Theories of Papyrus Manufacture and the Conservation Treatment of Papyrus

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1 Introduction

Papyrus is an ancient Egyptian writing material made from the papyrus plant. It has been one of the most important vegetal writing materials in history, and for Egyptian industrial arts one of the most useful plants ever known in the world, growing in every marsh (Erman, 1894).

It represents the first writing material at all comparable with our present-day paper. Papyrus was used as a writing material in Egypt for several millennia; it is made from the pith of the papyrus plant; it was used from at least 3500 B.C. until the 11th century (Gilmour, 1956). Sheets and rolls of papyrus provided an ideal surface for writing with reed pens and cakes of carbon black and red ocher pigment. Egyptian scribes were able to record on papyri everyday details. Papyrus is the writing material closest to paper in some of its characteristics, but it differs in that the vegetable fibers of which it is made are not isolated as are those for paper in the phase preceding the fabrication of the sheet (Hunter, 1974). The Egyptian climate, however, was the only one favorable to its conservation, and almost all the items that have come down to us were found in that country (Menei, 1998).

2 Characteristics of Papyrus Plant

The papyrus plant (*Cyperus papyrus*; its name is the ultimate source of our word paper) is a kind of sedge (*Cyperus papyrus L.*) which grows in the shallows of rivers and lakes in many parts of tropical Africa. By the 19th century increased cultivation had destroyed the reed's native habitat, so that it was believed that papyrus had become almost extinct from Egypt more than 150 years earlier. El-Hadidi (1971) reported the occurrence of a few strands of papyrus growing wild along the shores of Lake Umm Risha, in the Wadi Natrun area. The plant grew abundantly along the banks of the Nile River, in marshy areas. At present the plant grows indigenously in the area of the upper Nile in the Sudan. Recently it has been cultivated near Cairo.

The plant grows to about four meters high and has a tall, green triangular shaped stem, which is wide at the base and tapers to the top, where it separates into a wide flower-head or umbel as shown in Fig. 1.

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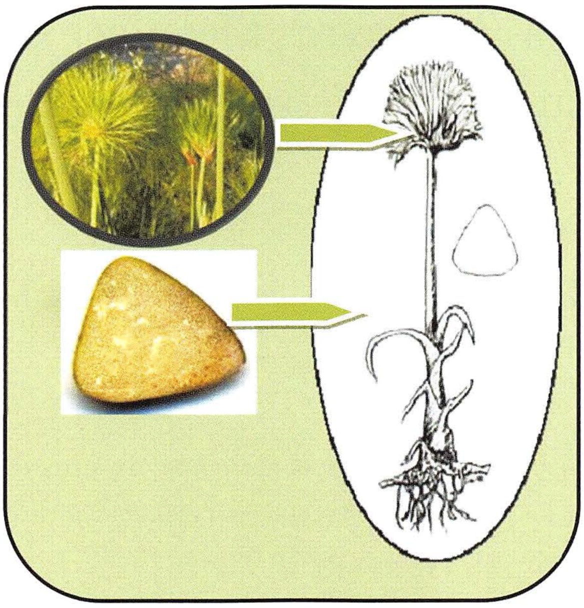


Fig. 1 Papyrus plant and cross-section of stem of papyrus
(http://www.snv.jussieu.fr/bmedia/papyrus/12-tige.htm)

The stem is approximately five to eight centimeters thick. The base is surrounded by broad, spear-shaped leaves. The leaves are formed at the base of the stalk (Fig. 2).

Fig. 2 Base of the stems
(Photo by Eve Menei, http://www.snv.jussieu.fr/bmedia/papyrus/12-tige.htm)

Where umbels and stalks emerge from what is called the rhizome, a horizontal, root-like stem that sends out shoots from its lower surface and leafy shoots from its upper surface, usually in a horizontal position, grow horizontally along the soil. The rhizome is often thick and contains the reserves for nourishment (Fig. 3).

Fig. 3 Papyrus produces thick rhizome creeps horizontally along the soil, it has roots (http://www.pflanzenblog-in.de/2008/04/19/cyperus-papyrus-rhizome-zur-vermehrung/)

2.1 Anatomical Structure of the Papyrus Stem

The stem encases the papyrus pith, from which the writing material is made and in which fibers are embedded that carry nutrients from the roots to the umbel. The pith, or parenchyma, is cream colored with a spongy texture and high cellulose content, but the fibers are woody or ligneous; thus, the plant is suitable for producing sheets of paper as the fibers give rigidity and the pith substance to the manufactured sheet. Papyrus has some specific qualities, for example, a high content of the parenchyma cell.

A magnified cross-section view of the soft white pith reveals that the pith is made up of many relatively large parenchyma cells building vertical air-tubes. Parallel to these air-conducting intercellular spaces run a large number of fibro-vascular bundles that serve to transport nutrient and water from the roots to the flowerhead and give rigidity to the structure. Sometimes the fibro-vascular bundles are interconnected by slanting thin fibrous bundles. The intercellular spaces are built up lengths out of the parenchyma cells that are vertically arranged in a stacked honeycomb-like network.

In the cross-section, these parenchyma cells appear to be circularly arranged around the air-tubes (Figs. 4 and 5). The parenchyma cells are usually empty, but may sometimes contain one or more calcium oxalate crystals (Wallert, 1989).

