverse side, then the theory proposed herein would be given considerable support. It is likely, however, that if a frontal image discoloration exists on the reverse surface of the Shroud, it would be somewhat

* Giovanni Riggi photographed the reverse surface of the Shroud in the area of the facial image during the investigation of 1978. This was accomplished by inserting an optical probe between the Shroud and backing cloth. In these photographs, there was no obvious facial image visible. However, the "three" blood mark on the forehead was barely visible and judging from the relative intensity of the body image and the "three" blood mark on the viewing side as seen in Figure A-1, it is likely that a body image on the reverse side, if one exists, is below the threshold of detectability in Riggi's photographs.

less intense than the discoloration which is observed on the normal viewing side because that side presumably entered the body first. However, one complication might exist; depending upon how the body was actually wrapped in the Shroud, it is possible that the sides of the cloth were folded back onto the top of the body, making a double layer with the top part of the cloth. It is unclear how such a folding configuration might affect the generation of a possible frontal image on the reverse side of the Shroud.

6. *Photochemical Modification of the Shroud Blood.* Given that the assumed radiation stimulus induced a chemical change in the cellulose of the Shroud, which we refer to generically as the "body image", it is reasonable to ask if certain chemical changes might also have been induced in the blood which remained attached to the Shroud during the hypothesized collapse. This possibility could be addressed by further direct chemical testing. In this context, I would like to note that the off-elbow bloodstain, discussed above, is a brown color, whereas the blood flow to which it is connected on the forearm is red, suggesting a possible chemical difference between on- and off-image bloodstains (Ref. 21).

IV. Final Remarks

Thus, the hypothesis of a collapsing cloth into a radiating body appears to explain all known characteristics of the Shroud image and makes certain testable predictions, some of which have yet to be verified. I have endeavored to show that this hypothesis arises strictly from considerations of specific image characteristics. The major problem with the hypothesis is, of course, to explain why a human body would behave in such a manner. It is beyond the scope of this paper to address this question and it is unclear how physics would have to be modified in order to accommodate the thesis presented here. But in spite of the unconventional nature of the hypothesis, I think there exist sufficient reasons to seriously consider it as per standard practices of the Scientific Method. I would hope, however, that it would not be rejected merely on the subjective grounds that it is "unconventional". As pointed out in the text, more studies and data are required in order to test the theory further.

It might be that a simple piece of cloth, known as the Shroud of Turin, represents a valid case for rethinking certain concepts of modern science. To this end, I would encourage my colleagues in science to realize that the image on the Shroud of Turin is far from being defined by one radiocarbon test, but could be one of history's greatest scientific puzzles.

APPENDIX A

Body and Blood Misregistration

Consider Figures A-1 and A-2, which show a photograph of the Shroud face and accompanying diagram. The diagram correlates various blood features with locations on the facial image where they originated according to the studies of Lavoie and Adler (Ref. 14). The proper interpretation of this diagram is that a given blood mark and corresponding point on the body image refer to the same point on the presumed body which gave rise to both. The fact that the blood feature and corresponding body image point do not occur at the same point on the Shroud means that the Shroud must have been in two *different* draping configurations when the blood and body image transfers occurred. The magnitude and direction of the displacement vectors in the diagram are a measure of the amount by which the two draping configurations differed.

In the diagram, we note that the blood and/or stains that occur at the top of the head appear to originate from an imaginary line, labeled A, which follows the contour of the hairline, labeled B. It is significant that the asymmetries in the hairline, B, appear to be "echoed" in Line A. This correlation argues that the blood and body images were generated from the same facial structure, or possibly that they were originally coincident before the hypothesized collapse.

Of additional note is the bloodflow labeled C in the diagram. In the Lavoie and Adler study, this bloodflow is repositioned over the forehead. This explains why this feature looks as though it has flowed over a hard surface (i.e., the forehead) rather than along strands of hair.

Finally, image feature labeled D shows where part of the body image appears to distort from the face. It is suggested in the text that this might be a "motion blur" effect associated with the proposed collapse.

