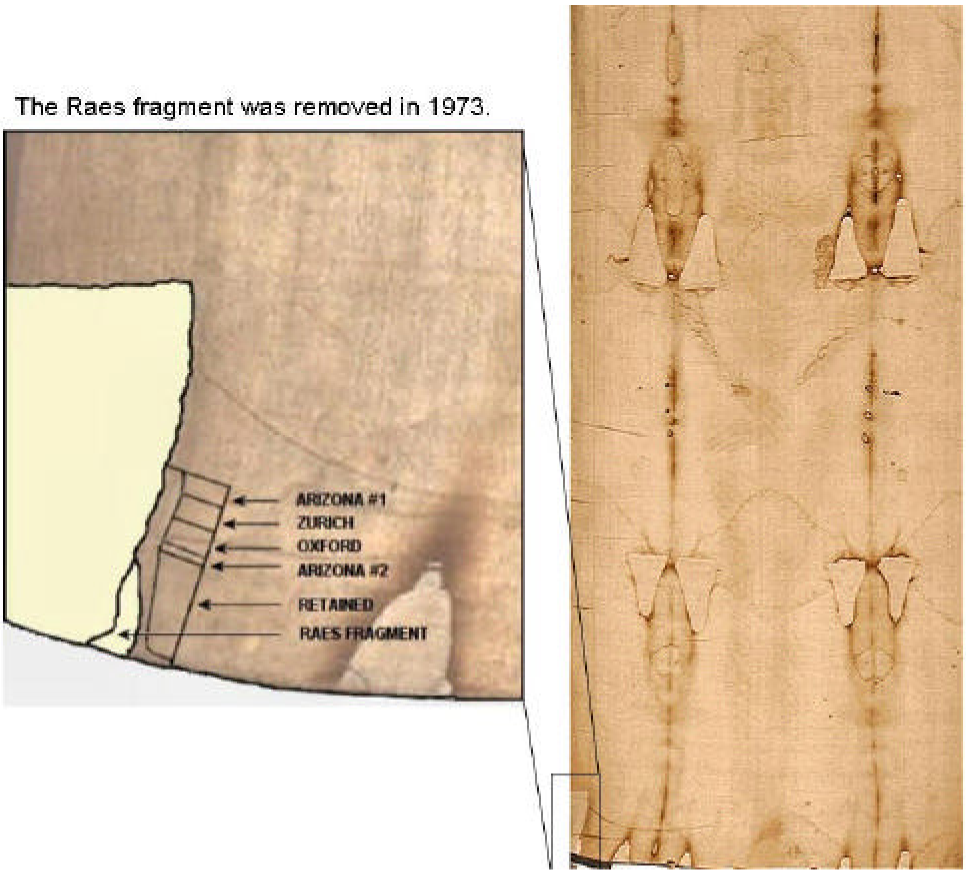
Discrepancies in the Radiocarbon Dating Area of the Turin Shroud

M. Sue Benford and Joseph G. Marino

In 1988, Carbon-14 findings from three Accelerator Mass Spectrometer (AMS) Labs independently dated a sample removed from the Turin Shroud, unarguably the most widely-studied linen cloth in history. The dates reported ranged between AD 1260 –1390, thus, leading to the conclusion that the cloth originated in the Middle Ages (1).



Approximate locations of questionable area used for C-14 dating in reference to full frontal portion of the Shroud. © 1978 Barrie Schwortz

Since the dating, many hypotheses have been proffered attempting to explain the C-14 results (2), which appear contradictory to a plethora of data pointing to a more ancient origin (3,4,5,6).

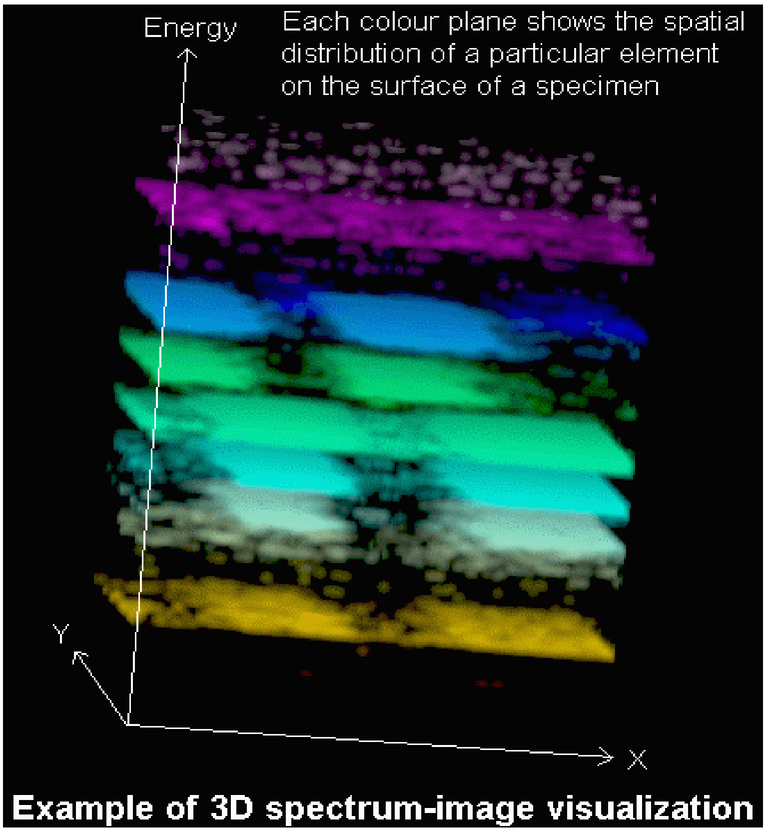
An acceptable hypothesis of why the Shroud dated between AD 1260-1390 must satisfactorily explain the precise, statistically-determined angular skewing of the dates corresponding with the individual laboratories, with reference to the location of the subsamples received (7).

The hypotheses of generalized ionizing radiation, thermal effects, environmental carbon monoxide enrichment, deliberate tampering or substitution of the samples, and bioplastic coating are incapable of meeting this latter requirement, as is the premise that the cloth itself, is, *in toto*, medieval (2).

In 2005, the late Raymond N. Rogers authored a paper in *Thermochimica Acta* that reported the results of experimental tests evaluating the hypothesis that the radiocarbon dating of the Turin Shroud was invalid due to the intrusion of newer material in the sampling area (8). Based on data obtained from his analyses of samples from the area, Rogers concluded that the combined evidence from chemical kinetics, analytical chemistry, cotton content, and pyrolysis/ms proved that the material from the radiocarbon area of the Shroud is significantly different from that of the main cloth. Rogers identified an organic dye made from Madder root, calcium, and Gum Arabic, along with an aluminum mordant.

What we plan to present to you in our presentation today is additional documentation from a previously- unpublished 1978 Shroud of Turin Research Project (STURP) study that clearly delineates surface chemical differences between the radiocarbon sampling area and other parts of the Shroud, excluding the charred areas. In addition, new data will be examined in light of existing radiographic findings, textile evidence from the adjacent Raes sample (sample extracted in 1973 for scientific examination by textile expert Gilbert Raes of the Ghent Institute), blinded-expert analysis of the C-14 sub-sample from Zurich (one of the three laboratories that dated the Shroud in 1988), independent microscopic confirmation of surface contaminates in the Holland-backing cloth/C-14 region, and historical-restoration information documenting known techniques resulting in both front and backside "invisible" repairs.

One of the numerous scientific tests conducted in 1978 by STURP included "Spectrally-resolved Quad-Mosaic Photography" (9). This study, utilizing state-of-the- art NASA technology of the time, was designed to generate color discriminability products capable of conducting a chemical distribution analysis of the surface of the linen cloth. According to the STURP researchers in charge of this study, "The generation of color products was considered the most important image processing task. From a color enhanced, relative color display, the color of different features of the image can be compared" (10). The colors, of course, indicate different chemical compostions.