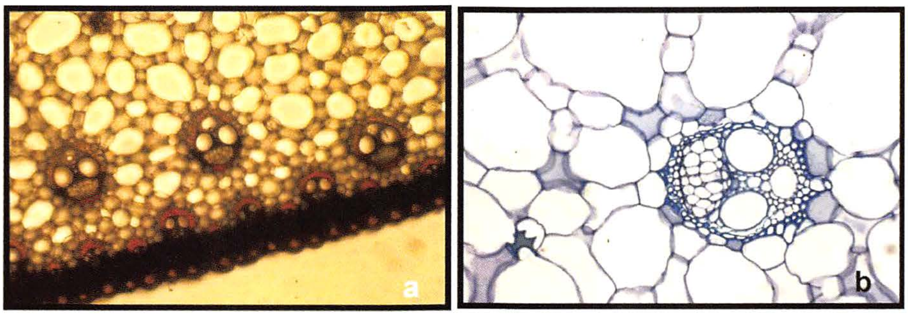


Fig. 4 (a) Handmade section: acid fluoroglucine staining: the lignified tissues (part of the vascular boundless and the epidermis) appear red; (b)Cross-section of fresh papyrus showing vascular bundle and parenchyma cells, circularly arranged to form air-tubes, 100x (E. Franceschi, et al., 2003)

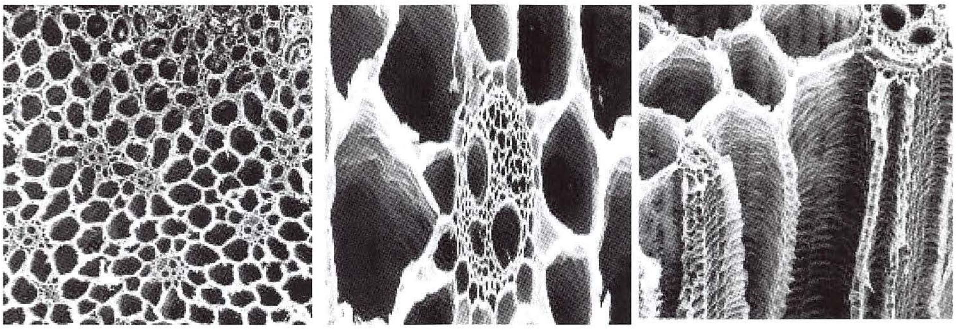


Fig. 5 Detail of the central stalk region of papyrus perspective (SEM).
The unicellular form of the parenchyma blades limits gaps
(http://www.snv.jussieu.fr/bmedia/papyrus/12-tige.htm)

2.2 The Chemical Composition of Papyrus

Papyrus is composed of about 57% cellulose, 27% lignin, 9% minerals, and 7% chemically bound water. The pith material consists mainly of cellulose (54-68%) and lignin (32-24%); the proportions are based on variables such as age, manufacturing process and environmental effects (Weidemann and Bayer, 1983).

3 Papyrus Paper

The most important use of papyrus was as a material to record writing. The papyrus manuscripts are considered part of the national heritage and are scattered all over Egypt in the libraries of monasteries, private collections and societies, and are found especially in Egyptian, Coptic and Islamic museums. The general characteristics of papyrus sheet are its thinness, elasticity with smooth texture, extreme durability, high resistance to tension and pressure, lightweight, satin-like feel, non-porousness, and its bright, color ranging between yellow and brown (Waly et al., 2002). The papyrus plants are also used for making boats, boxes, ropes, sandals, a floral collar (Fig. 6), cartonnage, and as the wrappings and bandages of animal mummies etc. (Abd el-Maksoud and El-Amin, 2013).

Fig. 6 Small papyrus box, floral collar and sandal from papyrus decorated with sema-tawy symbols, from Tutankhamen's tomb. Valley of the Kings, Egypt, 18th dynasty (New Kingdom), 1332-1323 B.C.
(Left: http://www.egyking.info/2012/03/tutankhamun-papyrus-box.html, Middle: http://www.metmuseum.org/toah/works-of-art/09.184.214-.216, Right: http://www.agefotostock.com/en/Stock-Images/Rights-Managed/FAI-18085)

3.1 Theories of Papyrus Manufacture

When we think of ancient Egypt we think of papyrus paper. Egypt was its inventor. The principle importance of papyrus was as a surface for writing and illustrations. It is still unknown, though, exactly when papyrus was created in Egypt as a writing material. A papyrus sheet is a laminate structure composed of fibers running vertically in one layer and horizontally in the other layer. This is what gives papyrus its characteristic grid pattern when viewed in transmitted light (Owen and Danzing, 1993).

Much about the history of Egypt and the ancient world came down to us as recorded on papyrus paper. It was in use by First Dynasty, about 3100 B.C., as attested to by the hieroglyphic sign of a papyrus roll, which has also been considered the image of a book. Such rolls of papyrus have been found at early sites. In the First Dynasty Tomb of Hemaka, a roll of papyrus was discovered, but, alas, it was blank. Small fragments are known from Fifth Dynasty, 2477-2467 B.C., at King Neferirkere's temple at Abusir near Giza, and these fragments are now housed in Cairo, Berlin, and University College London. Therefore, it was in production in the Early Dynastic and Old Kingdom periods. Usually rolls of and documents on papyrus were kept in wooden chests, in jars, or in sacred statuaries.

3.2 Papyrus: Secret of the Egyptians

Although the making of papyrus as a writing support is almost 5,000 years old, not a single written description by the Egyptians exist to explain their process. Pictorial displays in tomb murals and carvings do not reveal the process of sheet formation; however, these pictorial displays often depict the papyrus plant (Fig. 7) (Owen and Danzig, 1993).

