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STORAGE CONDITIONS AND PHYSICAL TREATMENTS RELATING TO THE DATING OF THE DEAD SEA SCROLLS

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ABSTRACT. The Dead Sea Scrolls have been analyzed by paleographic, non-destructive and destructive testing. The dates of their creation have been in dispute since their discovery. Research has established their authenticity, but a variety of conditions including the methods of skin preparation, variation in storage conditions and post-discovery restoration treatments could have introduced changes now affecting dating efforts. Comprehensive analyses were not possible until recently. Such analysis must be performed to establish a concrete framework for all the texts.

Professor R. B. Blake told a story in response to a question of why so little remained of writing on leather. He said that on one of his expeditions to Asia Minor, one of his native servants exhibited proudly some chamois trousers of his own manufacture, upon which Professor Blake detected with sorrow, traces of medieval writing (Reed 1972).

INTRODUCTION

A recent ^{14}C study of 14 Dead Sea Scrolls by Bonani *et al.* (1992) is a welcome addition to the analytical literature on the Scrolls. The authors have undertaken a more comprehensive sampling than any previous study, an effort that T. B. Kahle and I proposed in an article in *Nature* in 1986. In that article, we commented on amino acid racemization analysis of the Dead Sea Scrolls published by Weiner *et al.* (1980). Our comments then, as mine now, relate to the potential effects on dating results of prior storage conditions and restoration treatments. Other points raised in the *Nature* article referred to the different types of animal skin used and the methods of skin preparation to produce a useful writing surface. In this article, I present a general background of the Dead Sea Scrolls and a more detailed account of chemical treatments used on the Scrolls and other factors, including environmental conditions resulting from storage, which may be sources of variation in the physical properties of the Scrolls relating to dating efforts.

DESCRIPTION OF THE PROBLEM

The story in the epigraph emphasizes the importance that leather has always had to mankind. The meager remains of the vast parchment libraries of antiquity have perished mainly by fire, water and biological degeneration. The discovery of the Dead Sea Scrolls in 1947 focused the attention of the public on a few fragments of what was the great Semitic heritage of writing and scholarship. Since our cultural foundations in writing originate in this heritage, every discovery lifts the mists from the rich, and now largely lost, literature of the pre-Christian era. Each time caches of ancient books are found, some commentator asks if there are not more texts waiting to be found. Why have some ancient texts survived and others perished? In most archaeological excavations, the only traces of writing on leather are dark stains in the soil. Occasionally, in a bog or dry cave, given remarkable conditions for preservation, a fragment or scroll will "persist". Skin is not only of great use to man for everyday use, but it is food for many life forms. It is because of its impermanence that we study its conditions of preservation. In this study, the age of the surviving objects is of great importance. Knowing the age of leather objects, one can determine a relative time frame for aging. Properly prepared parchment and vellum objects can survive in stable environmental conditions for several thou-

sand years (Reed 1972). Writing on perishable materials, such as paper and papyrus, and less perishable materials such as stone and clay, has survived, but only a sample of what existed remains.

When the sensational discovery of the Dead Sea Scrolls was first reported in 1947, most scholars responded with mistrust. Documents similar to the Scrolls had been appearing on the antiquities market for many years prior to 1947, without provenience and with mysterious "original owners". As was obvious from the excavation of the caves (Barthelemy and Milik 1955; Benoit, Milik and de Vaux 1961; Baillet, Milik and de Vaux, 1962), most of the scrolls originally deposited in the caves had been removed long before the caves' discovery. Kahle (1959) provides historical evidence that the Qumran caves were discovered in the 9th century AD. Earlier "discoveries" of scrolls were made in the first part of the second century (Driver 1965). The quantity of broken scroll cases and fragments found on the floor of Qumran I indicates that the original library was much larger than the amount found in 1947 and the following years. It is possible that the caves were "mined" of their valuable contents for some time by desert tribes. The story of the shepherd who followed a stray animal to a cave (Cross 1954) is a curiously common tale of "lost" treasure, such as the Avroman deeds (Minns 1915).

Creators of forgeries tend to fill known gaps in the archaeological record, as Kurz detailed in his classic study (1948) and I recently expanded (Caldararo 1992). In this context, the Temple scroll should be the most suspect, as it contains supposedly lost instructions on construction of the Temple of Jerusalem as well as the missing "Statutes of the King" (Yadin 1992).