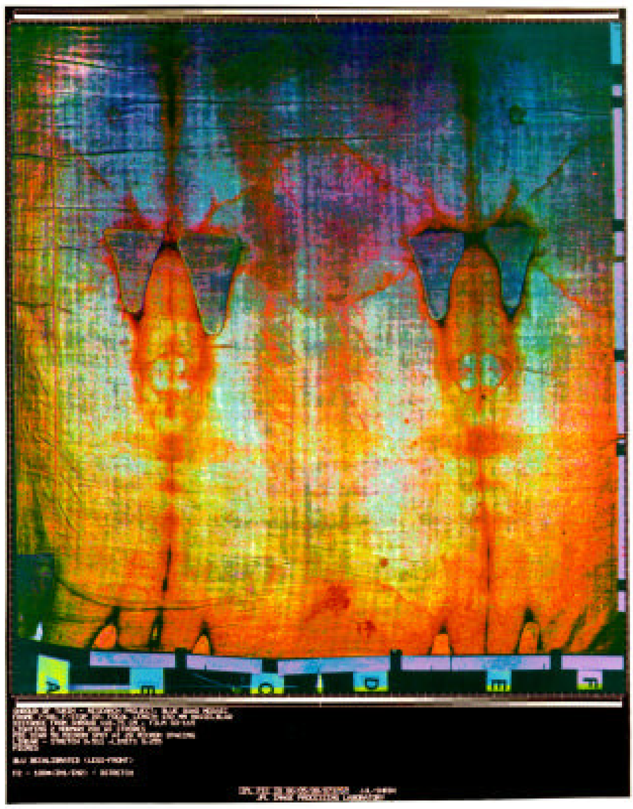


The STURP authors noted that ". . . if the chemicals were spectrally differentiated, the multispectral classification process could provide a map of chemical composition throughout the Shroud image . . ."

The technique employed principal component analysis, also known as Karhunen- Loeve transform (10). Researchers at the University of Kent explain that, "Multispectral imaging entails acquiring several images of the same scene using different spectral bands. For instance, a digital colour camera detects three separate images for the red, green and blue components of light." (11)

The STURP authors noted that ". . . if the chemicals were spectrally differentiated, the multispectral classification process could provide a map of chemical composition throughout the Shroud image . . ." (12). In keeping with this objective, our paper includes a critical evaluation and related discussion of the previously-unpublished original four Quad-Mosaic images to identify areas of chemical correspondence pertinent to the radiocarbon sampling area.

Holland cloth is exposed through the missing corner of the Shroud adjacent to 1988 radiocarbon sampling area.



Lower-ventral image of Quad-Mosaic.© 1978 Avis, Lynn, Lorre *et al.*

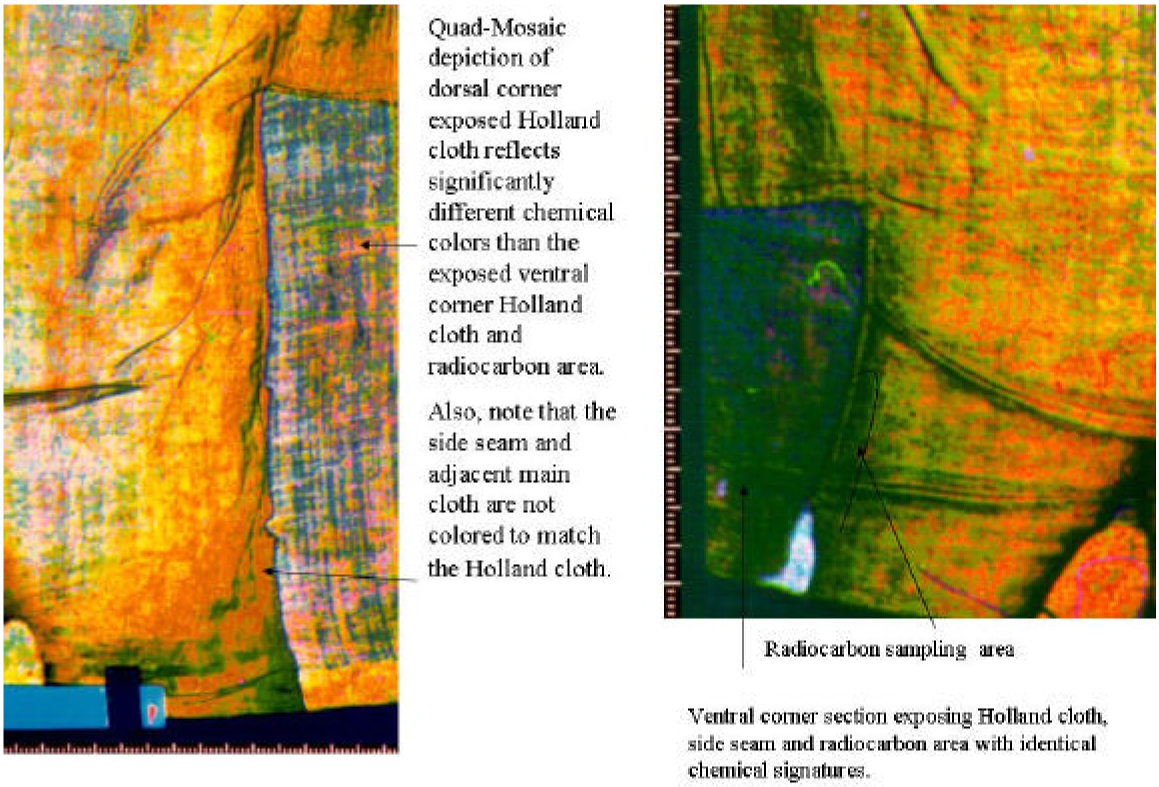
Evaluation of the image from the ventral-lower corner depicts the radiocarbon sample area next to the Holland cloth, which is observable due to the missing 5.5” x 3.5” (14 cm x 9 cm) corner piece. According to textile historian Mechthild Flury-Lemberg, who observed the area during her work to restore the Shroud in 2002, both of the Shroud’s missing corner pieces were already missing prior to the addition of that backing cloth in AD 1534, which had been added during repairs made due to fire damages in 1532 (13). Both the exposed Holland cloth and the adjacent radiocarbon sample area are a uniform dark-green color. The ventral-corner section consists of a unique, uniform solid dark-green region in a rectangular pattern with distinct borders. The dark green encompasses the side seam and extends approximately an inch (3 cm) into the main Shroud cloth region. Similar solid geometric patterns with defined borders in this hue are not observable elsewhere on the cloth..

Charred areas on Shroud resulting from a fire in 1532 AD.

Charred regions on the Quad Mosaic are represented by the same dark green color as seen in the Holland cloth/radiocarbon sampling area.