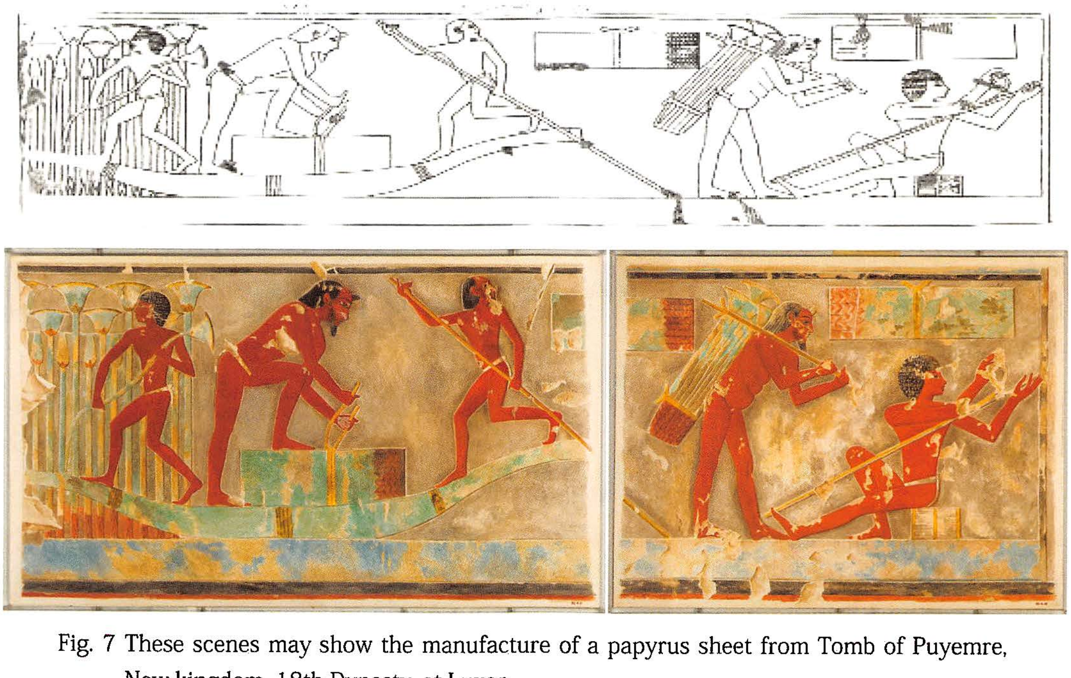


Fig. 7 These scenes may show the manufacture of a papyrus sheet from Tomb of Puyemre, New kingdom, 18th Dynasty, at Luxor
(Lower left: http://www.metmuseum.org/collection/the-collection-online/search/544591, Lower right: http://www.metmuseum.org/collection/the-collection-online/search/544592)

Only one document by the Roman naturalist Pliny the Elder, the author of *Natural History,* xiii, 74-82, described in detail specifications for the manufacturing of papyrus. Unfortunately, this description is ambiguous and lacking in details.

Attempts to conduct reconstructions of the manufacturing process remained unsuccessful for a long time. Reconstructions beginning with James Bruce (1790), by Stoddard (1834), and finally by Lucas (1928) did not meet with much success. Only the method followed by Perkins and Gunn (1930) yielded a more or less usable product. Modern study and experiments by Lewis (1974), and Ragab (1980), have resulted in a method that is now commonly accepted as the classical manufacturing process. Commercially produced papyrus sheets by Ragab and El-Kattan do indeed show some resemblance to antique papyri (Wallert, 1989).

The different ways to cut the papyrus stem lead to different methods for making the papyrus sheet (Fig. 8).

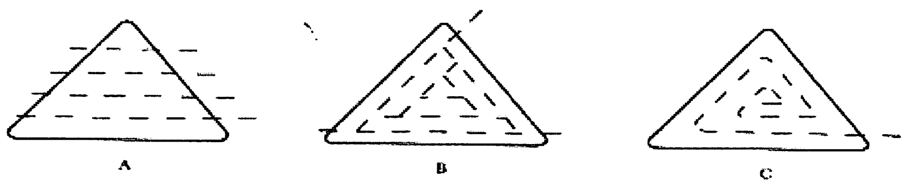


Fig. 8 Three suggestion as to how papyrus pith was cut: A) cutting from one side (the Ragab method); B) cutting from three sides (a method suggested by Corrado Basile), and C) peeling (the Hendricks method) (Parkinson and Quirke, 1995)

3.3 The Strips Method (Traditional Theory, Classical Process)

Although we have no record of how ancient Egyptians produced the paper, modern scientists have experimented with the plant using this method, known as the strips method. The following steps are probably closest to the method used (Fig. 9).

1- A stalk of papyrus is clipped near the base, and just above water level the stem is cut into pieces of the required length (usually about 30 cm).
2- The outer layer is removed. Then strips are cut along the pith either parallel through the triangular shape or along the sides of each triangular face.
3- The strips should all be around the same length and thickness to create a constant shape for the sheet. These strips are put under water to achieve water distribution in the parenchyma cell and to make the strips flexible. Also, soaking the papyrus strips is important for activating the plant's natural juices, which act as a glue to hold the strips together. In ancient times, it was thought that the Nile waters were essential to the papyrus-making process. In water the papyrus strips acquire a slightly brownish appearance.
4- The strips are then laid down on a smooth surface, parallel, and one by one, just touching or slightly overlapping each other by 1/16 inch. There is still some discussion as to whether the strips were butted up to each other, or overlapped. Examination of ancient material suggests that both methods

could be used (Leach and Tait, 2000).

