

The Image Formation Mechanism on the Shroud of Turin: A Solar Reflex Radiation Model (the Optical Aspect)*

by

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Summary. Unprejudiced logical analysis of the main available data, in the first instance of those collected in 1978 by the American interdisciplinary team known as STURP, suggests that the image of the dead man on the Shroud of Turin resulted from (a) the reflection by the anointed body of transmitted *solar rays* and their projection onto the inner side of the cloth, and (b) the chemical registration of this reflex image by the topmost fibers of the linen, probably with a water or oil solution of aloes and myrrh acting as catalyzer. This reflex radiation model requires the following: (1) action at the shortest possible distance (i. e. a maximum clinging of the Shroud to the body except for a narrow intervening liquid film) which explains the high resolution and the absence of serious distortions, and (2) double exposure — of both the face and the back — of the enveloped corpse to the Sun, which accounts for the presence and optical symmetry of both the frontal and the dorsal images. An attempt is also made to reinterpret the so-called three-dimensional information encoded in the image. Although some chemical issues are also mentioned and a historical reconstruction of the burial procedure is suggested, first and foremost the optical aspect of this mechanism is addressed here.

1. Introduction

The Shroud of Turin is a linen cloth, traditionally considered to be the burial sheet in which the body of Jesus Christ was wrapped and placed into the tomb. Its most prominent feature is the presence on it — apart from traces and remnants of real bloodstains — of visible discolorations showing the frontal and dorsal negative life-size images of a naked dead man with obvious signs of crucifixion, whipping and wounding.¹ It dates to at least the middle 14th century, and such indeed was the result of a radiocarbon testing performed in 1988 by three University laboratories — Arizona, Oxford, and Zurich, supervised by the British Museum — who reported a calibrated

calendar year of A.D. 1260-1390.ⁱⁱ Yet many scholars, medical experts, and scientists are presently challenging this result on historical, scientific, methodological, and deontological grounds.

Although positively documented only since 1357, the existence of the Shroud in much earlier times, particularly in Edessa (present day Urfa, Turkey) until 944 and in Constantinople (present day Istanbul, Turkey) from 944 to 1204 when this city was seized and plundered by the Crusaders, is confirmed by numerous indirect sources. Moreover a very plausible link has been found between its disappearance from Byzantium in 1204 and its reappearance 150 years later in France: the wife of its first known French owner, Geoffrey of Charny, was a direct descendant of Othon de la Roche (who died in 1224), one of the leaders of the sack of Constantinople and later Duke of Athens and Thebes.^{i,iii,iv}

According to many specialists, the carbon dating was flawed by a series of methodological errors: The samples were taken from a particularly dirty place, all other scientific evidence (historical, medical, etc.) were ignored,^v the possible influence of a fire that severely damaged the cloth at Chambéry in 1532^{vi} and of a patina (varnish) due to organic deposits by *Lichenothelia* fungi and *Rhodococcus* bacteria^{vii} were also ignored. There were also a number of infringements to the previously agreed to rules of procedure (e.g. reliable measurements were not taken; the samples were not weighed before their destruction; detailed records of the tests were not kept; no blind tests were performed; the tests were not performed simultaneously, as planned; the results were divulged to the media before their scientific publication, etc.).^{viii,ix}

Moreover, the 14th century dating poses many more problems to the historian and archaeologist than it solves since the outstanding knowledge of anatomy, forensic pathology, Roman crucifixion methods and so on displayed by the would-be medieval forger and his extraordinary skill in creating such a queer, and pointless, combination of real (positive) bloodstains^{x,11} with a negative picture, the realism of which would show up only 450 years later (in 1898) thanks to photography, defy rational explanation. Many of the very detailed and accurate results obtained in 1978 by the interdisciplinary American scientific team known as the Shroud of Turin Project (STURP) ^{xi} ^{xii} are also incompatible with the 1988 carbon dating.¹¹⁻¹⁸

In this paper we therefore assume that the traditional view and the combined evidence of the forensic, anatomic, physical, chemical, biochemical, historical, philological, and other research conducted from 1898 to the present day (except the carbon dating) are fundamentally correct, and we accept as plausible the conclusion that the Shroud *was* indeed the authentic burial cloth of the man later known as Jesus Christ. We also assume that the reader is familiar at least with the most important relevant scientific literature, particularly with Ref. 1, 11, 16, and ^{xix}.