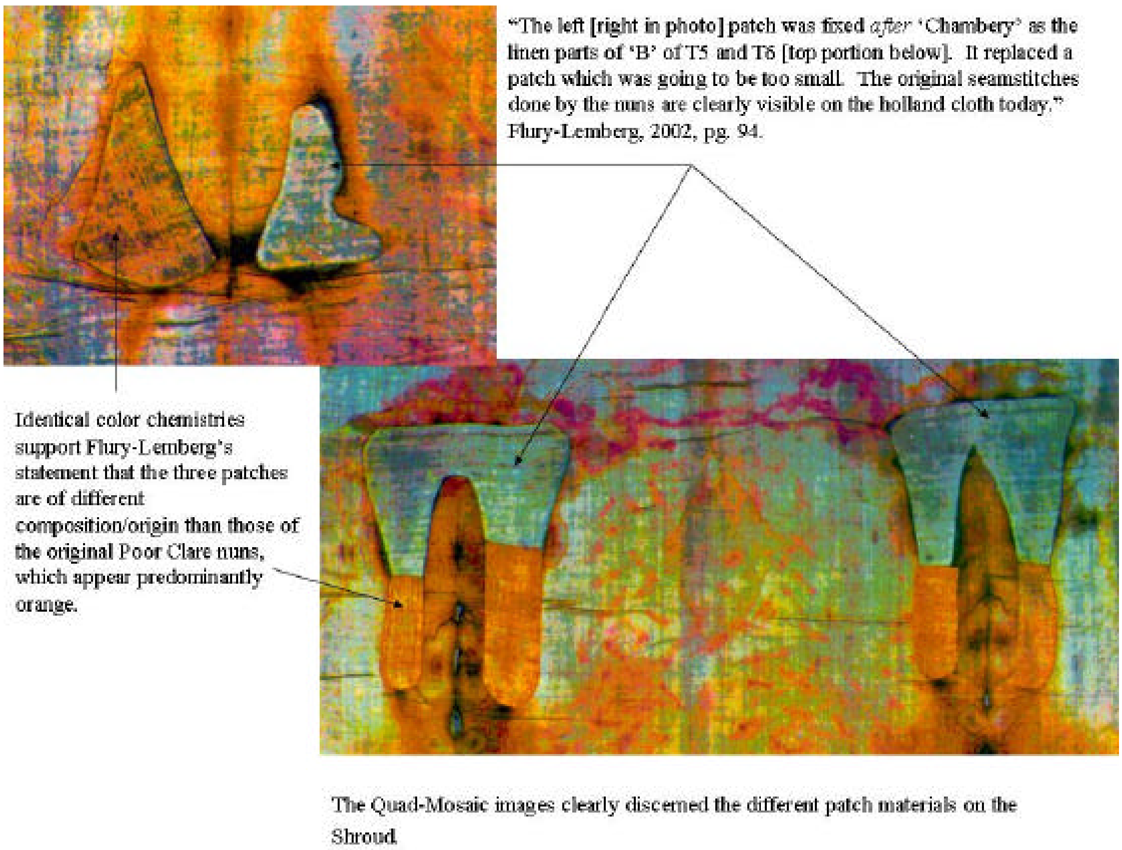
Close-up comparison of lower ventral corner of the Shroud showing C-14 sampling area © 1978 Barrie Schwortz (left), © 1978 Avis, Lynn, Lorre *et al*. (right)

Also observable in this Quad-Mosaic image are several areas showing charred cloth that resulted from the 1532 fire. These areas, and the other charred areas throughout the cloth, range from medium to very dark green. Non-charred areas also contain some scattered dark green color in random patterns and with indistinct borders.



Left – Quad-Mosaic close-up of dorsal-side missing corner region; Right – Quad- Mosaic close-up of ventral-side missing corner region. © 1978 Avis, Lynn, Lorre *et al.*

Images of the larger dorsal missing-corner-piece section, also exposing some of the Holland cloth, have a completely different chemical-color signature, consisting of a myriad of lighter-toned colors. Noteworthy is the fact that the color variation within the dorsal-section Holland cloth does not extend into the adjoining side seam or the main cloth section, as it does on the ventral side.

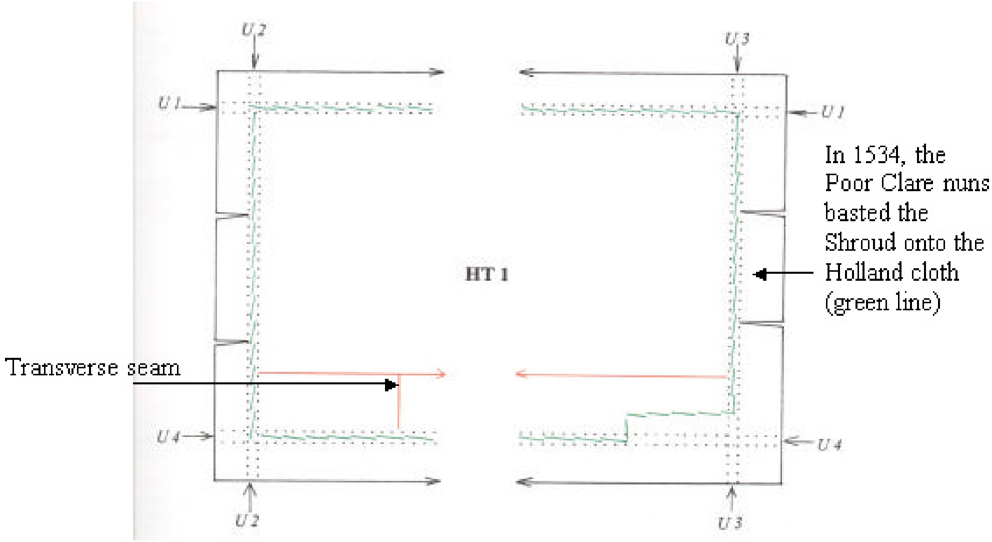


Quad-Mosaic images showing ventral-side patches. © 1978 Avis, Lynn, Lorre *et al*.

In terms of evaluating the reliability and validity of the Quad Mosaic to reveal true surface chemical discrepancies via the color patterns on the Shroud versus reflecting simple illumination variations, evidence for this can be found in the images of the known patches attached to the Shroud. The clear difference among the patches with differing historical provenance and, thus, different preparation techniques, supports the assertion that the Quad-Mosaic images provide valid indicators of surface-exposed chemical variation throughout the Shroud.

Research has demonstrated that the charring of cellulose materials significantly increases carbon content (~20-30%) as compared to corresponding non-charred material (14). The carbon content of charred cellulose and cotton ranges from approximately 43 to 71 percent of total weight (14). As such, it is possible that the Quad Mosaic's chemical-color signature reflecting the medium to very dark green on the charred portions of the linen Shroud may represent carbon. Rogers observed copious amounts of Gum Arabic on yarns obtained from the radiocarbon sample area. Gum Arabic is composed of pentose-sugar units. Rogers further identified the organic dye made from Madder root along with calcium. Although unconfirmed, the calcium may have been calcite. Calcium Carbonate was used in medieval dyeing and may have been incorporated with the red Madder, which was typically used with a white base (15). Each of these substances, identified by Rogers from the radiocarbon sampling area, is comprised primarily of carbon.

The Quad Mosaic reflects significant differences between the two exposed ventral and dorsal Holland-cloth sections in the excised-corner regions. The dark-green signature is missing from the Holland cloth on the dorsal region of the cloth. Conversely, the exposed ventral-region Holland cloth, side seam, and adjacent radiocarbon sampling area consist of a deliberate, uniform and well-delineated dark-green chemical signature.

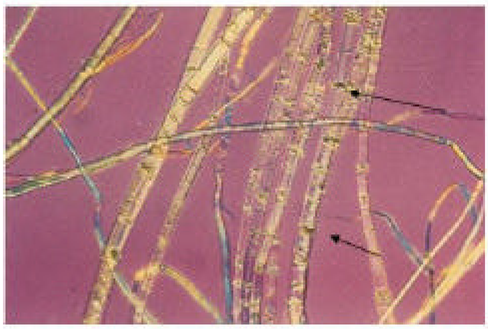


The Holland cloth was made wider (red line) by 30 cm to match the width of the Shroud. This strip consists of two pieces joined by a transverse seam. © 2003 Mechthild Flury-Lemberg

The spectral discrepancies noted between the two exposed regions of the Holland cloth is likely explained by the observation that these are two separate pieces of cloth added to the Shroud at different times and under different circumstances. First recognition that the Holland cloth was not a single, uniform piece of material came following radiographic examinations by the STURP team in 1978. Mottern, London and Morris found that, ". . . the Holland cloth is not one piece but instead three pieces hand sewn together." (16) Flury-Lemberg further noted that ". . . the lining had been made wider by the addition in the length of a 30 cm wide strip in order to match the width of the Shroud. This added strip consists of two pieces . . ." (17). Flury-Lemberg also found the two pieces were stitched together forming a transverse seam (17). The smaller of the two pieces from the added strip was under the ventral missing-corner/C-14 region.

Also in the ventral missing-corner section, which we hypothesize to consist of restorative surface dyes and what was likely an undocumented "invisible" medieval repair, is the section from which the 1973 Raes sample was extracted for analysis. In this sample, Raes found that the side seam had been attached to the adjacent main Shroud by a 2-ply-linen sewing thread (18).