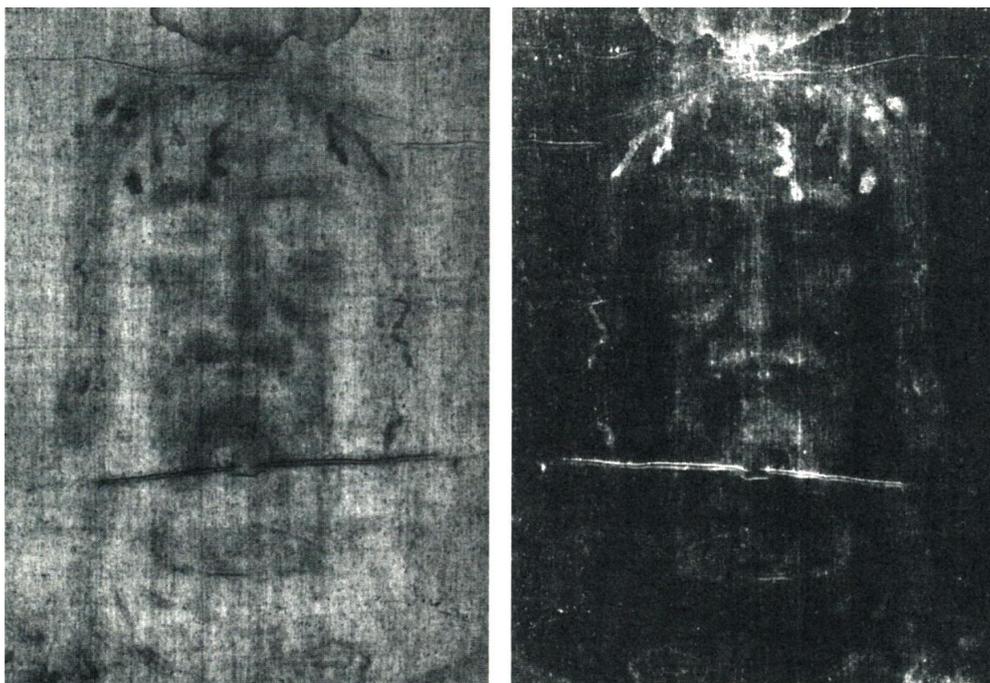


Fig. A-1: Shroud face.