The study of the Dead Sea Scroll fragments found in 1947 has been impeded by a division of the fragments among nations and scholars with restrictions on publication and translation rights. Recent events have eased this situation, and photographs of the Scrolls were circulated among scholars and students by the Biblical Archaeological Society (Shanks 1992). Misunderstandings and rumors regarding the content of the fragments were generated in the past 40 years because of the sequestration of the Scrolls and by the stalled translations (Wilson 1969).

With the release of the original photographs, the Scrolls were viewed for the first time in their entirety. However, during the 50-yr interval, the fragments had aged and deteriorated, either due to improper storage or to treatments for "improved" legibility. Comparison of the original photographs taken after discovery and the fragments now in the Rockefeller Museum in Jerusalem show, in many cases, vastly different objects. Microfilm archives of the Scroll fragments kept at the Huntington Library in San Marino, California—where the *ca.* 3000 photographs reside—seem to support the contention that the Scrolls have undergone aging expected of prepared skin exposed to normal environmental changes, hydrolysis and other agents of deterioration (Hansen, Lee and Sobel 1991). This information should be considered with caution, however, as no comprehensive comparative analysis of the Scroll material or the original Scrolls has been undertaken. Frank (1992) asserts that much of the Scroll material has faded from exposure to light. Weiner (personal communication, 1995) notes that, from his examination of a Scroll and comparison of it to a photograph taken in the 1950s, he sees no difference.

STATE OF PRESERVATION

A conference at Stanford University in 1992 focused on: 1) access to the Scrolls by scholars; 2) the relation of the Scrolls to the Essenes; and 3) the influence of the authors on the early Christian church. Little attention was paid to the physical condition of the Scrolls, their status as documents when compared to other parchment writings or to the body of the Semitic text. A brief study com-

paring the surviving Scrolls and the physical layout of the Qumran site to our knowledge of the libraries of antiquity (Pedley 1964) supported the idea of a library at the site.

Other fragments and manuscripts from the area do not conform to the manner in which the Qumran I objects are assumed to have been originally stored (Cross 1954, 1958). Kahle and Caldararo (1986) described how restoration treatment and parchment preparation methods affect the results of dating studies. Reed and Poole (1962) concluded from examining Scroll fragments from Cave 4 that they were not all made at precisely the same time or according to the same methods. Quite possibly these prior treatments or different histories of the body of materials termed "Dead Sea Scrolls" could affect ^{14}C dating. The testing procedures described by Bonani (1992), with samples taken from different parts of scrolls, would seem to mitigate contamination problems.

The wide range of treatments and exposures (Tables 1 and 2) might call for a controlled study of ^{14}C analysis applied to ancient samples with different preparations and modern samples exposed to conditions that degrade skin products and to artificially aged samples. Variables would then be: 1) preparation methods; 2) restoration chemicals and 3) chemical interactions during aging of skin components and residual reagents. Such an experiment would provide us with controlled results on contaminant removal from test samples. In the preceding article (Jull *et al.* 1995), the ^{14}C results of sample 4Q258 indicate the potential value of such a study. In this study (Jull *et al.* 1995, Table 2), the dates for their sample 1 of 4Q258 were *ca.* 300 yr younger than the paleographic dates. More intensive pretreatment of a second sample from 4Q258 fell within the paleographic range. Aging under natural conditions can show different results due to unforeseen variables (Table 3): for example, leather is unstable at a pH other than 3 to 6. A low pH can indicate an acid attack, perhaps a residue of a tanning process (Stambolov 1969). Poole and Reed (1962) found gallic acid in every sample they analyzed from Cave 4. Leather so degraded when in contact with moisture will darken, in many cases, irretrievably. In some of the Qumran caves, percolating water had so damaged scroll material that the floors of the caves were covered with gelatinous slime (Reed and Poole 1962). White ants damaged some Scrolls, and where fragments were found in a heap, covered fragments remained white whereas exposed fragments turned dark brown (Harding 1948/9).