400x photomicrograph of Shroud image fibers showing dark lignin at growth nodes. Rogers, 2002



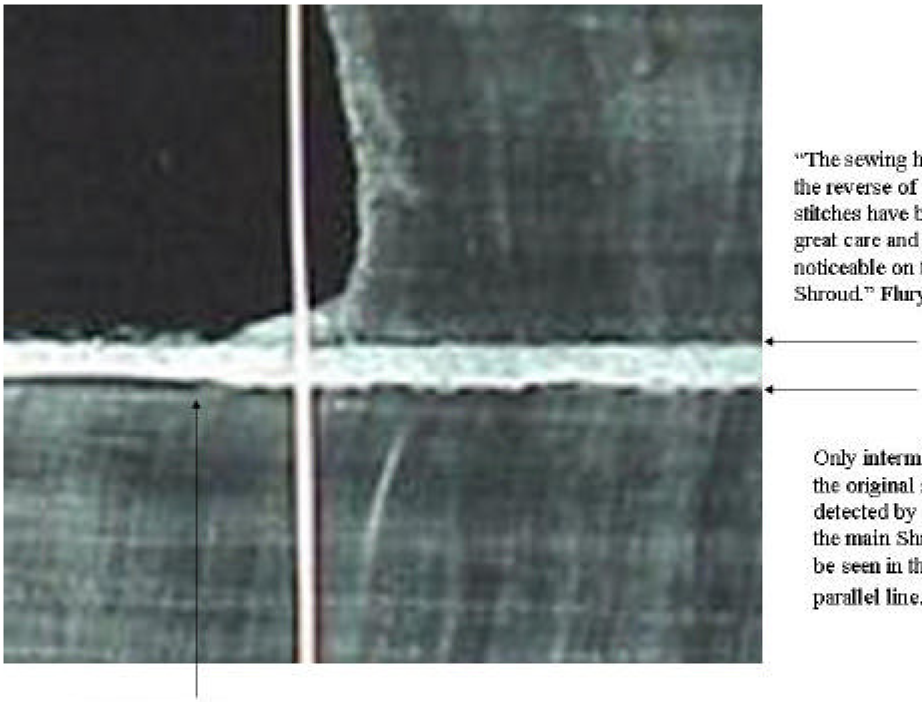
Photomicrograph of Raes "Piece 2" showing dark lignin at growth nodes characteristic of the main Shroud. No cotton is observable. Raes, 1991

Both Raes and Rogers detected cotton in Raes' Piece 1 as indicated by the arrows. "Very little lignin is visible at the linen growth nodes of the Raes and Holland cloth samples." Rogers, 2002

Photomicrographs of Piece 1, Raes 1991, courtesy Shroud Spectrum International

Top, Left – photomicrograph of Shroud image fibers; Top, Right and Bottom – photomicrographs of fibers from the Raes sample extracted in 1973.

By removing the sewing thread, Raes was able to separate his sample into two distinct pieces, which he identified as "Piece 1" and "Piece 2." Each piece exhibits different characteristics, such as cotton content, lignin content at the growth nodes, and thread size, suggesting two different origins of the yarns.



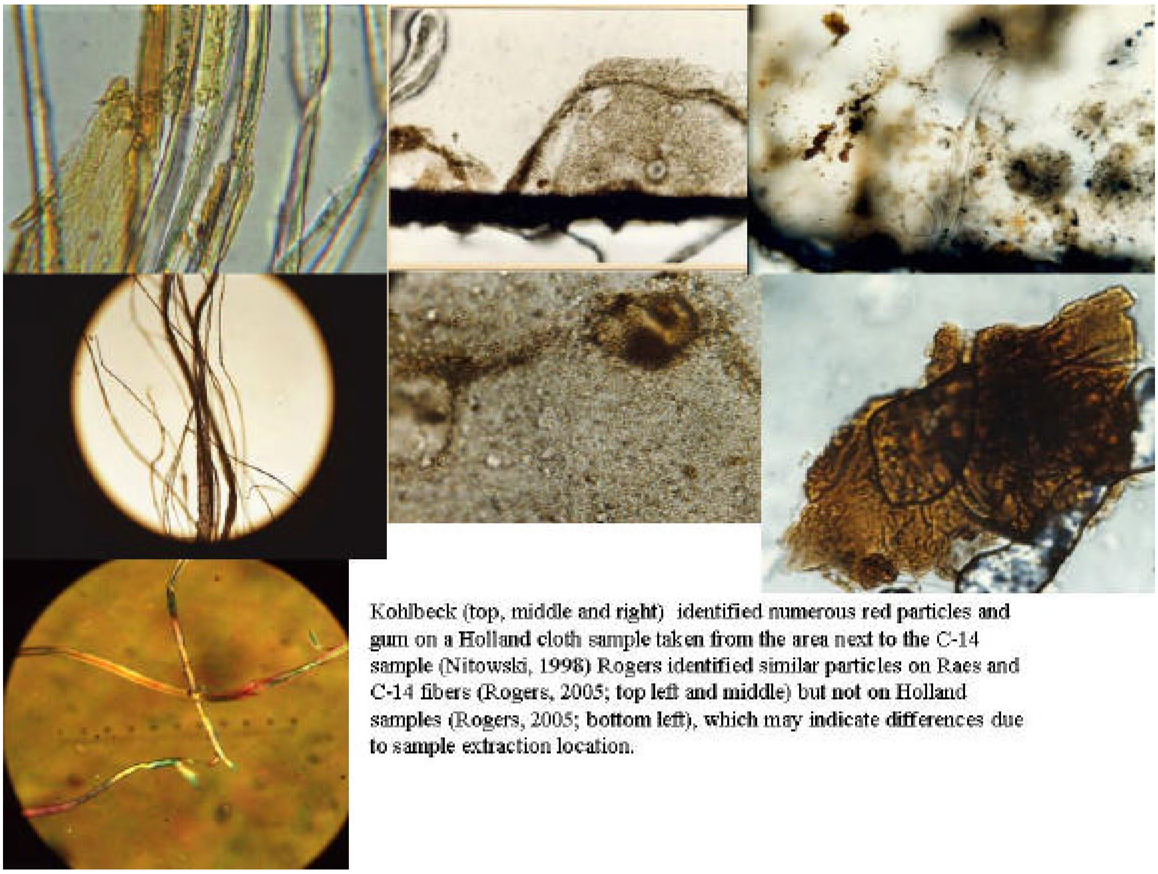
Radiograph of ventral missing corner region. © 1978 Mottern, London, Morris

Further, the significance of the sewing thread Raes identified is that its character and quality along the length of the side seam were observable via radiographic examination. STURP researchers reported that "The radiographic images substantiate the 4-5 mm width of the 'seam.' In addition, two rows of stitches, one along each edge of the 'seam,' are observable." (19) Flury-Lemberg makes an important observation about the side seam and adjacent stitches. "The sewing has been done from the reverse of the fabric and the stitches have been executed with great care and are barely noticeable on the face of the Shroud." (20) While top-side radiographs of the ventral corner show a continuous sewing thread next to the side seam in the C-14 region, beyond this region, the stitching becomes intermittent and barely visible in the main Shroud as confirmed by Flury-Lemberg.

The continuous, fully-observable sewing thread represents a significant change of technique, and suggests this section of thread, which incorporated the Raes sample and C-14 sample areas, was applied from the top instead of the reverse of the cloth. This further implies the two sections of sewing threads (C-14 region versus main Shroud) were applied at different times and by different artisans with the main Shroud stitching possibly from the same time period as a cloth from Masada in Israel, dated to BC 40 to AD 73 (21).