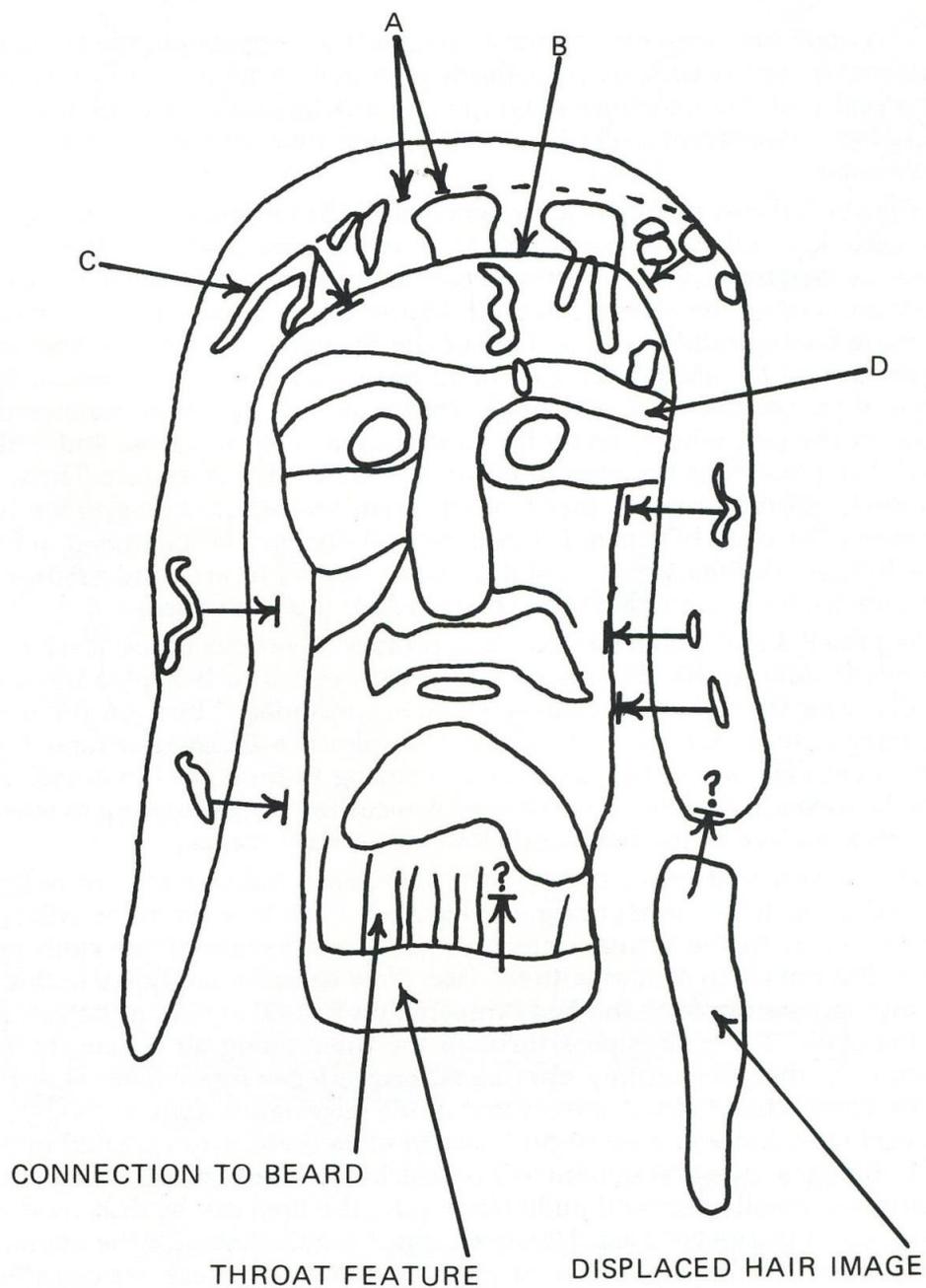


Fig. A-2: Diagram of Shroud face. Arrows show where blood features originated on the body surface according to Lavoie's study (Ref. 14). Arrows with question mark are my suggested displacements of image features due to hypothetical collapse. Line A designates a visible pattern in the top hair that appears to correlate with the hair/forehead line designated by B. Blood feature C is discussed in the text. Area D designates a region where the facial image appears to distort away from the face.

APPENDIX B

Diagram of Cloth Collapse Hypothesis

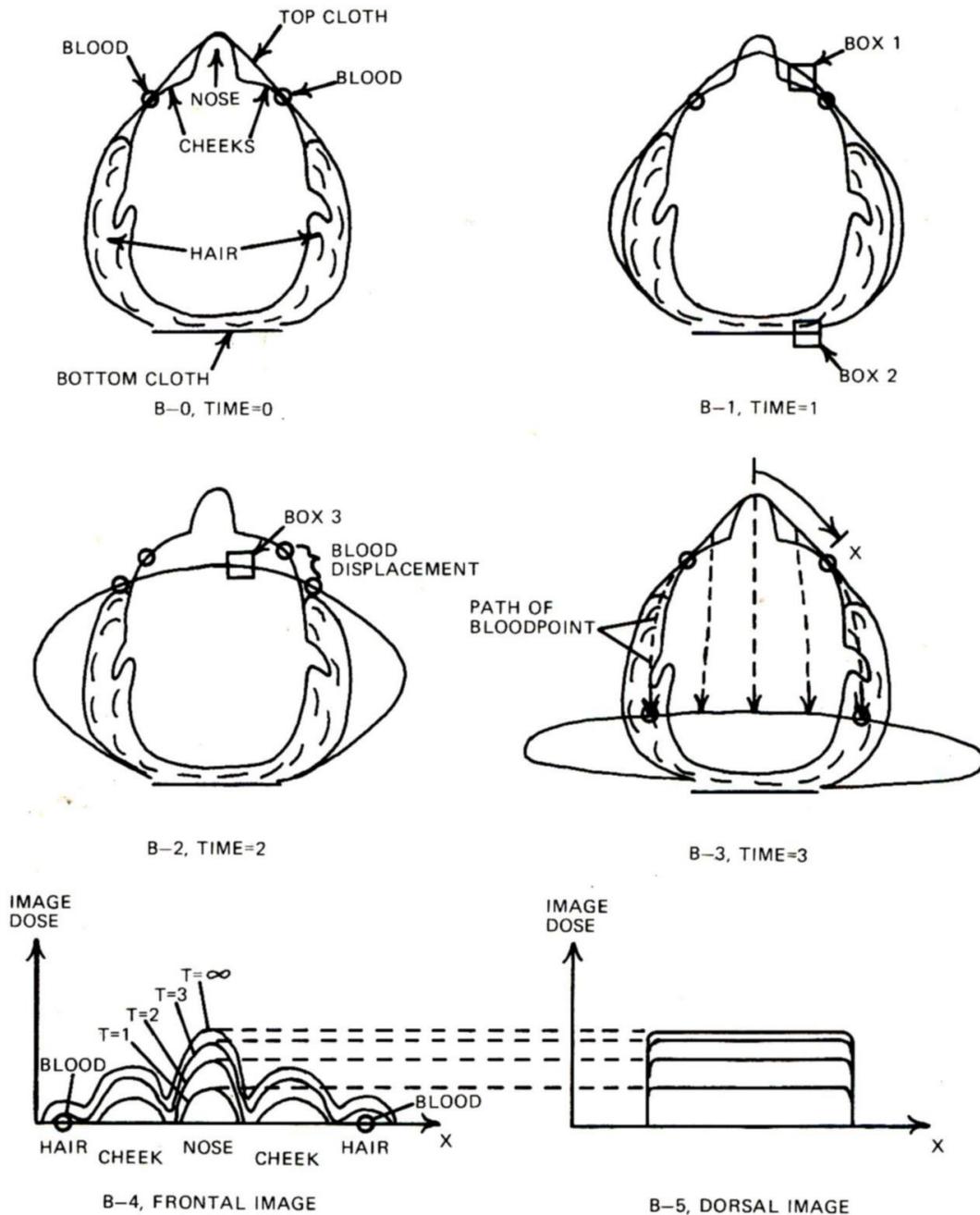
This appendix presents a series of diagrams to supplement the technical explanation of the collapse hypothesis provided in the text. It is to be understood that the following diagrams are strictly qualitative for the sole purpose of illustration and no quantitative information should be inferred from them.