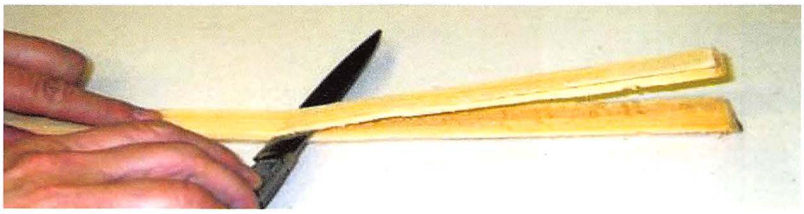
5- Then a second layer of strips is laid on top of and perpendicular to the first.

6- Pressing and/or hammering with a mallet or stone brought the strips together, and the fibers of the two layers intertwined (Bloom, 1999).

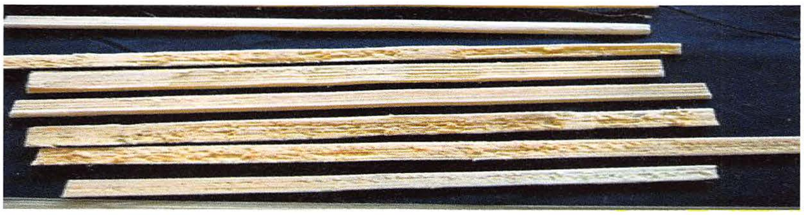
7- When the strips have all been laid out, they are covered with a sheet of linen and felt, and then sandwiched between two boards in a press. The sheet will remain in the press for a few days until it is dry.

8- When the sheet is dry; it is removed from the press. Initially, the surface of the papyrus is somewhat rough. It may be burnished slightly with a stone, or the paper is polished with a piece of ivory, or a shell, to flatten and smooth roughness. The ends can be overlapped and hammered together to make longer sheets.

(a) Removing the outer rind



(b) Slicing pith into strips



(c) Strips of papyrus

(d) Strips of papyrus after soaking

(e) Laying down the first layer of strips, then laying down the second layer at right angles

Fig. 9 The stages of strips method
(http://www.lib.umich.edu/papyrus_making/)

Then the paper is ready to receive writing.

The papyrus is made by these methods, and the overlap between the strips is much too obvious because the grid pattern is apparent when it is viewed in transmitted light (Fig. 10).

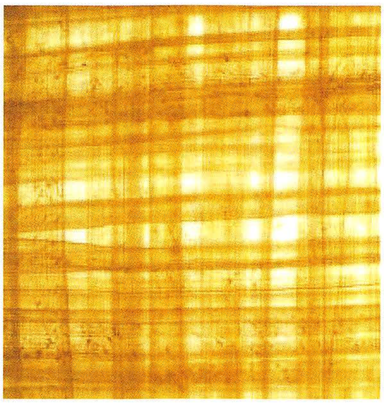


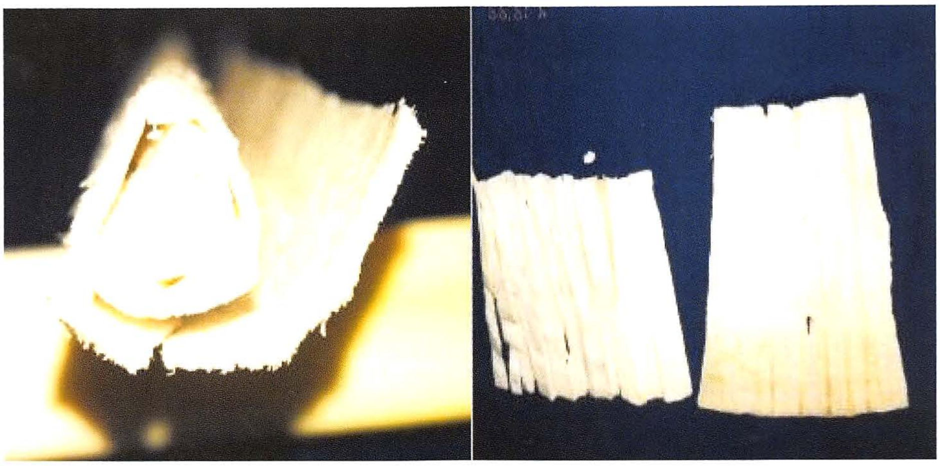
Fig. 10 The grid pattern of the papyrus sheet is made by the strips method
(http://commons.wikimedia.org/wiki/File:Blank_papyrus_paper.jpg)

3.4 Peeling Method

A second, more recent theory of the ancient manufacture of papyrus sheets was derived from an interpretation of Pliny's description of the process. The pith was not cut into strips, but was peeled continuously down to its core. This method uses the following steps:

1- The outer rind of the papyrus is first removed.
2- Next, the needle is moved parallel to one of the sides from the top downwards.
3- When the second corner is reached, the pith is simply turned through 60 degrees so that the peeling is continued without interruption.
4- Thus, the stem is peeled continuously down to its core so that it opens into one single sheet (Fig. 11).

(a) The pith is peeled down to its core (Effendi, 1999 and Wallert, 1989)



(b) Two of the peeled layers pressed together perpendicular to each other to form single sheet

Fig. 11 The Stages of peeling method (Effendi, 1999)

5- Two of these peeled layers were then pressed together perpendicular to each other to form a single sheet of writing papyrus of good quality. A sheet made from peeling would have avoided a lattice-like effect, as is seen in modern papyrus.

The adhesive was used only to join the individual sheets to form a roll (Fig. 12).