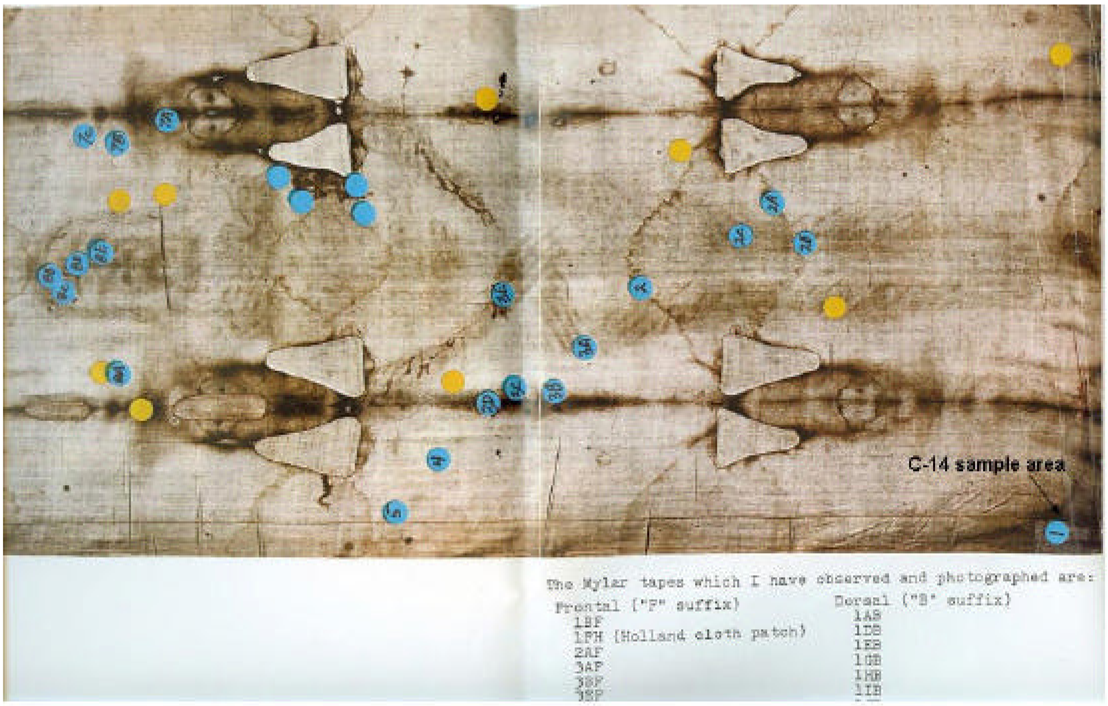
Another distinctive characteristic of the cloth also points to a pre- medieval origin of the Shroud. Although debated in the past, image-analyses tools and techniques have clearly identified the existence of horizontal and vertical bands throughout the Shroud. According to the Cambridge Textile Book,"Tapestry-woven coverlets and hangings were characterized in Hellenistic and early Roman times by 'shaded bands', which incorporated subtle colours of graded yarns. Combined later with figured designs, ***shaded bands had vanished by the fourth century***" (22). Thus, the Shroud, with its shaded bands could not likely have been created after the fourth century.

As we first described in a paper in Orvieto, Italy in 2000, other observations support the assertion that expert and undocumented manipulation took place in the C-14 sample region. Independent, blinded analyses by textile experts of the Zurich sub-sample used for C-14 dating also revealed significant discrepancies in the two sides of the sample (2). In the analysis of the sub-sample, by Albany International Research Company, Louise Harner remarked that “the float is different on either side of the sample” (2). It forms a thick/thin, thick/thin pattern on the right side, whereas the left is much more consistent throughout. Harner surmised that this was due to each side of the pattern being woven independently.



Representative photomicrographs of Holland cloth fibers independently examined by Rogers and Kohlbeck.

As mentioned previously, Rogers reported finding significant amounts of surface contaminates on both the Raes and the C-14 yarns. In contrast, he reported that, “There was absolutely no coating with these characteristics on either the Holland cloth or the main part of the shroud”(23). However, independent microscopic analysis of one of the yarns extracted from the ventral-corner-exposed Holland cloth by microscopist Joseph Kohlbeck of Hercules Aerospace, revealed copious amounts of unidentified red particle contaminates (24). This discrepancy may be explained by the different locations from where the Holland-cloth samples were taken. Reports indicate that while most of the Holland yarns were extracted through burn holes in the main part of the Shroud (25), one yarn sample, which Kohlbeck examined, was taken from the exposed Holland cloth in the ventral corner (26). According to Kohlbeck (27), his sample from the ventral corner *was not returned to Rogers for comparative analysis*; thus, confirming the above scenario explaining the different results. This supports the Quad-Mosaic findings showing that the same surface chemistry extended from the ventral-exposed Holland cloth into the adjacent C-14 region material, but varied considerably from other regions of the Holland cloth and main Shroud.

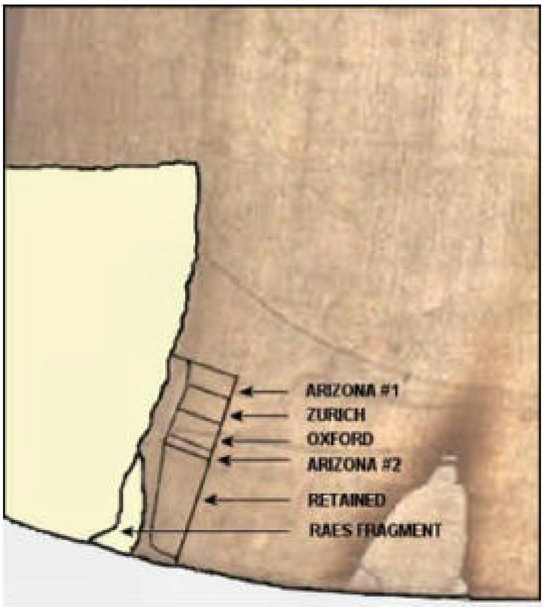


Sample 1FH (Holland cloth patch) was examined by Joseph Kohlbeck and not returned to Ray Rogers for analysis. Other Holland cloth samples, examined by Rogers, were extracted through burn holes and did not show similar surface debris. The C-14 sample area is adjacent the #1 above and showed similar debris. © 1998 Eugenia Nitowski,

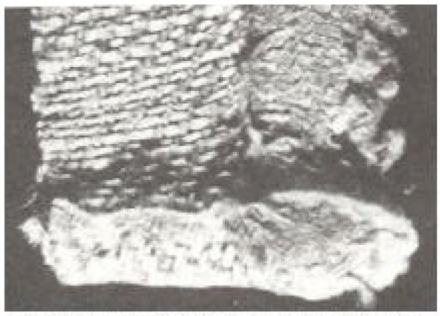
The area labeled "1" in the above photo shows the location of the "1FH Holland cloth patch" sample examined by Kohlbeck that contained red debris and was not returned to Rogers for examination.

An archaeologist, the late Dr. Eugenia Nitowski, who obtained numerous Shroud fibers from Rogers, conjectured that the red particle contaminates discovered by Kohlbeck were the burial spices Aloe and Myrrh. However, this assumption was based solely on her comparison of the debris with reference photos of the suspected substances and not via chemical analyses. She reported, "The study could go no further [beyond photo comparison], because of the inability to perform testing which would either remove or destroy materials from the tapes" (24). Along with the lack of any chemical characterization of the debris, the fact that the singular yarn (1FH) with the impurities came from the ventral missing-corner-exposed-medieval Holland cloth and not the main Shroud, argues strongly against Nitowski's assumption that the debris was from burial spices. Based on the Quad-Mosaic data and Rogers' findings, it is far more plausible that the 1FH impurities were also red Madder and Gum Arabic as chemically-verified by Rogers in multiple adjacent samples.

The Quad-Mosaic images, radiographic findings, textile evidence from the adjacent Raes sample, blinded-expert analysis of the Zurich C-14 sub-sample, and independent microscopic confirmation of surface contaminates in the Holland-cloth/C-14 region support Rogers' assertion that a surface dye was added to the Shroud in the area of the 1988 radiocarbon sampling to disguise an undocumented repair. These data further confirm that this substance included the exposed Holland cloth on the ventral, but not dorsal, side of the cloth. Thus, the application of this substance occurred sometime after the Holland backing-cloth was attached to the Shroud in 1534 and prior to the 1973 Raes sample extraction, but was intentionally added to only one side of the cloth. These data further support the theory that the radiocarbon sampling area was manipulated during or after the 16th Century.