Figures B-0 and B-3 show a sequence of cloth configurations during the hypothetical collapse process spaced at equal time intervals. The drawings correspond to a cross-sectional cut through the face at the level of the nose and across the cheeks and hair. Figure B-0 corresponds to the initial draping configuration at time $T = 0$ of the Shroud over the face and was derived from an actual CAT scan of an enshrouded subject to obtain this type of perspective. Of particular interest is that the cloth touches the sides of the face where, according to the arguments of Lavoie and Adler (Ref. 14), blood was transferred to the Shroud by direct contact. Then, as the body starts to become mechanically transparent, according to the hypothesis, the cloth begins to fall into the body region, as illustrated in Figure B-1. As this happens, radiation dose begins to accumulate on the Shroud where it has entered the body region (i.e., the nose).

Figures B-4 and B-5 depict the dose profiles at various times, $T = 0$ to 3, corresponding to the time snapshots of Figures B-1 to B-3, plus the final profile after the radiation/collapse event is concluded. Thus, for the frontal image, an initial "bump" in the dose plot can be seen at time $T = 1$ which corresponds to the nose image starting to form. In the dorsal image, however, a constant level of dose is recorded corresponding to where the back surface of the head and cloth are in hard contact.

The reason that other parts of the face (e.g., the cheeks) are not recorded at the time corresponding to Figure B-1 can be seen in the enlargement, Box 1. In the frontal depiction, we see a section of the cloth just above but not yet in contact with the face. Now consider, as shown in Box 1, all rays emanating from the body directed towards Point A on the surface of the cloth. These rays pass through the intervening air where, by assumption, they are rapidly attenuated and effectively do not reach the cloth. Only when Point A moves within the attenuation zone of the hypothetical radiation will dose begin to accumulate there. As explained in the text, this zone must be millimeters or less in thickness in order that body features as small as several millimeters (i.e., the lips) can be discerned on the basis of image contrast. However, since the thickness of the attenuation zone is small compared to the gross anatomy of the face, we can effectively assume that radiation dose does not accumulate until the cloth intersects the body surface.

Now, on the dorsal surface of the head at Point B in Box 2, located in Figure B-1, the body and cloth surfaces are in firm contact. Within the spherical hemisphere centered at Point B with radius equal to the attenuation length of radiation in the body, photons are emitted which, if oriented properly, will arrive at Point B and be absorbed. However, at Point C on the cloth, the situation is the same as for Point A in Box 1. Point C lies outside the attenuation zone for the radiation in air and, hence, no radiation dose accumulates there. Owing to the assumed thinness of the attenuation zone and the fact that the dorsal part of the cloth remains stationary



Figs. B-0 to B-5: Diagram of collapse hypothesis.

throughout the collapse event, the final variation in dose along the cloth from Points B to C will exhibit a near step discontinuity, making the dorsal image appear macroscopically as a direct contact image. That is, while the frontal image is a time record of the dose accumulation in the cloth during its passage through the body region, the dorsal image is a map of cloth-body contact for a fixed cloth-body configuration.

Returning now to the dynamically changing configuration of the top cloth at later times, as depicted in Figures B-2 and B-3, we see that the dose accumulations increase with time that a particular cloth point is inside the body region. At the contour corresponding to Figure B-3, at time $T = 3$, we can see the dose accumulations corresponding to the nose,

cheeks, and hair. Comparing this dose contour with the initial cloth-body distances at time $T = 0$ of Figure B-0, we can see that a correlation exists between the two variables.