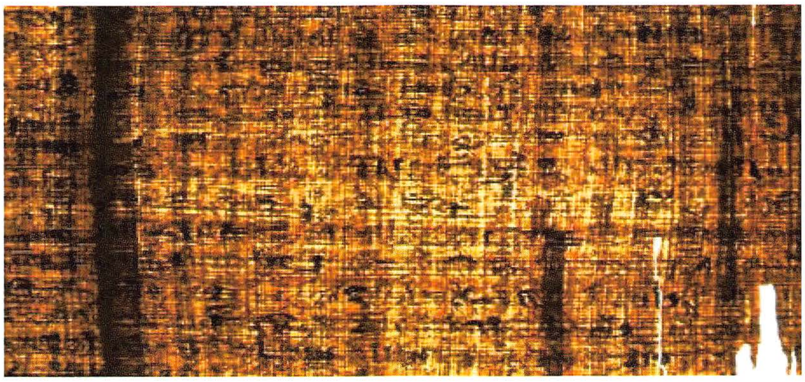


Fig. 12 An adhesive to join the individual sheets to form a roll, which was used by the ancient Egyptians
(http://www.brooklynmuseum.org/community/blogosphere/wp-content/uploads/2011/01/Image-032.jpg)

In a more recent study, it has been suggested that both methods may have been used in antiquity.

The third process for making papyrus is as follows:

The outer layer of the plant is removed; the inner layer of the plant is sliced into thin strips, these strips are soaked in water, and then weaved together by pressing them for hours (Fig. 13). The natural sugar in the plant acts as glue holding the strips together.

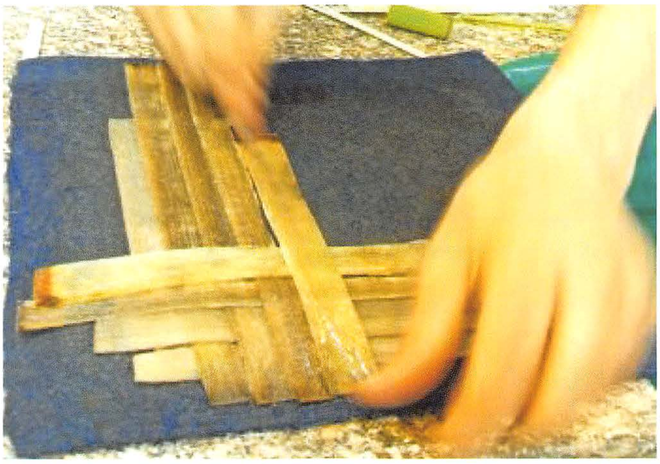


Fig. 13 The third process for making papyrus
(T. Jeremy, http://farm7.staticflickr.com/6025/5960430916_2f35b28218_z.jpg)

4 Reasons for Adhesion or Bonding of Two Papyrus Layers

Many writers in the past and present times gave different explanations as to how the papyrus layers adhere together to form a papyrus sheet.

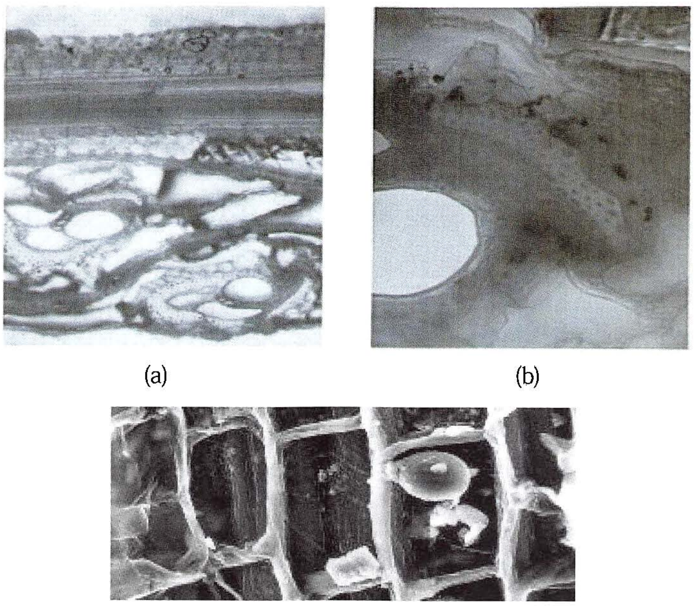
Pliny attributed adhesive properties to colloidal matter in muddy Nile waters (Dimarogonas, 1995). Ragab showed in his studies which carried out in Ragab Papyrus Institute at Cairo, that mud carried by Nile water does not play any adhesive role. More recently, Wake suggested that the suspended silt and microorganisms, present as colloidal suspension, might at least supplement other adhesive agents.

Basilell noted that Nile water always contains "Natron" (sodium carbonate/bicarbonate). Then he found that Natron often contained a considerable proportion of aluminum sulphate. Trials with this appeared to give an improved product. Also his chemical analysis of an ancient Egyptian papyrus showing 4.05% aluminum, while fresh papyrus reed from Syracuse showed only 0.009%. Thus the idea of additional aluminum salt having been introduced into the papyrus writing material was supported, so the relevance of the river water may be vindicated (Allen, 1996).

Reynolds carried out considerable chemical analysis on papyrus plants, no starch could be detected. Then he examined a cold-water extract from macerated pith. Fairly extensive analysis revealed the presence of araban, galactan and a little rhamnan, as well as some nitrogenous material. These polysaccharides (derived from arabinose, galactose and rhamnose) are all well- known as natural gums. Clearly these are suitable and appropriate for bonding in the papyrus writing material (Allen, 1996).

Ragab has argued that the sap of the reeds plays no part in the adhesion. He proposed the notion that physical bonding is the main reason for the lamination of the horizontal and vertical layers. Ragab attributes the bonding to the intimate physical entanglement of the fibers and suggests that it is closely similar to paper (Ragab, 1978).