Yet, although there has been much progress since 1898 and especially since 1978 in the scientific study of the Shroud, researchers, including the members of the STURP team, were unable to explain the mechanism by which the double image of Jesus was formed on the linen. “No technologically credible process has been postulated that satisfies all the characteristics of the existing image,” according to Schwalbe and Rogers^{12,cf.16} and all the other scientific conclusions regarding the history of the cloth and the medical and forensic authenticity of the wounds and bleedings it depicts as well. This is the problem we address here.

But, since it is a twofold problem with an optical aspect to it requiring practically no experimentation and very little argument and a photochemical aspect that on the contrary requires a great deal of further research and experimentation, we shall now focus almost exclusively on the former aspect and on the historical context.

We are not concerned here with the bloodstains, which, as already said, have been proved to be traces of real blood without direct relevance to the formation of the body images.^{10,11}

2. Problems

As usually assumed, “the general layout of the frontal and dorsal images can be interpreted as having been produced from a body enveloped between folded halves of the Shroud”.¹⁶ The corpse is perceived as having been laid on its back on the dorsal half of the cloth with the frontal half spread over the face, breast, arms, and legs.

The main problem arises from the contradiction, on each of the halves, between the complex character of the two surfaces involved, that of the body and that of the Shroud in which it was wrapped, and the high resolution, geometric correctness and anatomical accuracy of the corresponding image.

An additional problem is posed by the physical and optical similarity of the images on both halves of the Shroud, although the dorsal side of the body must have been gravitationally pressed to the cloth by its weight with an estimated average pressure of 26.8 g/cm^2 as against only 0.35 g/cm^2 for the pressure of the cloth on the contact areas of the frontal side of the body.^{12,16}

A third problem is that of the third dimension apparently encoded in the shading of the frontal image.^{16,20^{xx}}

Any image formation process involves three main factors: the source of the image (the object it represents), in this case the dead body; the transfer (or application) mechanism, in this case some kind of radiation, exhalation, or skin secretion; and the receptor of the image (the screen), in this case the inner side of the cloth of the Shroud.

Previous studies have shown that both images appear like rectilinear orthogonal projections of an unknown nature coming from the body and oriented in two opposite directions onto both halves of the Shroud such as would have been possible if the source of the image had had only two dimensions and been suspended between the flattened planes of both halves of the Shroud. Such a situation, which is scientifically untenable but helps us better understand the geometrical proportionality of the images, has been labeled *the vertical alignment* of the image and strongly speaks in favor of a radiational acting-at-distance transfer mechanism.^{xxi}

On the other hand, the high resolution of the images [at least as good as 0.5 cm (Refs. 11, 16) or even approaching 0.1 to 0.2 cm (Ref. 22)] suggests rather a contact mechanism of transfer. But in that case the way the Shroud must have been laid on the body seems to require the formation of lateral images on both sides and of an uninterrupted transition between the image of the face and that of the back of the head with all the distortions they involve.

The so-called tridimensionality implies a reverse correlation between the intensity of the shading and the estimated distance from the body, which indicates that only the darkest parts of the image could have been in direct contact with the body whereas other parts were acted upon at a distance.

Finally, note that the image itself was produced by some agent that left on the Shroud a superficial brownish degradation of the cellulose by oxidation, dehydration, and conjugation of the polysaccharide structure of the topmost microfibrils of the linen, changes that can be obtained by sulfuric acid or heat but usually at the expense of superficiality.¹²

Such are the main elements of the problem that led STURP to the conclusion that the image is “an ongoing mystery”.