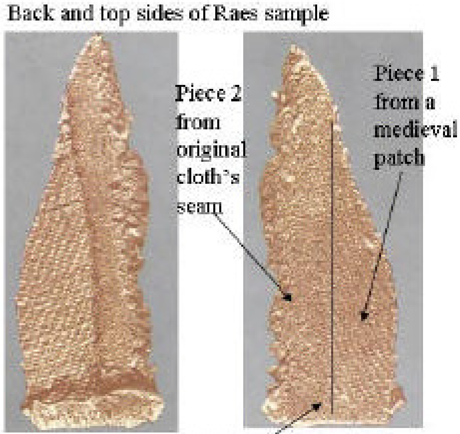


Raes "Piece 1" contained cotton, minimal lignan at growth nodes, and was sewn to the original Shroud's seam, hypothesized to be "Piece 2," with a 2-ply fine linen S-twist yarn (27 x 2 Tex).



Magnified back (weft) side of Raes sample.

Back and top sides of Raes sample

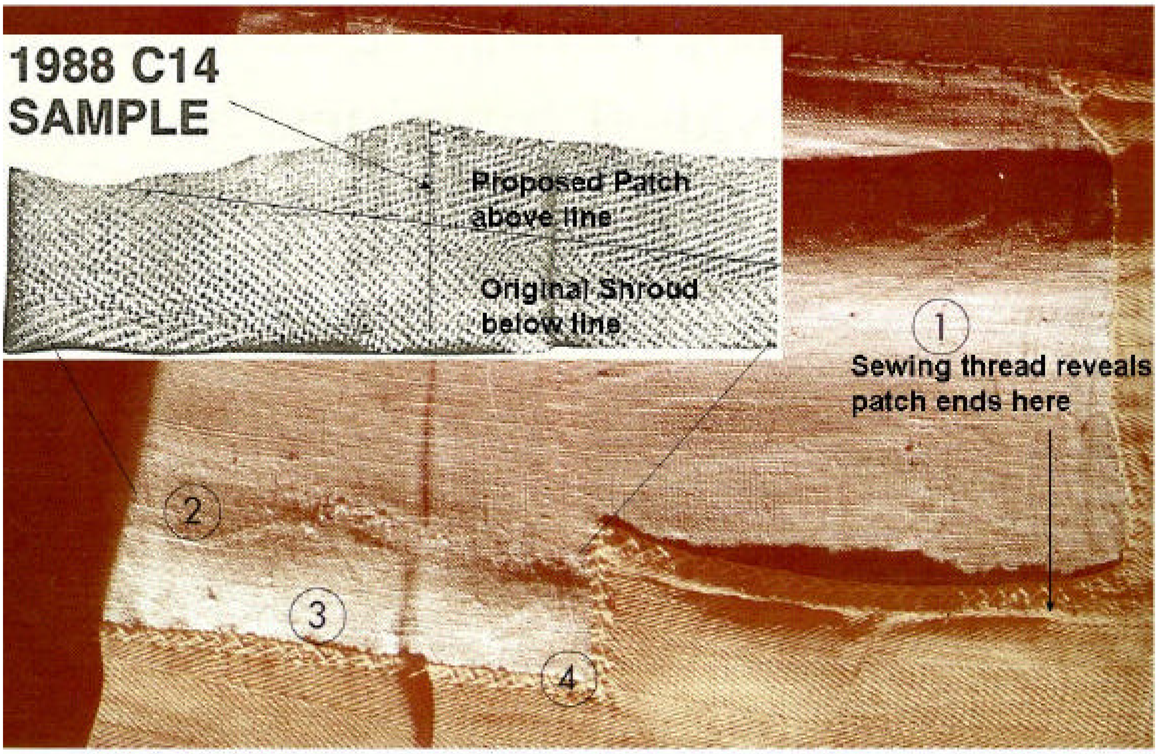


Medieval portion of sewing thread as observed by Raes and via X-ray

Raes photos courtesy Shroud Spectrum International, 1991

The Raes sample is highly significant due to its thorough examination and adjacent location to the C-14 sample area. Given the stark differences between yarns found in the Raes' Pieces 1 and 2, combined with the existence of the sewing thread, which connected the two disparate materials, we hypothesize that Piece 2 was the original Shroud material/seam and Piece 1 was a cotton-containing patch made to resemble the original Shroud cloth..

In this paper we have also discussed additional supporting evidence that, not only is the Raes and C-14 sampling region anomalous in comparison to the main Shroud cloth, but the piece of Holland cloth in the ventral corner is also significantly different from the rest of the Holland cloth. The most probable scenario is that the original smaller section of Holland cloth was extracted for relics. This section was most likely replaced with newer material that did not match the exposed dorsal section of Holland cloth.



Ventral corner of the Shroud with 1= replaced Holland cloth, 2 = Raes sample area, 3 = C-14 sample area, 4 = connecting stitches of main cloth to removed area. The pullout area portrays proposed medieval patch region in reference to the overall sample. © 1996 Gino Moretto

Also consistent with the data is the hypothesis that the person(s) responsible for taking this section of Holland cloth also extracted a small section of main Shroud cloth directly adjacent to the side seam and missing ventral corner, i.e., the C-14 sampling area. To hide the extraction, the missing material would have been patched and surfaced dyed, along with the newer backing material, such that it would not have been detected. Starch, which was identified in this area, was routinely used by medieval restorers to disguise invisible mending (28).

Historical evidence demonstrates that it was not only possible for medieval weavers and embroiderers to invisibly mend textiles such that they were not top-side detectable, but it is also recognized that they could choose whether or not to permit their handiwork from being detected on the back side as well.

Historically, reweaving was not carried out through a support fabric and was often executed so skillfully that it is not always recognizable as a later addition, although differences in the rate of dye fading have often revealed its presence . . . Evidence of reweaving would now [16th Century] usually be left deliberately visible on the reverse of the tapestry by the presence of the warp ends and knots (29).

As this passage infers, skillful medieval weavers could choose whether or not to leave evidence of their work on the back side of a fabric.

Although a less-than-conventional restoration practice, it is known that in early part of the 16th Century the art of “reversing” was practiced such that tapestries could be viewed intact from either side of the cloth. “In August 1524 Wolsey’s Wardrobe of the Beds . . . ‘were shorne and new dressed on the wrong side’. . .” (30). Reversing resulted in the lack of any telltale signs of a back-side repair.

It has been previously hypothesized (2) that if an undetected 16th Century repair impacted the C-14 sampling area the ratio of medieval to 1st Century material would have been approximately 60% to 40% based on expert observations (2); however, the area would have been a mixture of both age groups.

In this scenario, it is important to note that there is a requisite overlap and intermixing between the newer patch material and the existing textile via the integration and splicing of frayed edges into the damaged textile and vice versa. The unavoidable interweaving required of this invisible mending technique would, most assuredly, have created heterogeneity in the C-14 sample area.

It is worthwhile to go into some detail explaining what splicing is and how it pertains to the Shroud's carbon dating. Splicing is a technique of joining two yarn ends by intermingling the constituent fibers so that the joint is not significantly different in appearance and mechanical properties with respect to the parent yarn. The effectiveness of splicing is primarily dependent on the tensile strength and physical appearance.