By 1979 experiments by Wiedemann carried out using cuts of Egyptian papyrus with microtome clearly showed the two layers, in length and laterally (Fig. 14). Tests with iodine/potassium iodide proved the non-existence of a starch adhesive. Only isolated grains of starch, grown in the papyrus plant, are clearly visible (Wiedemann, 1979). By using polarized light microscopy, it was also possible to detect starch granules within the plant tissues. The same compounds are also detectable in sections of modern and ancient papyri sheets (Fig. 15).



(a) (b)

(c)

Fig. 14 (a) Microtome cut shows the two layers, in length and laterally-250x, (b) Grain of starch, grown in the papyrus plant-1000x, (c) Ancient papyrus showing large grain starch seams (SEM)

(a, b; Wiedemann, 1979, c; Photo by Marie-Caroline Bignicourt, http://www.snv.jussieu.fr/bmedia/papyrus/22-micro.htm)

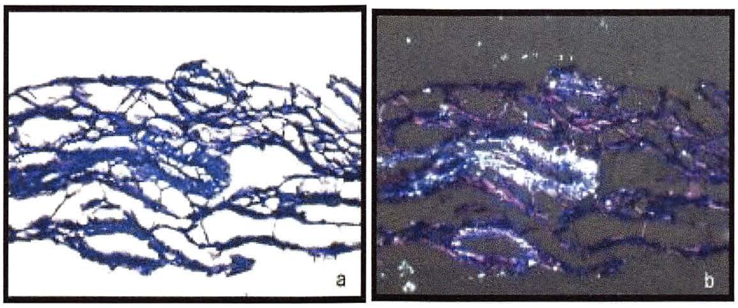


Fig. 15 A section of papyrus sheet using polarized light microscopy
(E. Franceschi, et al., 2003)

Modern views of the structure of paper attribute its structure and strength to the formation of hydrogen bonds between the very fine fibers which have been formed by vigorous disintegration of the pulp from which the paper is made. There is nothing comparable to this "beating" or the totally random suspension of fibers which it produces during the production of papyrus (Hunter, 1974). Allen followed the conclusions of Hepper and Reynolds that the principle agent is the sap of the papyrus reed, and entirely support this conclusion (Hepper and Reynolds, 1967). It has been shown to be of an entirely appropriate chemical composition and is entirely consistent with my own examination of specimens of the ancient material. The aluminum salts present in water from the Nile may have had some role in providing a satisfactory writing surface (Allen, 1996).

5 The Museums' Collections of Papyri

The general condition of the papyrus collections in the museums is poor as a result of age, improper previous treatment, questionable housing methods, and poor climate control. Most of the condition problems found on the papyri were similar to those often seen with works on paper. For example, previous restorations such as Western paper backings and repairs made with many small pieces of pressure-sensitive tapes were noted. Inherent problems included deterioration of the papyrus from the corrosive action of copper-containing pigments and flaking paint. Staining and resinous-like accretions were found on the surfaces of many pieces. Environmental factors influence the condition of papyrus as well. Fluctuations in humidity contributed to the growth of mold and to salt migration on the surface of many papyri stored within glass sandwiches. Evidence of insect damage was observed with associated losses in the papyrus. Several pieces have symmetrical losses which span the sheet, indicating the damage occurred while the papyrus remained rolled. In a few cases, inactive egg casings were found as well as insect impressions in the paint layer.

6 Deterioration Factors of Ancient Papyri

Although papyrus is flexible when newly made, it will deteriorate like any other organic materials (Leach and Tait, 2000). Papyrus was always subjected to tears and breaks at the hands of the reader. If kept in unsuitable conditions papyrus can suffer through hydrolysis, becoming more yellow-brown, or oxidation, becoming weaker and more brittle. A sheet can eventually decay into a skeleton of fibers and a handful of dust. When in storage, a roll can grow mold or rot with the damp and can be eaten by rodent or insects, particularly by white ants, when it is buried. Also, the manner in which papyrus was discovered in modern time has often compounded the damage because many papyri were not excavated in ideal conditions (Parkinson and Quirke, 1995).

Most of the problems encountered are caused by unsuitable old restorations. Scientists were often only interested in unrolling the papyri and reading the texts (Menei, 1998).

In the past century papyri were unrolled directly onto backings of white or colored paper or acid cardboard. Once unrolled, papyri were cut into convenient sections for mounting. Unfortunately, the backing has deteriorated owing to the poor quality of the paper and the board used. This can, in turn, cause damage to the papyri. Sometimes the papyrus conservators secured the sheets of papyrus onto a film of gelatin (with or without cellulose nitrate adhesive) or laid them directly onto waxed glass, or Goldbeater's skin. These films degrade over time and gradually become black.

The papyri were unrolled and mounted onto celluloid film that was burnt (Parkinson and Quirke, 1995).

7 Treatment Conservation of Papyrus

7.1 Conservation Aims

The aim of papyrus conservation is to stabilize the objects to prevent any further damage. Therefore, minimum intervention is carried out for the actual physical conservation which is concentrated on cleaning, straightening fibers, removing all the previous repair tapes, joining and repairing the fragments, a treating mold.

The most important principles of papyrus conservation are that the treatment should preserve the object while maintaining its historical integrity. The treatment should also be reversible, in case the treatment is unhelpful or inappropriate in the long term.

7.2 Documentation (The First Step before Conservation)

After photographing all fragments, the fragments should be inspected by the conservator for damage.