The dose accumulations corresponding to times $T = 0$ to $T = 3$ also illustrate that, as the collapse progresses, radiant emission decreases in intensity. Thus, the difference in dose accumulations during equal time intervals decreases. As explained in the text, the reason for assuming that the radiant emission decreases with time is so that the variations in dose corresponding to body surface structure do not become overwhelmed by the average dose level which would otherwise increase without limit.

In Figure B-3, the trajectories of various cloth points are shown. For cloth points near the midline, the paths are essentially vertical, consistent with the vertical alignment characteristics of the Shroud image (Ref. 6). However, for points near the edges of the face, some horizontal movement occurs. This could result in a "motion blur" effect in regions where the cloth, in essence, skims over the body surface as, for example, for the bloodpoint feature indicated in Figure B-3. This movement repositions the bloodstain received from the side of the face over the hair image. Such an effect might explain Feature D in Figure A-2.

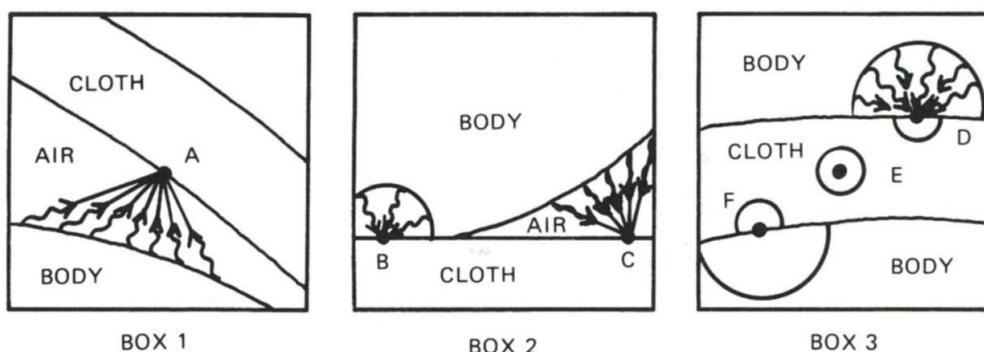
As can be seen in Figures B-1 through B-3, the cloth is pushed away from the sides of the body during the collapse. Owing to the very thin attenuation zone, essentially zero dose is recorded in the side regions of the cloth. This accounts for the absence of side images on the Shroud. Note, however, that blood transfer did occur by *initial* cloth-body contact at the sides of the body (e.g., blood flow off the elbow) (Ref. 7).

Finally, the enlargement diagram corresponding to the cloth segment in Figure B-2, Box 3, depicts the situation inside the body. Points D and F which reside on the surface of the cloth receive radiation along rays originating within the attenuation zone for radiation emitted from the surrounding body region. However, the interior Point E receives radiation from within a spherical attenuation zone made smaller by the presence of neighboring cloth material which absorbs the radiation. Thus, the resultant dose at Points D and F is greater relative to that at Point E, implying that the frontal image should reside on both surfaces of the Shroud, but essentially not inside. However, according to Box 2, radiation affects only the exposed (i.e., upper) surface of the Shroud in the dorsal image at contact (i.e., Point B). Hence, only an image on one side of the cloth is predicted to exist there, whereas, on the frontal image, discolorations should occur on both sides of the Shroud linen.

APPENDIX C

Discoloration Effects of Ultraviolet Radiation on Linen

As described in the text, ultraviolet radiation can be considered as a candidate for the "stimulus" which imprinted the image onto the Shroud linen. How and why it was generated is beyond the scope of this paper; however, it is postulated to account for the body image discolorations on the Shroud of Turin. This type of radiation is proposed primarily because it is a known radiation with several desirable characteristics to explain the image. For wavelengths in the "Vacuum" or "Extreme" Ultraviolet region (i.e., less than about 150 nanometers), this type of electromagnetic radiation is absorbed over millimeter distances (or less) in standard density air.



Boxes 1 to 3: Closeup diagram accompanying Figures B-1 and B-2.

Such absorption is necessary, in the context of the collapse hypothesis, to account for the several millimeter resolution of the Shroud image. In addition, the photon energies associated with this radiation are sufficient to cause (non-thermal) photochemical reactions in cellulose. Finally, such radiation is absorbed over fibril-like distances in cellulose, consistent with the observed discolorations of the Shroud's surface fibrils.