How does one describe this darkening? Is there a comparable physical condition among objects prepared for writing in the Near East? Reed (1972) compared the surface of fragments of the Dead Sea

TABLE 1. Treatments Applied to Scrolls and Fragments

Scroll(s)	Material	Reference
Cave 1	Glycerine	Plenderleith (1955)
	Water	
	Water	Cross (1954)
		Benoit (1956)
Most scrolls	Moisture	Wilson (1969)
	Alcohol	
	Oils	
?	Araldite on Temple Scroll?*	"Araldite" (1961)
Copper scroll	Araldite celluloid in acetone Durofix	Baker (1962)

*The plastic substance reported by Bonani *et. al.* (1992) on the Temple Scroll may be celluloid, which was noted in the literature by a reference to Scott's (1927) work on an Egyptian scroll. Scott used celluloid in acetone and amyl acetate 1:1.

TABLE 2. Tests on Scrolls and Fragments

Scroll	Test	Sample(s)	Reference	Results
Cave 4	For gallic acid	Numerous	Poole and Reed (1962)	Positive
?	For tannins	?	Reed and Poole (1964); Reed (1972)	Positive for ellagic acid*
Isaiah Cave 1	^{14}C	Linen wrapping	Libby (1955: 84)	2117–1717 BP
Fragment Wadi Murraba'at Fragment from Cave 4	Shrinkage	Scroll	Burton, Poole and Reed (1959)	Relative date correlated with other methods to 130 BP† Relative date similar to Murraba'at
Isaiah-B Thanksgiving Genesis Apocryphon Temple A ? Cave 4	Effects of relative humidity	Unknown sample from Temple A was contaminated with what appeared to be PVA‡; it was not tested.	Schilling and Ginell (1993)	No overall consistency in response of Scroll fragments in relation to modern degraded parchment. Scroll fragments did respond more slowly to RH.

*Tested a variety of other leather objects from other locations and periods

†Tested by the same method as fragments of an Egyptian Aramaic letter (*ca.* 2500 BP). The results fell in an expected range of the Murraba'at fragment.

‡Polyvinyl chloride

TABLE 3. Observations Relating to Condition of Scrolls

Scroll	Observation	Citation
?	Scrolls attacked by white ants; covered Scroll fragments were white; exposed fragments were brown.	Harding (1948/49)
Cave 4	Electron microscopy shows collagen fibers in good condition, but with characteristics of aging. Light microscopy shows distribution from tannin stain.	Reed and Poole (1962) Reed (1972)*
18 Dead Sea Scroll samples; 5 from Murraba'at	Histological structures of follicles well preserved. Follicle grouping perfect only in 2. Dead Sea samples and 2 from Murraba'at. Fewer follicles found in modern parchment compared to ancient samples. In general, ancient follicles lost pigment.	Ryder (1958)† Ryder (1963)

*Samples from Wadi Murraba'at and Romano-British leather found at Catterick included.

†Samples from Aramaic Documents included.

Derrick (1991) studied fragments of the Scrolls using FT-IR spectroscopy. Her results were non-homogeneous. Test results varied from area to area within a fragment. Her samples were taken from the outer edges of Scrolls and may represent more degraded areas. Some fragments were less degraded than others: for example, Temple B and Cave IV 9A3 were most degraded, and those from Khirbet Hird were the least degraded. Sectioning and IR microspectroscopy and cross-polarized light microscopy showed that degradation products and inorganic components were concentrated on or near the surface. Alum was found only in the Khirbet Hird samples and the sample from the Temple Scroll. Silicates, presumably from pumice used as an abrasive in skin preparation, was found in all of the exterior surfaces of the Scroll pieces except for the backside of the Thanksgiving Scroll. Carbonates were found in all samples but were in greater concentrations on samples from Cave IV.

Scrolls with those of the Aramaic Documents (500 BC) and the Philistine Documents (900–700 BC). Apparently, the Dead Sea Scroll fragment and the Aramaic Documents had been treated with vegetable tannins. This was confirmed by sectioning and examination with light and electron microscopy.