For each fragment a documentation form should be filled out as follows:

Inventory: locally assigned inventory number
Date: date (or estimated date) of the fragment
Place: place (or estimated place) of the origin of the fragment
Subject: brief description of the contents of the fragment
Dimensions: Measure the fragment by placing it on top of a millimeter of paper. Measure the length from the beginning of the roll to the end

Color: e.g., light cream, light brown, medium brown, dark brown, charcoal brown
Consistency: e.g., strong, friable, delaminated fibers
Conditions: e.g., pests, fire, water, or mold damage, mud, salt, dirt, other

Inks:
Lamp black (soot): black, 300 B.C.E.; usually stable in water
Iron-gall: brown, 3rd, 4th Century; often one can detect ink burns
Mixed (lamp black and iron-gall) ink: brownish; mixed ink can be water soluble
Green ink: verdigris from a pigment containing copper
Condition of ink: e.g., strong, flaking off, missing, rubbed off, faded

Direction of the fiber: The most common practice was to use the side with the fibers oriented horizontally as the recto (front) -the fibers are parallel to the long edge of the roll; on the verso (back), the fibers are vertical
Photo documentation: before, during and after treatment (Lamb, 2005)

After examination and documentation of the papyri, practical conservation can begin. Conservation treatments include: testing inks, consolidation, solvent treatment, joining and repair, aqueous treatments such as blotter washing and humidification, stain reduction and enzyme treatments. The use of facings and the vacuum suction table were found inappropriate.

7.3 Testing Ink

Before any treatment is started, test the inks in the papyrus in several different areas: with a moist cotton swab or an eyedropper, drop one tiny drop of water over the ink and then cover this area with a small square of blotting paper and a glass weight. Check both the cotton swab or the blotter and the ink after a few seconds (up to two minutes or longer, if a wet treatment is anticipated) and make sure the color does not bleed or smear. Do the same test with ethanol or a mixture of ethanol and water.

7.4 Fixing Ink

When ink is lifting or very flaky, run some thin methyl cellulose or hydroxy propyl cellulose (HPC) underneath it from a fine sable brush (no. 00) and tack the ink down very gently with a mini spatula. A very thin wheat starch paste can also be used.

7.5 Mechanical Cleaning

Cleaning is always necessary before carrying out repair work because of the undesirability of dirt particles becoming trapped in the repaired area (Murrell, 1971).

This process can be done with a soft brush, and when the fibers of the fragment are not too fragile.

Always brush in the direction of the fiber from the middle to the edges. In some cases where the mud is very heavy, the dirt can be loosened up with a bristle brush. Then gently blow the dirt off, with a sharp pointed tool (such as fine-pointed tweezers or dentist's tool), also using just air to remove loose particles by blowing with a rubber air bulb. Both recto and verso should be cleaned this way if time permits. For conservation tasks ranging from removing dirt to aligning individual fibers of the papyrus, specialized tools are required. These tools range from a cotton swab to high-quality surgical steel picks and tweezers (Lamb, 2005).

7.6 Removal of Poor Quality Tape

Sometimes in an old improperly repaired conservation, many fragments adhered with numerous small pieces of brown tape, glassine tape, gummed paper and pressure-sensitive tape before being placed inside the glass sandwiches have to be removed. Removal off such kinds of this tape is necessary due to the non-archival nature of the adhesive and because many of the joins held with the tapes were not perfectly aligned. By flooding the tapes with the solvent and slowing evaporation with a Mylar cover for approximately 10-15 minutes, the tapes and adhesive can be mechanically removed. The tapes and adhesive can also be moistened very lightly with a brush or damp blotter and after a few minutes, the tape can be lifted or peeled away. Ethanol and toluene can be employed to swell the adhesive, which then has to be removed with tweezers or cotton swabs soaked in solvent. These solvents have not had any effect upon the papyrus or the paint layers.

8 Humidification of Papyrus

Humidification is an essential part of the conservation of papyrus. Especially when dealing with water sensitive objects the application of moisture creates problems.

To achieve controlled humidification of papyrus, different aides have been found particularly useful, for example: the use of an expensive high-tech-like ultrasonic humidifier, and a humidification chamber or moisture permeable materials like 'GORE-TEX.' The application of permeable materials known by their trade name as 'GORE-TEX,' which' is a membrane, are specially treated with expanded polytetrafluoroethylene (PTFE), which is a material with similarities to Teflon. The use of moisture permeable materials for this purpose, which allows humidity to reach the object without wetting it, offers an easy and inexpensive technique for the humidification of water-sensitive objects like fragile papyrus, which also using for removal of residual adhesive, and the removal of old lining from the papyrus. 'GORE-TEX' is suitable for conservation treatment. Due to its porous structures and the hydrophobic character of the 'GORE-TEX' membrane it prevents water and a mixture of water with polar solvent in liquid from penetrating, but it is permeable for gases like water vapor and solvent vapor (Dobrusskin, 1990) (Fig. 16).

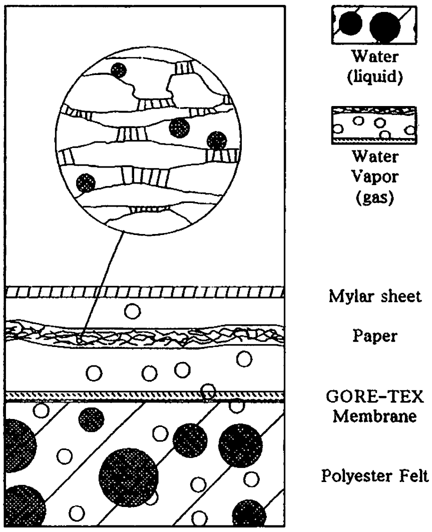


Fig. 16 Illustration which shows how small droplets are stopped by the 'GORE-TEX' membrane from penetrating and wetting the paper, but water vapor still migrates through the membrane. The cellulose fiber of the paper absorbs this water vapor and can bind to it in a semi- liquid state (Dobrusskin, 1990)

The characteristics of 'GORE-TEX' enable the conservator to treat papyrus with water vapor in very controlled way. For humidification treatments it is advisable to build a 'GORE-TEX' sandwich (Fig. 17).