3. Misleading Presuppositions

The contradictions just described — between vertical alignment and wrapping, full contact, partial contact and action-at-distance, the uniformity of both images, the gravitational asymmetry of the frontal and dorsal sides of the body, etc. — are the logical result of a number of tacit presuppositions none of which has been questioned so far.

Three are particularly important.

Presupposition 1. The images were produced by some chemical or radiant agent originating inside the body.

Presupposition 2. The images were formed while the body lay in the tomb.

Presupposition 3. Both images, the frontal and the dorsal, were produced simultaneously.

None of these presuppositions is substantiated by anything except the involuntary association of these images with the subsequent resurrection of Jesus, as described in the Gospels. In our opinion, resurrection is not a matter for scientific investigation, and the only assumption we are entitled to as scientists is that the images could be *either* a natural accidental byproduct of the burial procedure itself, not of the mysterious disappearance of the body, *or* a forgery (but, as stated, the hypotheses based on the latter assumption must cope with new problems and reject an important part of the available evidence).

Once we eliminate Presupposition 1, we no longer need to look for sources of energy, radiation, evaporation or whatnot inside the corpse of a dead man or try to understand how their pluridirectional diffusion or emission could have produced on a complex surface an image the optic quality of which requires either a focalizing lens or at least a beam of strictly parallel rays and a flat surface.

Once we eliminate Presupposition 2, we immediately identify the nature of those parallel rays. On a spring afternoon in the Middle East the whole atmosphere vibrates under the burning *rays of the Sun*. They could not have sprung out of the body, but they could very well have been *reflected* by it.

Eliminating Presupposition 3, we have solved once and for all the problem of alleged gravitational asymmetry between the frontal and the dorsal images. The rays of the Sun could not have reached the body on both sides at once, but nothing prevented the body from being turned over alternatively from front to back. And if so, there would have been no asymmetry.

Certainly this does not solve the main problem, and it even creates new ones, e.g., why both sides of the body were exposed to the Sun, but it clears up many sources of confusion.

Hence we have the following hypothesis. Both images were created by solar rays when and because the Shroud containing the body was exposed to the Sun, first face up, then face down (or the other way around). The rays were transmitted through the linen, reflected by the body and projected onto the inner side of the Shroud.

Could this lead to the formation and transfer of an image of the body onto the cloth such as what we have? This is the optical aspect of the problem. And if yes, how was this image imprinted on the linen? This is the photochemical aspect of the problem. Finally, what combination of circumstances could have created the unusual photochemical and optic conditions required to produce and record the image? This is the historical or, rather, philological (exegetical) aspect of the problem.

We answer the first question exhaustively in Section 4 (although without discussing in detail the concrete local effects on the accuracy of the image), suggest with others the most likely answer to the second question in Section 5, and try to reconstruct in Section 6, on the basis of the Gospels, the most probable sequence of events, acts, and motives that accidentally created the necessary and adequate conditions for the images to be produced and recorded on the linen.

4. Optics

The main optical scheme is fairly primitive. The bigger the distance between a screen and an uneven (distorting) mirror, between the cloth and the body, the more smudged and distorted is the *reflex image*, since the reflected rays, unless reflected by a plane surface, are no longer parallel. But if the linen *clings* to the body, i.e., if there is practically no distance between it and the cloth, no topographic distortion occurs even if the reflecting surface is far from being plane and perpendicular to the rays. This is one important point.

The second important point is the *floodlight effect* of parallel solar rays. Only reflecting surfaces appear on the image, and only those surfaces that are oriented towards the Sun *are* reflecting surfaces; only they can intercept and reflect the solar rays. This excludes the very possibility of (lateral) images appearing on the sides and the top (in the so called epicephalic zone) of the body on both the frontal and the dorsal reflexes (not to speak of images of the back appearing on the frontal reflex and of the front appearing on the dorsal). And this is the main cause of the apparent orthogonality of the images.

More popularly speaking, the combined effect of these two factors is to create on the inner side of the cloth, at a microscopic distance from them, an almost exact reflex replica of all the surfaces of the body shining under the transmitted parallel rays of the Sun.