The Philistine Documents were in better condition than the other two and, unless the skin was remarkably preserved, their authenticity is questionable. Other tests comparing the three Philistine Documents showed that the Philistine Documents were similar to modern parchment. For a description of the distinguishing characteristics of parchments and leather as they apply to Judaic religious uses, see Figure 1. Reed and Poole (1962) divided their samples from Cave 4 into three groups based on appearance, feel, microscopic examination and some chemical tests. These are:

Parchment-like fragments	57 samples
Gewil-like fragments	12 samples
Leather fragments	9 samples

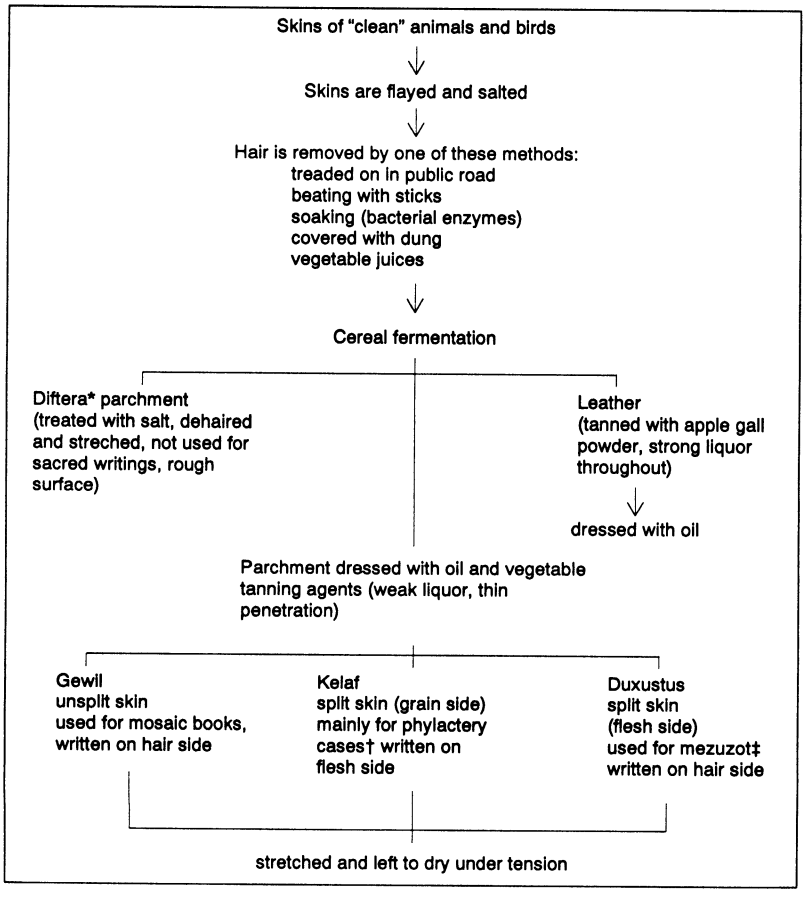

Fig. 1. Description of parchments and leather fabrication; data from Reed and Poole (1962). *Diftera: a rough parchment, suitable for everyday use; †Phylactery case: a case containing a strip or strips of parchment inscribed with passages of Scripture; ‡*Mezuzot*: pieces of parchment inscribed with texts from Deuteronomy on one side and the name of God on the other. The *mezuzah* is rolled and put into a case and attached to the doorpost of a residence.

Restorers have known for some time that faded ink can be regenerated by rubbing parchments and leather with tannic acid. Gallic acids—as well as other acids—were often applied hot and had remarkable results (Wachter 1981–1982). This may partly explain the blackened appearance of the Shapira Scrolls (Allegro 1965). Alum was often applied by restorers to increase the adhesion of ink and to prevent mold. Comparing the blackened and gelatinized areas of some of the Scrolls with parchment documents that have been exposed to acid treatments might identify which Scrolls have been treated. This might also explain some of the wide range of testing used by various researchers (*e.g.,* Weiner 1980; Schilling and Ginell 1993).

It would be interesting to continue these studies on more fragments from Dead Sea Scroll materials, the Damascus Document, the Avroman deeds (*ca.* 100 BC), Stein's leather writing fragments from Khotan, and some of the oldest surviving examples of writing on skin from Egypt (Driver 1959). Other skin documents that could provide samples for a varied series are from the Firkowitch Collection in the Russian Public Library in Leningrad. The conditions under which some of these objects were preserved are known and assumptions can be made for the others. Initial studies in this direction have had conflicting results.