Discoloration effects of ultraviolet radiation on linen have been studied by the author. One experiment consisted of irradiating a linen sample, handwoven like the Shroud (by Kate Edgerton), with the 254 nanometer mercury line at approximately 1 milliwatt/cm² for five days. This corresponded to an accumulated dose of about 400 Joules/cm² or, equivalently, 5E20 photons/cm² (4.9 eV/photon). It is noted that, while this shortwave ultraviolet radiation does not lie specifically in the vacuum ultraviolet, its photon energies are sufficient to induce photochemical reactions in cellulose.

After illumination with ultraviolet, it was noted that the exposed area was bleached relative to the background cloth. When exposed to longwave ultraviolet radiation the bleached area also fluoresced more than the background. The cloth sample was then aged in an oven at 150°C for up to 18 hours. At various times the sample was removed and a reflectance spectrum recorded from 420 to 680 nanometers at 20 nm intervals (excluding 460 nm because of possible spectrometer problems). Spectra were recorded for both UV exposed and unexposed (background) areas. Visually, the bleached region discolored faster than the cloth background and took on a brownish color, similar to that of the Shroud image. The brownish color was restricted to the surface fibrils since they had been exposed to ultraviolet radiation which is absorbed over fibril to sub-fibril distances. By inference, according to Arrhenius extrapolations, the same phenomenon should occur at room temperature, but over a much longer time scale. Thus, if ultraviolet radiation photoimprinted the image onto the Shroud fabric, subsequent, natural aging would have reversed the initially bleached image into the brownish appearance it has today. During this reversal, there should have necessarily been periods when the image was not visible to the naked eye.

Figures C-1 and C-2 show the reflectance measurements for the background and UV exposed regions of the cloth sample during the oven bake, with corresponding curves for each sample taken at the same aging times. The initial reflectivity of the UV sample is greater than that of the

background which accounts for the observed "bleached" appearance. However, with time, the UV reflectivity "caught up" with and passed the background which also browned with time, but not as fast.

Figure C-3 represents the same experimental data in Pellicori's format (Ref. 22) where color ratio of the spectral curves (i.e., reflectivity at 680 nm to that at 440 nm) is plotted against mid-band color reflectivity (at 550 nm). From this representation we learn that the UV and background regions of the sample age along different color curves. Note that for a given mid-band reflectivity the UV discoloration is always somewhat redder than the cloth background. The reason for the slight redshift is due to the initial offset caused by the bleaching of the cloth by the ultraviolet dose which persisted throughout the aging experiment. Thus, once the aging experiment commenced, the UV and background regions tracked along nearly parallel paths in Pellicori's color space.

If this redshift phenomenon is generally characteristic for UV exposed cloth, then we might be able to test the hypothesis that ultraviolet radiation produced the Shroud image by plotting reflectivity measurements made directly from the Shroud in Pellicori's color space. To this end, we note that Pellicori's color plot of Figure 3 in Reference 22 suggests that the body image is slightly redder than corresponding light scorch regions of like mid-band reflectivity on the Shroud. This observation led Pellicori to speculate that the redshift might be due to a slight tint of blood (Ref. 22). However, in the context of the above UV experiment, it might be that the redshift in Pellicori's data is due rather to the color shift induced by ultraviolet radiation. Indeed, the bloodstains, also shown in Pellicori's Figure 3 plot (Ref. 22), are not sufficiently red to account for the redshift of the body image data points by blood tinting, as Pellicori suggests.

This impression is further strengthened if Gilberts' reflectivity data (Refs. 23, 24) are plotted according to Pellicori's color scheme. Like Pellicori's reflectivity measurements, the Gilberts' Shroud data (for the nose and calf) exhibit a noticeable redshift. Inasmuch as we are interested only in relative shifts of the body image from a thermally aged background (i.e., faint scorches), it should be permissible to apply a linear renormalization of the Pellicori and Gilbert data to align their Shroud scorch data with the experimental oven data corresponding to the unsensitized sample for comparison. Once this is accomplished, as seen in Figure C-3, the five Shroud body image data points (three in Pellicori, two in Gilbert) without exception exhibit a slight redshift relative to the background or unsensitized aging curve. In this regard, it is noteworthy that both the oven data and the renormalized Gilbert measurements for the 1532 scorches fall along a well defined line which indicates that the redshift of the body image data is probably significant.