The third point concerns the tridimensional effect. Insofar as this effect is real (we have neither VP-8 Image Analyzer at our disposal to check it, nor sufficient reason to doubt its reality, although the photographs of VP-8 images and of John Jackson's cardboard sculptural models published in various books and journals do not look fully convincing), it must, however, be illusory since, in our opinion, except for some local narrow depths and gaps where shading is absent (between hair and cheeks, under the eyebrows and around the eyes, between the legs, on both sides of the forearms), there must have been no distance at all between the body and the cloth. This is required, as we said, by high resolution.

Judging by Enrie's life-size negative photography (a positive image on a black background) and disregarding the (negative white) bloodstains on the tip of the nose, the mustache, and the beard, we can distinguish no more than three different definite levels of shading : *none* (background and places listed above: *n o c o n t a c t*); *medium* (transition between none and maximum: parts of the cheeks, upper lip, neck, lowest part of breasts, sides of abdomen, legs above the knees etc. (all these places have in common their declivity as compared with the horizontal plane, hence: *c o n t a c t m i n u s d e c l i v i t y*); and *maximum* (topmost relief of forehead, nose, cheeks, mustache, beard, breast, abdomen, forearms, knees etc. — and almost the entire dorsal image, etc.). (Hence there is *c o n t a c t o n r o u g h l y h o r i z o n t a l p l a n e s* — more exactly on planes *r o u g h l y p e r p e n d i c u l a r t o t h e s o l a r r a y s*.)

The attenuating effect of declivity is easily explained by (*a*) the angle of reflection and (1) the smaller amount (weaker intensity) entailed (compared with the orthogonal reflection) of the light it receives per unit of the surface, as well as (2) the lengthening (again compared with the orthogonal reflection) required of the — microscopic but no less real — path between the point of reflection and the point of impact on the Shroud, together with (*b*) the absorption effect of the transparent liquid medium through which it passes (on this medium, see below).

Now, in the case of three-dimensional bodies such as ours, declivity, and especially gradually increasing declivity, implies distancing from the local top horizontal (tangent) plane, and is thus cognate to distancing from a cloth touching the body on that plane. Since the local top horizontal planes do not coincide with one another (the top points of the body relief have varying heights) they create the illusion of a *top reference surface of tridimensionality* shaped as a cloth loosely draping over the body shape.¹⁶

The proposed scheme has the additional advantage of not requiring even a limited transparency of the Shroud. Simple translucency is quite sufficient, provided that the contact is the closest possible and that the inner side of the cloth is photosensitive. And the good translucency of the Shroud has been amply demonstrated by the photographs of STURP member Barrie Schwartz' in transmitted light (transmitted, moreover, through two fabrics: the Shroud and the backup Holland cloth sewn to it by nuns after the 1532 fire).

5. Chemistry (approaches)

We mentioned a liquid medium. This brings chemistry onto the scene. How could the cloth have been made photosensitive?

The answer is suggested by John, the author of the fourth Gospel, who reports the use of 100 Roman pounds (almost 33 kg) of a mixture of aloes and myrrh to bury Jesus according to the custom of the Jews (John 19.39), and by the modern Sicilian doctor of medicine Sebastiano Rodante, who conducted experiments on the properties of this mixture. One of Rodante's conclusions is: "Cloths soaked in a water or oil solution of aloes and myrrh, exposed to the action of solar rays, after 5 min take on a superficial color of brown sepia. The cloths do not become sensitized on the side opposite to the luminous source. The coloration becomes progressively more intense as the time of exposure is increased (15 min) and it always remains superficial. The cloths soaked in this solution and then dried, on the contrary, are not sensitive to solar rays even after prolonged exposure (60 min)."^{xxii}