Rebricova and Solovyova (1987) compared parchments with an electron microscope and subjected samples of modern, 18th-, 17th- and 12th-century parchment to enzyme attack, biochemical analysis and microorganism destruction. These results demonstrated the general stability of parchment to resist destruction, but soluble collagen varied among the samples unrelated to age, whereas sample hydrolysis by collagenase was consistent with age. Reed (1975) studied preparation methods for parchment and how these affect aging; Hansen, Lee and Sobel (1991) continued this research with vellum and parchment. Their results explain some of the mechanisms leading to variations in stability and resistance to degradation in skin products. Horie (1990) studied the deterioration of objects made of skin in museum collections, which detailed the problems in identifying ideal conditions to prevent deterioration. Hansen, Lee and Sobel (1991) found significant differences in parchment response to changes in humidity with the method of preparation, although their samples were limited to Medieval, Talmudic and modern objects. Comparing unidentified Dead Sea Scroll fragments, the authors report unpublished experiments showing that, in contrast to modern parchment, the Scroll fragments exhibited a state of deterioration "consistent with their age". They base this conclusion on the reduced extraction of collagen (70% compared with 90% for modern parchment) and on the fact that the extent of degradation varied but that evidence of denaturation, hydrolysis and oxidation were associated to a greater extent with both brittle areas and darker, discolored areas.

However, considerable damage to the Scrolls resulted from their storage in the basement of a bank. The humidity caused extensive microorganism growth, rendering some of the Scrolls illegible. The Scrolls were cleaned but no report has been published. McCarter (1992) contends that the Copper Scroll is deteriorating and has actually lost mass along the edges of the saw cuts made by Baker. If corrosion is active, steps should be taken to stabilize the Copper Scrolls. This recalls Corwin's efforts to stabilize the Copper Scrolls by reduction in the 1950s ("Unrolling" 1956). Corwin experimented with replicas of the Copper Scrolls created to mimic the metallic composition and corrosion products and adhered debris of the original. These conservation experiments showed promise, but the treatment was never applied to the Scrolls.

DATING AND PROVENIENCE

The fact that the Scrolls have been substantially altered is not so disturbing to an archaeologist as that none of the Scrolls, as we have come to know them (Table 4), has provenience. Not only are

there few completed archaeological reports for the caves and Qumran, but what has been presented as preliminary reports is inadequate, inconsistent and lacking in scientific information (Caldararo 1984–1985). None of the original Scrolls was found *in situ,* and none has been linked to any of the caves by scientific evidence. Teicher (1963) and Davies (1988) criticized the archaeology related to Qumran and the caves related to the Scrolls and their fragments. Barthelemy and Milik (1955) showed drawings and photographs of Cave 1, but as the objects were found on the surface, the loci of their discovery were not shown, nor were stratigraphic notes made.

TABLE 4. The Original Dead Sea Scrolls

1.	St. Mark's Isaiah Scroll (1QIsaa) Associated with Cave 1
2.	Hebrew University Isaiah Scroll (1QIsab) Associated with Cave 1
3.	A Midrash on the Book of Habakkuk (1QpHab)
4.	Manual of Discipline(1QS)
5.	The War of the Sons of Light with the Sons of Darkness (1QM)
6.	Thanksgiving Psalms (1QA)
7.	Lamech (Genesis Apocryphon) (1QApoc)

This in contrast to Yadin's 1963 report, which clearly depicts locations and details the excavation. Attempts to associate writing materials removed from caves by the Ta'amireh tribe are horrifying in documenting their destructive methods (Lapp 1978).

As T. B. Kahle and Caldararo suggested in 1986, the Scrolls need to be put in context, which can be done, now that the Scrolls are available for examination. The Scrolls and the fragments found in the caves, as well as other related skin writing materials found elsewhere, such as the Damascus Document, should be examined using a variety of non-destructive testing methods to build a database with which to determine their associations.

A first step would be to photograph all the fragments that came from the caves since 1947, using infrared film, and then to compare the photos with those taken by Najib Albina of the original state of the Scrolls (Sanders 1992). Unfortunately, some of Albina's negatives are now ruined. Reed (1991) has undertaken a survey of the Scrolls, fragments and photographs. If this work can be correlated with the infrared imaging of Zuckerman and Bearman (Wilford 1993), reconstruction may be possible. The bulk of these data will enable the comparison with the Scrolls as they first appeared before handling, exposure and treatments resulted in their present, deteriorated condition. As the ^{14}C data have been found to contain significant discrepancies (Rodley 1993), the Scrolls should be sampled by separate groups and assigned to independent testing sites as was done with the Shroud of Turin (Gove 1987, 1990).