In addition, certain comments recorded on-site in Turin during the 1978 examination in official expedition notebooks by various investigators corroborate the above reflectivity data. One investigator (author) did not see any redshift whereas others apparently did. Thus, if the body image is redshifted, the effect must be quite subtle as the reflectivity data suggest. In addition, I looked for and did not observe blood in the moustache region as Pellicori suggested (Ref. 22). The pertinent comments are as follows:

1. "Visually, under several light orientations, the body image color in the

face is indistinguishable from the flare area on either side of the face of the scorch from the 1532 fire." (J. Jackson, 12 Oct 78, entry #9)

- "Moustache just above mouth and parts of beard also have slight red tinge." (D. German and E. Jumper, 11 Oct 78, entry #3)

Note: These areas are among the most intense of the Shroud image and constitute one of Pellicori's data points in Figure C-3 (comment mine).

- "There does not appear to be any blood on moustache." (J. Jackson, 12 Oct 78, entry #7)

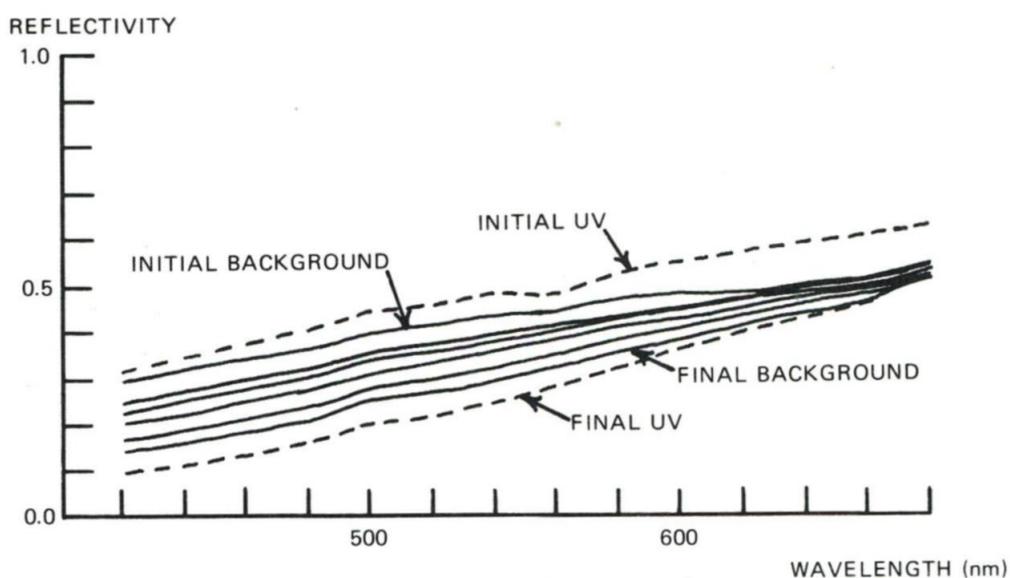


FIGURE C-1

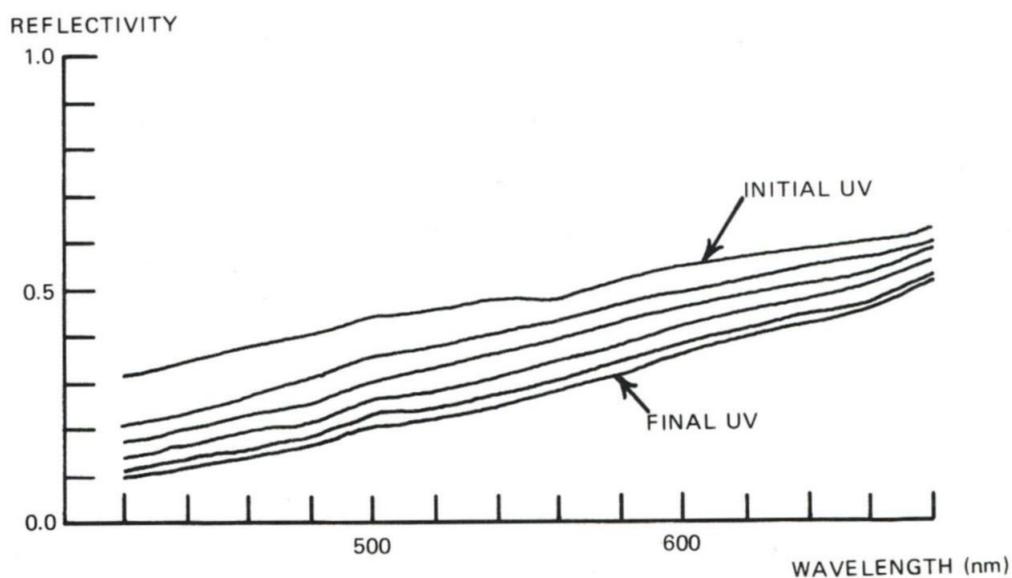


FIGURE C-2

Figs. C-1 and C-2: Absolute reflectivity versus wavelength for background control sample (C-1) and for UV presensitized sample (C-2). The six curves in each diagram correspond to the same times. The maximum and minimum curves for C-2 are drawn in C-1 for convenience.