Unfortunately Rodante says nothing of the nature and stability of this color and whether it is also the result of an oxidation and dehydration process of the cellulose of the fibrils. However, even earlier, STURP member Samuel Pellicori found it worthwhile to suggest in this journal, the "original presence [of aloes and myrrh] on or reaction with the linen in the context of serving as catalyzers or accelerators of darkening where contact was made."¹⁷

But in Rodante's view, solar rays helped only to fix later on the Shroud images formed on it earlier, in the tomb, by another mechanism (contact in the presence of aloes and myrrh moistened by bloody sweat), and more recently he paradoxically came to believe in a flash of solar light emitted by the resurrecting body.^{xxiv}

As to Pellicori, having obtained discolorations similar to those on the Shroud by baking samples thinly coated with skin secretions, myrrh, aloes, and olive oil, he worked out a *latent image* hypothesis, according to which the burial cloth was sensitized by absorbed materials transferred from the corpse by direct contact, and the latent image was developed in time by a gradual process of locally catalyzed cellulose degradation.^{12,17,xxv}

But neither explained the absence of lateral images and distortions.

The problem of the part played by aloes and myrrh as well as skin secretions in the process of *recording* the images thus deserves close consideration and further experimentation which, once completed, will be dealt with in a separate paper. Our sole purpose here is to show that an optically consistent explanation of the images is possible and to point to the direction in which future research could develop.

One aspect, however, can be dealt with briefly here. Since the Sun is not still, but moves across the sky, there obviously must have been some correlation between the time of exposure and the resolution of the image. The angular velocity of the Sun being 15° per hour and the body-Shroud distance in the areas of high resolution of the latter being at most, let us say, 1-2 mm, elementary trigonometric calculation shows that the position of the point of impact on the inner surface of the Shroud of a ray reflected by one and the same given point of the body will in 1 h move by 0.3-0.6 mm in the direction opposite to that of the Sun. Since according to Rodante, 5-15 min are quite sufficient for the rays to darken the linen, it seems that practically the resolution is limited by nothing except the weave of the fabric.

Yet one problem still deserves examination, even though it belongs rather to history and New Testament philology than to physics or chemistry: the purpose of the double exposure of the Shroud with the body in it under the sunshine. Following is a hypothesis that will be developed and argued in detail elsewhere.

6. Gospel Interpretation

Many commentators of the Gospels have noted that the burial of Jesus was hasty. Joseph and Nicodemus were short of time. Sabbath was nearing (Matthew 27.57; Mark 15.42; Luke 23.54). Jesus had died in the ninth hour, i.e. after 2 p.m. Sabbath was to begin at sunset, after the third star, i.e. shortly after 6 p.m., and thereafter all activity was forbidden for 24 h. Many things had to be done, from obtaining Pilate's permission to take the body off the cross to completion of the funeral rite. We may be sure that all that needed to be done *was* done — except the last item. Because at sunrise on the third day, which was the first day of the new week, women from Jesus's circle went to his tomb *to anoint him with spices* that they had prepared from Friday (Luke 23.56) or bought the same day, i.e. probably on the previous evening (Mark 16.1), or both.

Let us not forget three things.

First, that after 36 h it would have been necessary to tear the body from the Shroud, all the blood and clots having dried out and making it stick to the cloth.^{xxvi} But to anoint the body and complete the rite, it was necessary first to unwrap the corpse.

Second, that all this happened in the Middle East, on an afternoon a fortnight after the spring equinox. Afternoons at this time of the year in those places are almost as hot as summer. Even in the cool tomb it would not have taken long for decay to start, particularly in this case, after the torture the man had endured. But in carrying the ritual to completion, one would want to avoid the odor (cf. John 11.39).