One of the central controversies surrounding the Scrolls is when they were made and who made them. Linked to this is the question of whether they constituted a library, and if they were hidden or stored, as in a geniza.[1] The contents were later removed and buried (Bruce 1950). Much of the debate has centered around the history of Judea in the 200 yr before the current era (BCE), that is, before the birth of Christ, and the first 100 yr of the current era (CE). The Scrolls have been associated with the Jewish Essene and the Zakodite sects, among others, and their search for religious and cultural freedom from their Greek and Roman conquerors. The main theme of this association with

[1]A geniza is a room in or near a synagogue into which all sorts of written and printed material are deposited. The materials placed into such a room were not intended to be kept as in an archive, but were intended to remain there undisturbed for a certain time (Kahle 1959).

various sects is the emphasis that the Scrolls were hidden to prevent their destruction. This is curious, as neither the Greek Selucids nor the pagan Romans had a record of destroying the written works of their subjects. The Romans suppressed the religious works of only one group up to the first century, the cult of Isis (Gibbon 1932). The Ptolemys were known to seize the libraries of peoples to enhance their great collection at Alexandria.

Schiffman (1992) suggested that the Scrolls and the fragments from the caves were stored before the early Christian church had developed the New Testament. He also emphasized that the body of the Scrolls and the fragments from the caves constitute a variety of materials that do not fit the concept of the library of a narrow sect. This is a nebulous idea and introduces the prospect of an interesting study: to compare the contents of the Gnostic library discovered at Nag Hamadi and that of the Manichean writings found at Turfan with those of the Dead Sea caves and scrolls. Do they each represent a single type of collecting and purpose, or do they have similarities? Pedley's (1964) efforts provide some background information, but no firm conclusions.

Do the Dead Sea finds constitute a library or a geniza? First posed by Sukenik, this question was investigated in some detail by Del Medico (1958). Do the documents found in the Dead Sea caves compare with the remnants of the Cairo Geniza or the Islamic documents found in the walls of the Great Mosque of Sanaa (Dreibholz, 1983)? Here is a link to wider influences in the religious literature of the Middle East. We know that the Karaites were influenced by writings found in caves, and in the works of Ja'kub al-Kirkisani written *ca.* 937 are references to a Jewish sect he calls "cave people", who were active after the Sadduces and before the Christians. The Karaites refer to them as do Muslim writers of the same period. This leads to a third possibility, that the collection of writings in the caves were not deposited in haste, but were part of a community that lived in or near the caves where the writings were kept.

Kahle (1959) suggested, from considerable evidence, that the Karaites had removed several Scrolls from the caves near Qumran *ca.* 800 and that the fragments of Scrolls—especially the Testament of Levi—found in the caves probably belong to these Scrolls. It seems curious though, that they would remove only a few Scrolls. It seems more likely that the Scrolls were controlled by the desert tribes even then and that they sold these earlier few from their cache in the same manner as they did in the 1940s.

A fact that is only beginning to become clear is that the body of writings from the caves of the Dead Sea is varied and rich. This quality was also noted in the Gnostic library of Chenoboskion (Jonas 1963). Another striking similarity is that the teachers of the literature of Chenoboskion are never identified by name, as is true of the Dead Sea writings. Jonas (1963) noted the numerous similarities in the Dead Sea writings and those of the Gnostics and even conjectured a contemporary link between the Essenes and Gnostics. It is likely that we underestimate the number of desert religious communities of antiquity and their distribution and interaction. Gibbon remarks, quoting various contemporary sources, that a fugitive like Athanasius could elude capture by the Roman military and civil authorities in the wastes of Egypt and Palestine due to the community of ascetics who survived there.

SURFACE TREATMENTS

A treatment that would reveal much about the Scrolls is rubbing with oil of cedar. Thorough sampling of the original Scrolls and fragments with infrared spectroscopy (FT), emission spectroscopy and particle induced X-ray emission (PIXE) would establish a firm database for comparison. Kahle (1959) quotes from the pseudepigraphic work, *Assumption of Moses*, which dates from the begin-

ning of the current era, that one should anoint books with oil of cedar and place them into earthen vessels. This was advised to protect them for all times "to the end of the days" (Kahle 1959: 15). In Cave 1, two Scrolls were found still wrapped in linen and sealed in ceramic jars. Some of the Scrolls and fragments were covered with bat dung, especially the Book of Lamech (Genesis). Had they been removed from earthen vessels by looters? Can scrolls and jars be associated in cases where the jars exist only in fragments?