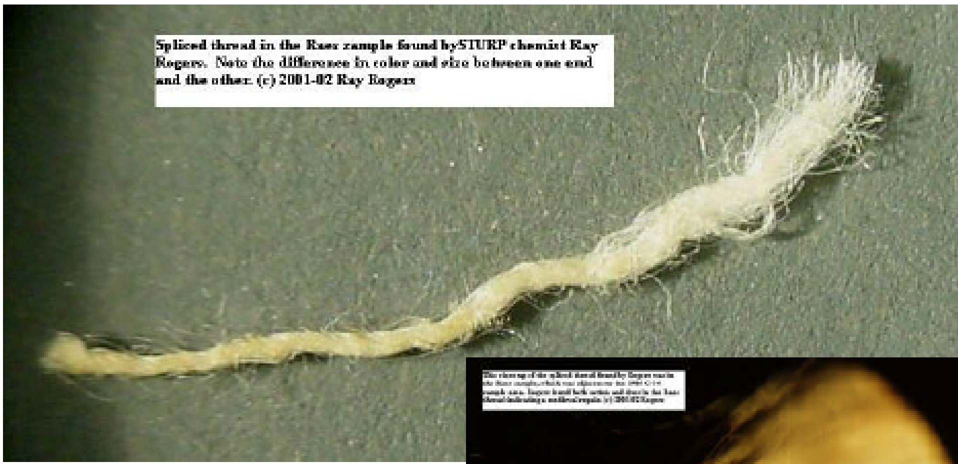
Wrapping
The tail end of each yarn strand is tapered and terminates with few fibers.

Twisting
The two yarn ends comprising the splice are twisted around the body of the yarn, each yarn strand twists on the body of the yarn on either side of the middle of the splice.

Tucking /Intermingling
The middle portion of the splice is a region (2-5 mm) with no distinct order. The fibers from each yarn end intermingle in this splice zone just by tucking.

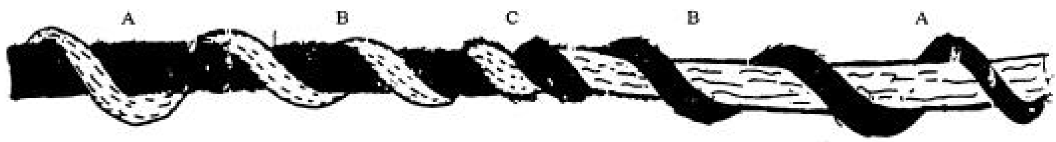
YARN CLEARING, KNOTTING AND SPLICING, M. Anbarasan, Premier Polytronics Ltd., Coimbatore, India

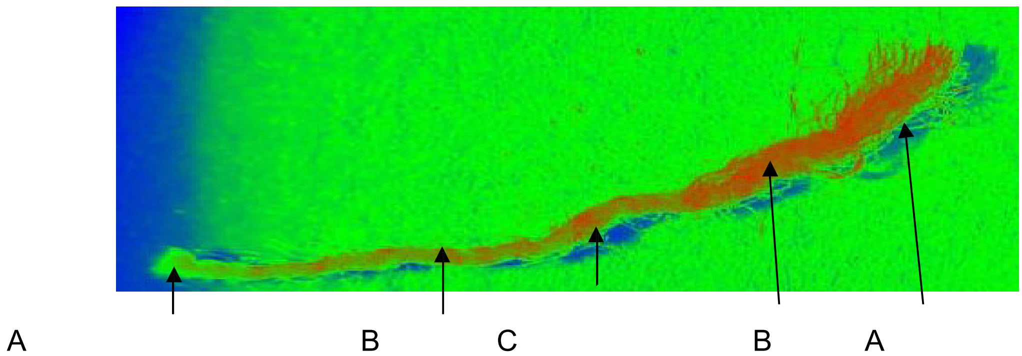
The splice is comprised of three distinct regions/elements defined by wrapping, twisting and tucking/intermingling.



Raes #1 showed characteristics of a spliced thread

We had hypothesized, and Rogers' later confirmed, the existence of a spliced yarn among the Raes samples he had received. According to Rogers, Raes #1 was straight as received indicating it was likely a warp sample. The splice was identified by Rogers as being 1.4 mm long. It would be hard to detect this feature in the weave, but notice that one end of the yarn is colored and compact while the other is "fluffy" and whiter. The colored end shows the gum coating on its surface, which is not on the inside.





Raes #1 demonstrates features of a typical spliced yarn © 2002 M. Sue Benford

This color-enhanced rendering of the Raes #1 thread, shows the comparative areas of overlap, twisting, and intermingling as described in the above illustration. Further discussion on the chemical and physical nature of this yarn and its surface contaminant will be provided in a separate paper at this conference by other authors.

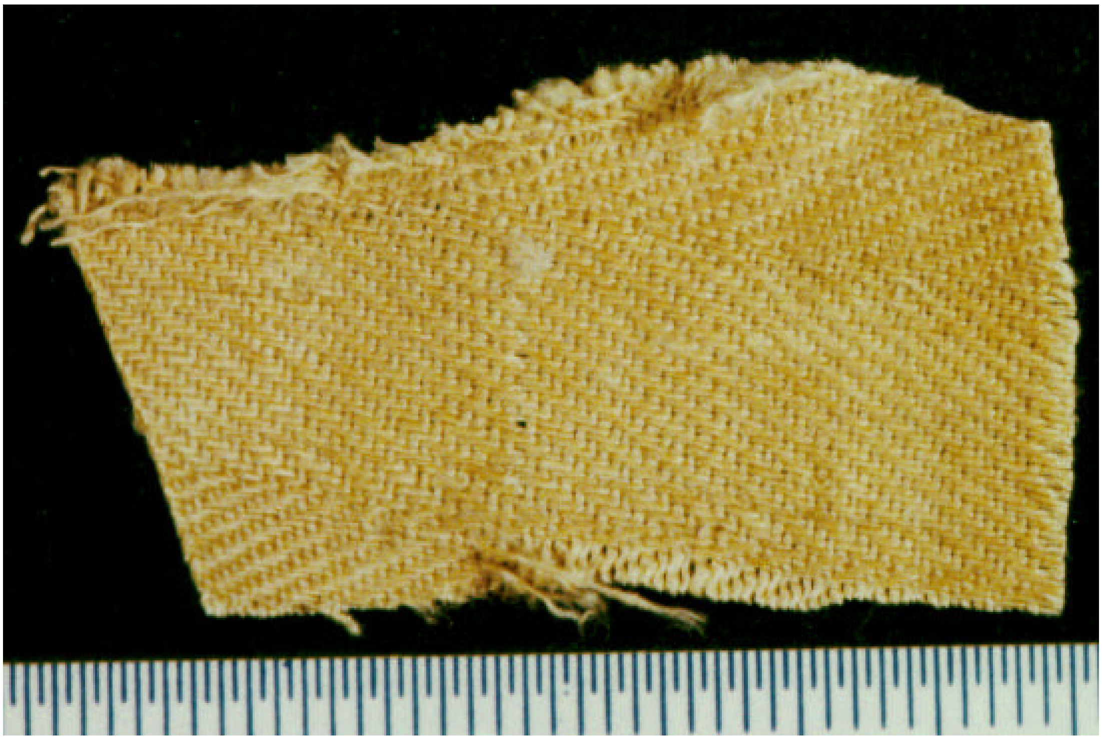
The exact ratio of patch versus original threads is not determinable by photographic analysis alone; however, a well-supported estimate, based upon weave- pattern changes, has been posited reflecting approximately 60% of the C-14 sample consisting of 16th Century threads while approximately 40% were 1st Century in origin. The radiocarbon date was calculated using the percentage of observed 16th Century versus 1st Century weave types appearing in the Oxford sub sample. (Representative

dates used were AD 1500 for 16th century and AD 75 for 1st century.) As proposed in our hypothesis, a sample containing ~ 67% AD 1500 radiocarbon and ~ 33% AD 75 radiocarbon should yield a calibrated date of ~ 1210 AD, which is what Oxford obtained in their C-14 dating.

Close-up of water stain with drawing indicating predicted location into the C-14 region. (Right) C-14 sample extraction site showing reserved sample location. © 2002 Mechthild Flury-Lemberg (left photo)

In terms of the C-14 area in relationship to the water stain, which has been posited to be much older than the 1532 fire and also impacted the sample area (31), photo

analysis demonstrates that this latter assertion is incorrect. This photograph, when placed next to an image showing the location of the reserve versus C-14 sample, clearly demonstrates that the entire C-14 sample area was outside the water stain region. The crease can be used as a marker to compare the two photographs and location of the C-14 sample.