Third, let us recall the historical context. Let us reread Flavius Josephus and his descriptions of the everyday horrors. It was common in those days for a Jew to die from a violent death and have his blood spilled. (When blood was spilled at the moment of or after dying, it had to be buried with the corpse, but blood spilled before death could be washed away.)^{xxvii} Since statistically one-tenth to one-twelfth of these victims died on Friday afternoons and their final burial had to be postponed until the day after the Sabbath, there must have been a regular need to prevent postmortem blood from drying out and the body from decaying too soon. Aloes and myrrh dissolved in oil or water have been known from time immemorial as moisturizers and antiseptics. Myrrh moreover is a good deodorant,²⁶ and its mixture with aloes was certainly part and parcel — together with specially waterproofed (presumably by the application and then drying of a dense solution of the same aloes and myrrh mixture) shrouds — of the standard funeral kit for wealthy victims of violent deaths.

Thus the bodies of these victims and the inner side of their shrouds must have been anointed with the liquid mixture of spices, the damp shining bodies introduced into the internally damp shrouds, the latter tightly pressed against the bodies, closed, perhaps even sewn, and then exposed

each side up in turn under the rays of the Sun so that their inner waterproof crust remained intact for at least two days.

This is also probably what happened to Jesus. If his Shroud is the only one to have come down to us, it must have been for three main reasons: the veneration he inspired in his followers, the disappearance of his body with the Shroud left behind, and the two extraordinary images which could be seen on it.

7. Conclusions

We believe that we have shown or suggested convincingly the following:

(1) The double image on the Shroud of Turin was formed by solar rays reflected by the damp shining body of Jesus and immediately intercepted by the damp inner side of the cloth in which he was wrapped.

(2) The high resolution and optical quality of this image, i.e. its apparent orthogonality, were a direct result of the very close contact between the body and the cloth and of the parallelism of the incident transmitted solar rays.

(3) The so-called three-dimensional effect (the encoding of a z coordinate) was due in fact to the smaller amount of light falling on the body and the somewhat longer paths of the sunrays reflected by the nonhorizontal surfaces of the body together with the attenuating effect of the intervening medium, the not fully transparent solution of spices;

(4) This image was imprinted on this inner side of the cloth by the transfer of the solar energy involved, and the aloes and myrrh solution serving as a catalyzer of the cellulose degradation process.

(5) The superficiality of the imprint could be linked to the presence of a thin crust of dried aloes and myrrh mixture used to precondition the Shroud (render it more waterproof) and to slow the evaporation of its internal moisture. The dry outer border of this crust (the double exposure to the sunrays was to reinforce it) acted as a screen that the reflected rays could not trespass and their energy accumulated there (probably in the form of extra heat), while the liquid solution on the damp inner side of the crust located just above the level of the innermost fibrils catalyzed the liberation of this energy and the degradation by it of the fibrils caught between the dry and the damp parts of the mixture.

(6) This procedure was probably meant to preserve the postmortem blood from drying and sticking to the Shroud and to delay the beginning of the decomposition of the corpse so that it could be unwrapped and the funeral rite completed 36 h later, when the Sabbath and the following night had passed.

The purely optical part of conclusions (1) and (2), since it is obvious, needs no experimental justification; such a justification may perhaps be needed for the proposed interpretation of 'three-dimensionality' (3).

True enough, as pointed out by one of our reviewers, preliminary calculations (estimates) of the diffuse irradiance reflected from the skin (in various conditions of light and moisture or oil) would probably be useful in preparing the chemical tests, while calculations showing whether the decrease in the diffuse intensity with distance can produce a gradient that reproduces the three-dimensional body topography would add credibility to our explanation. Unfortunately we are not sufficiently acquainted as yet with either the calculation techniques or the basic data such estimates involve. However direct experimental verification will be needed, and its results it will bring, positive or negative, are bound to be conclusive.

The hypothetical photochemical and physical processes — with their as yet unsolved problems, such as the exact composition of the aloes-myrrh solution; its quantity, density, fluidity, and other properties, the intensity of the Sun and the time of exposure necessary to initiate the image producing reaction — and their historical interpretation [(4)-(6)] require further studies and experimental validation, and therefore cannot be taken for granted.

But if their validation is successful, it appears that nothing could preclude, some day in April in Jerusalem, the performance of an ultimate real-scale, real-time, real-place experiment involving a life-size dummy, real spices and a real linen shroud.

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