At separate intervals after discovery, the Scrolls and the numerous fragments were treated by various methods to unroll them, to clarify the writing and to preserve their surfaces or ink, increasing the likelihood of contamination. Wachter (1962a, b) and Stambolov (1969) describe the use of parchment size (a glue made from parchment scraps) sprayed or painted on to the surface as a consolidant, a practice well known and widespread by the 10th century. Reed (1972) noted the use of castor oil applied either "neat" (undiluted) or with an organic solvent to increase the flexibility of parchment documents. Plenderleith (1955) found that fragments were permeated with a black bituminous substance which he identified as a decomposition product of the skin. Wilson (1969) reported extensive treatment with moisture and oils, including castor oil, to remove clay from the surface or to relax the skin. Some of these uses may be derived from Wachter (1962b) who listed spermaceti, sperm oil, neatsfoot oil, lanolin, milk, unbleached beeswax, Japan wax (from sumac plants) and Zapon (nitrocellulose applied in acetone).

Driver (1965) noted that some letters had been re-inked in the Isaiah A Scroll. Although contemporary repairs, corrections and marginal notations are common in the Scrolls, these re-inked letters appeared to Driver to be very recent. Milik, de Vaux and Baker (1962) reported the use of celluloid in acetone, which was a popular consolidant at the time (Caldararo 1987). Wachter (1962b) noted that the use of celluloid in organic solvents also provided sterilization against microbes. Baker (1962) described the use of Araldite 102 with hardener 951, and toluene for increased penetration of the Copper Scroll, and Durofix.

R. J. Gettens developed a method to unroll the Lamech Scroll (Genesis Apocryphon), humidifying it in a chamber at 50% relative humidity (RH) ("Unrolling" 1956). The Scroll was removed before he could try the method, but in 1955, N. Aviged, Yadin and James Bieberkraut used a similar method, at 75–78% RH at 17°C ("Unrolling" 1956; Yadin 1992). Benoit (1956) also reported a similar method. Plenderleith alternated humidity to relax and consolidate the skin with refrigeration to consolidate (Bruce 1950).

Stegemann (1991, 1992) developed an ingenious method for re-assembling scrolls from fragments based on wear and deterioration. He matches the pattern of both processes in the fragments as they would develop in a scroll. He uses clues such as color to associate missing pieces with acids. Color often reflects varied exposure to light (Harding 1948/9). Stegemann also uses ruled lines as clues to association. However, Driver (1965) believed that ruling was not consistently applied in the creation of the Scrolls, and that ruled texts are nearly absent in pre-Christian times.

Rabinovich (1994) reported that Scotch™-type, pressure sensitive tape, used to hold fragments of Scrolls together, darkened and stained the skin. Conservators used fuller's earth (an impure hydrous aluminum silicate) to remove the tape and adhesive, sometimes restoring obscured writing. This is curious, as pressure-sensitive tapes like Scotch™ tape usually age in a fashion resulting in embrittlement of the adhesive and detachment of the carrier film (Feller and Encke 1982). At this point, the adhesive is so brittle that it must be removed with organic solvents or by mechanical means. In some cases, the related stains can be reduced on paper objects (Caldararo and Sheldon 1992). From tape that has not aged so much as to become embrittled, the carrier can be removed using directed hot air

or a hot spatula, and the remaining adhesive picked up with a granular material such as fuller's earth. This is probably what Rabinovich (1994) described.

Conclusion

A detailed and systematic study of the physical aspects of the Scrolls is clearly needed to analyze preparation residues, traces of ritual use, degradation products, aging characteristics and treatment residues and effects. Such an investigation will then lead to a body of knowledge with which one can compare the Scrolls to other samples of ancient writing from which an analytical context can be developed. This context will enable us to better understand how to associate fragments as well as how to regard variations in dating methods among associated and non-associated remains.

In this paper, I have surveyed the published literature and abstracted information on storage and restorative treatments used in preserving the Dead Sea Scrolls for further study. A more thorough and formal survey should be organized to query those who have executed treatments on the scrolls. T. B. Kahle and I have made numerous queries over the past ten years, only one of which was answered (by H. Plenderleith). Although many of these individuals have passed away, information may still be available in notebooks and other personal papers. It is time for a concentrated effort to gather this material and make it available to the laboratory researchers who are attempting to date the Scrolls.

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