The reserve portion of the C-14 sample extraction does not reveal any observable water stain markings. © 1988 G. Riggi di Numana

Further, it is also notable that the reserve sample does not appear to have any water stain markings. According to the illustration of the water stain area, the stain should have gone directly through the mid-section of the reserve sample forming a distinct marking discoloration. Since the sample does not show any evidence of a water stain marking, this could very well be explained by the later addition of a patch in this area.

Given these new data, we have amended our previously-proposed historical scenario describing what happened in the C-14 area. We believe that it is still possible that Cardinal Louis de Gorrevod, overseer of the Shroud in the 1530s, cut out the 5.5” by 3.5” corner adjacent to the C-14 area to use for relics. This was done prior to the addition of the Holland cloth and did not include the side strip seam (note the frayed edges in the slide). At some time after the Holland cloth was attached to the Shroud, and after the Shroud left Chambery, expert embroiderers took a section of the Holland cloth from under the missing corner AND stealthily took a main Shroud “souvenir” next to the cut- out. The embroiderers left the original side seam intact in order to make it easier to reattach the new patch material without being detected. The embroiderers replaced both the Holland-cloth relic and small Shroud snippet with a cotton/linen blended fabric, surfaced dyed the cloths to match the much older main Shroud and stitched the patch back to the original side-strip seam from the top of the cloth.

1535 - Savoy is invaded by French troops. Charles III and his family abandon Chambéry. The Shroud is taken to Piedmont, passing through the Lanzo valley via Bessans, Averoles, Ceres, and Lanzo. Cardinal Louis de Gorrevod dies.
4 May - The Shroud is exhibited in Turin

1536 - 7 May - The Shroud is exhibited in Milan.

1537 - The Shroud is taken for safety to Vercelli because of the French invasions
29 March - The Shroud is exhibited from the tower of Bellanda, Nice

1540 - The Shroud is at Aosta

1541 - The Shroud is once again at Vercelli, where it will stay for the next twenty years
Timeline excerpted from the BSTS, NEWSLETTER NO: 44 - November/December 1996

Increased exposure to the populace and lower security during this tumultuous time period may have provided the opportunity for an unauthorized relic taking of the Shroud by an expert embroiderer.

We contend that the most likely time period by which this undocumented activity occurred was between 1535 and 1541, when increased exposure to the populace and lower security during this tumultuous time period may have provided the opportunity for an unauthorized relic-taking of the Shroud by an expert embroiderer.

In conclusion, it is impossible to quantify the amount of surface carbon, other contaminates, and/or intruded newer material in the radiocarbon sampling area based upon the Quad Mosaic or other data presented in this paper. Similarly, it is impossible to determine if either the surface carbon, or the manipulation it represents, had any impact on the 1988 radiocarbon dating. However, in light of these new data, along with a recently-posited theory that does not preclude a 1st century origin for the cloth (32), additional radiocarbon dating incorporating other areas of the cloth is recommended.

Further, characterization of the remaining C-14 samples, Raes samples and the Holland cloth to ascertain the presence of cotton, surface dyes and other restoration substances in accordance with these findings, is warranted.

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REFERENCES:

1. P. E. Damon, *et al. Nature*. **337,** 611-615 (1989).
2. J. G. Marino and M. S. Benford. *Sindone 2000 Worldwide Congress Proceedings*. Edited by Emanuela Marinelli and Angelo Russi. **Vol. I**. San Severo: Gerni Editori, 57-64 (2002).
3. L. A. Schwalbe and R. N. Rogers. *Analytica Chimica Acta*. **135**, 3-49 (1982).
4. A. D. Adler. *Archaeological Chemistry*. **625**, 223-228 (1996).
5. A.D. Adler. Proceedings of the International Scientific Symposium. **March 2000**, 219-233 (2000).
6. A. D. Adler and R. Selzer. "Sindone e Scienza – Bilanci e programmi alle soglie del terzo millennio", Atti del III Congresso Internazionale di Studi sulla Sindone, Torino. 320-333 (1998).
7. B. Walsh. http://members.aol.com/turin99/radiocarbon-b.htm (1999).

8. R. Rogers. *Thermochim. Acta.* **425,** 189–194 (2005).
9. *Operations Test Plan for Investigating the Shroud of Turin by Electromagnetic Radiation at Varying Wavelengths*. Shroud of Turin Research Project, Inc., 1978.
10. C. Avis C, D. Lynn, J. Lorre, S. Lavoie, J. Clark, E. Armstrong, J. Addington. *IEEE 1982 Proceedings of the International Conference on Cybernetics and Society*. October 554-558 (1982).
11. D.L.Mountain, P.G.Kenny, I.R.Barkshire and M.Prutton. *Proc. UK Eurographics*. **Vol. 1**, 95-102 (1996). Also see: cs.kent.ac.uk/people/staff/pgk/DeepMultispectral.html.
12. C. Avis C, D. Lynn, J. Lorre, S. Lavoie, J. Clark, E. Armstrong, J. Addington. *IEEE 1982 Proceedings of the International Conference on Cybernetics and Society*. October 557-558 (1982).
13. M. Flury-Lemberg. E-mail communication. 17 October (2007).
14. M. Hajaligol, B, Waymack, D. Kellogg. *Fuel.* **80** 1799-1807;1803 (2001).
15. *Pigments through the Ages*. Internet website http://webexhibits.org/pigments/indiv/overview/alizarin.html.
16. R. W. Mottern, R. J. London, and R. A. Morris RA. *Materials Evaluation*. **38** 39- 44;41 (1979).
17. M. Flury-Lemberg. Sindone 2002: Preservation. *Torino: Opera Diocesana Preservazione Fede* 20 (2003).
18. G. Raes. *Shroud Spectrum International*. **38/39**, March/June 3-6;5 (1991).
19. R. W. Mottern, R. J. London, and R. A. Morris RA. *Materials Evaluation*. **38** 39-44;42 (1979).
20. M. Flury-Lemberg. *Sindon N.S. Quad*. **16**, Dec. 55-76;60 (2001).
21. M. Flury-Lemberg. *Sindon N.S. Quad*. **16**, Dec. 55-76;60 (2001).
22. D. Jenkins, (ed.). The Cambridge History of Western Textiles (vol.1). Cambridge: Cambridge University Press: 113 (2003).
23. R. Rogers. *Thermochim. Acta.* **425,** 191 (2005).
24. E. Nitowski. *The field and laboratory report of the environmental study of the Shroud in Jerusalem*, Carmelite Monastery, Salt Lake City, Utah 21 (1986).
25. B. Schwortz. *IEEE 1982 Proceedings of the International Conference on Cybernetics and Society.* October 538-547;544 (1982).
26. E. Nitowski. *Through the Microscope: A Study of the Shroud of Turin in Photomicrographs*. Ariel Museum, Salt Lake City, Utah (1998).
27. J. Kohlbeck, Telephone communication. 12 January (2008).
28. O. Petrosillo and E. Marinelli. *The Enigma of the Shroud: A Challenge to Science.* San Gwann, Malta: Publishers Enterprises Group 149 (1996).
29. F. Lennard and M. Hayward. *Tapestry Conservation: Principles and Practice*. Burlington, Massachusetts: Butterworth-Heinemann 8 (2006).
30. F. Lennard and M. Hayward. *Tapestry Conservation: Principles and Practice*. Burlington, Massachusetts: Butterworth-Heinemann 16 (2006).
31. A. Guerreschi and M. Salcito. *Third Dallas International Conference on the Shroud of Turin: Dallas, Texas,* September 8-11, 2005, www.sanlorenzo.torino.it/ITA/testi2007/conf/Sindone-Dallas2005.pdf
32. M.S. Benford and J. G. Marino. *Chemistry Today*. **26:2**, 57-62 (2008).