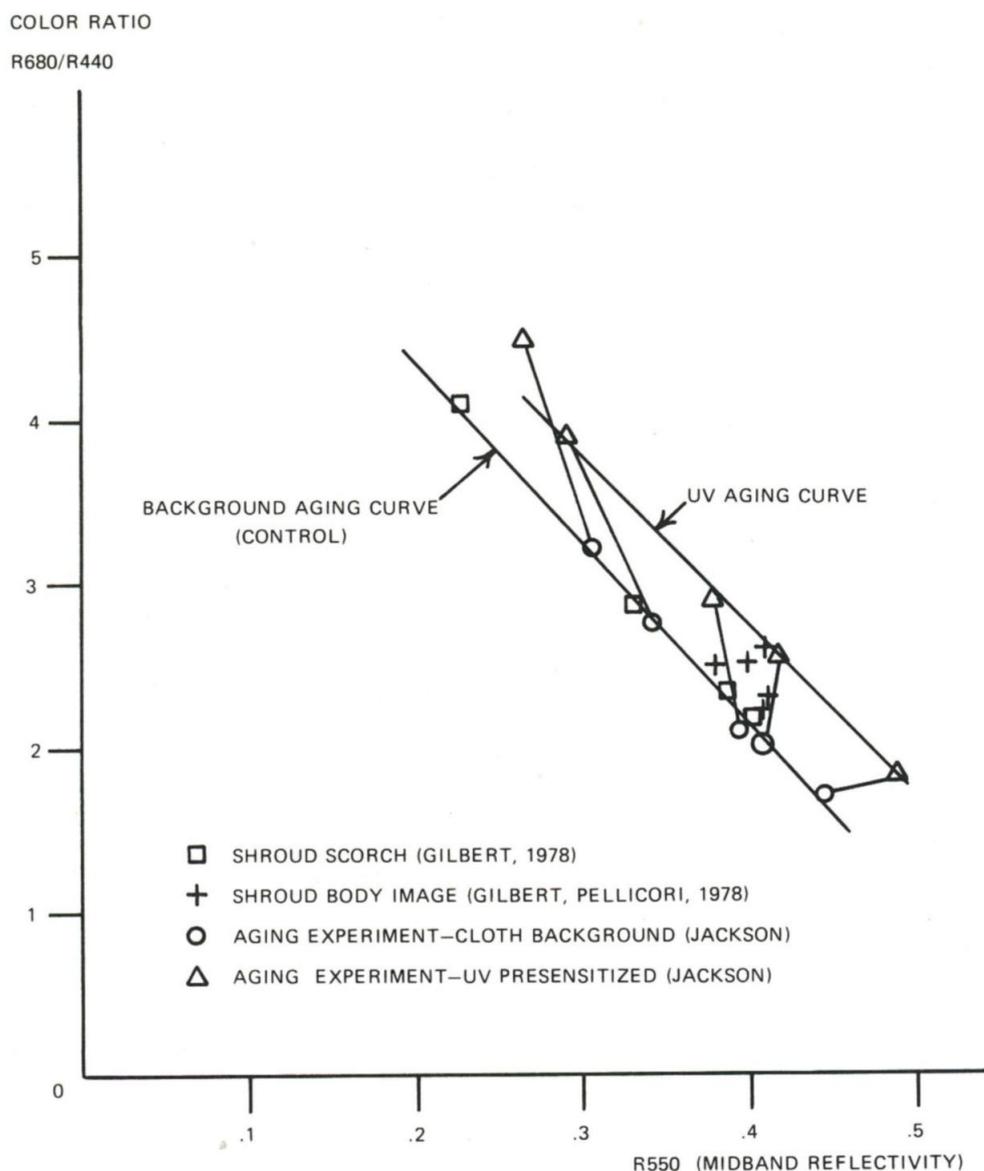


Fig. C-3: Color ratio (reflectivity at 680 nm to 440 nm) versus mid-band reflectivity (at 550 nm). Cross-lines connect experimental points corresponding to equal times. Note that UV sensitized sample moves along its color curve faster than the background cloth.

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