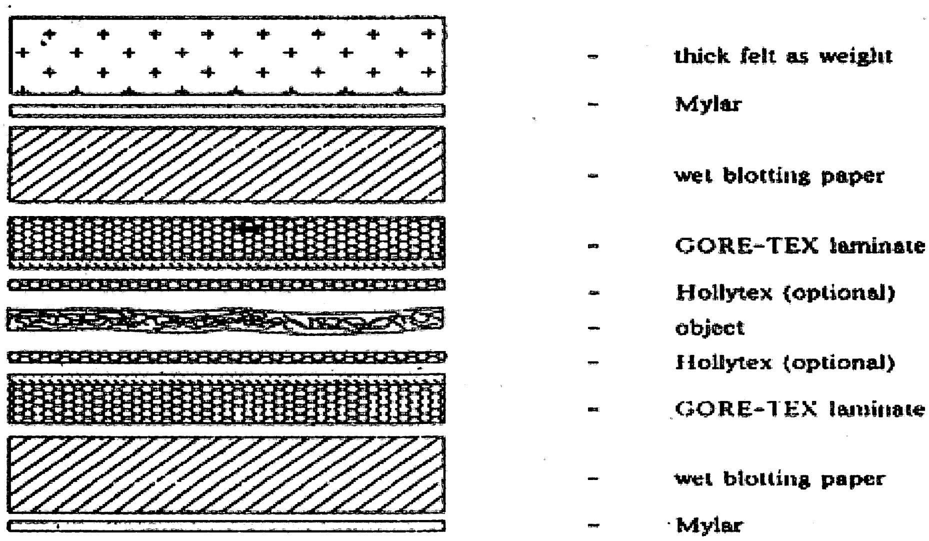


Fig. 17 The GORE-TEX sandwich (Dobrusskin, 1990)

9 Consolidation and Removal of Archaeological Papyri from Unsuitable Linings

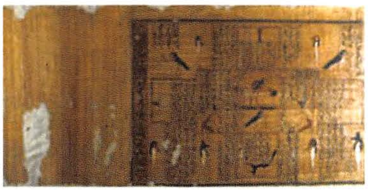
Most papyri were excavated in a roll form. Scientists were often only interested in unrolling the documents and reading the text. They used support material from improper linings (e.g., wood pulp cardboard of varying thicknesses, white or colored paper containing acidic materials, and goldbeater's skin), which caused deterioration of the papyrus.

Over the years these backings have deteriorated, and caused damage to the papyri. Another problem caused by acid paper backing is due to its sensitivity to fluctuation in relative humidity which has caused cockling. The cardboard used was of poor quality, and the method did not avoid mechanical problems of abrasion. It was also unsuitable for the typical, two-layer structure of papyrus: If the under layer is well glued to the board, the upper one is not. Because of the deformation of the board, it tends to split and to break down, so lacunae is often found in the upper layer where the script is, unless the second, under layer, had remained intact and glued to the board (Fig. 18) (Menei, 1998).

Fig. 18 Deformation of cardboard and splitting of papyrus (Menei, 1998)

9.1 Removal of Unsuitable Lining from Illustrated Papyri in the British Museum

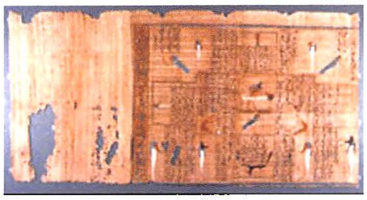
1- The first step is to humidify the papyrus through GORE-TEX.
2- The second step is to consolidate the painted areas by spraying them with 2% isinglass in water.
3- Consolidate unpainted areas by spraying them with 0.5% Funori in water.
4- After 24 hours apply facing tissue to recto with 10% Paraloid B72 in acetone allowing a small overlap between the strips of tissue.
5- Soften old lining cardboard by pressing the papyrus on dampened blotting paper for several hours prior to removal with tweezers.
6- If necessary, reline verso with high quality tissue, using wheat starch paste.
7- Remove facing tissue by pressing between acetone-soaked blotting paper.
8- Remove residual facing adhesive with acetone.
9- For ease of handling and display, the papyri are mounted between sheets of glass (Fig. 19) (Leach and Green, 1995).



(a) Papyrus before conservation treatment

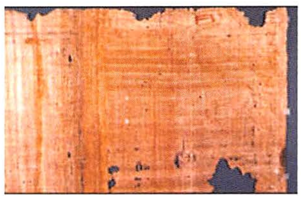
(d) The back of the papyrus is repaired using small paper strips

(b) A temporary lining or facing



(e) The papyrus after conservation

(c) The paper backing is removed with tweezers



(f) A hieroglyphic sign, previously covered by the old backing, was revealed

Fig. 19 Removing of unsuitable lining from papyri in British Museum
(http://www.britishmuseum.org/explore/highlights/articles/c/conserving_a_papyrus.aspx)

9.2 Use of Japanese-Style Technique in Removal of Unsuitable Lining from Illustrated Papyri in Louvre Museum

1- Apply facing from Gampi paper (19g/m^2), it has very smooth surface which will not catch the particles of carbon ink, and to avoid the problem of dimensional variation due to humidity during the treatment, the Gampi paper cut little rectangular pieces. For the adhesive, using 0.5% Funori in water. Funori's gluing power is not great, but strong enough to maintain the Gampi paper, allowing a small overlap between the rectangular pieces of tissue.
2- Soften the old cardboard lining, and peel it with tweezers.

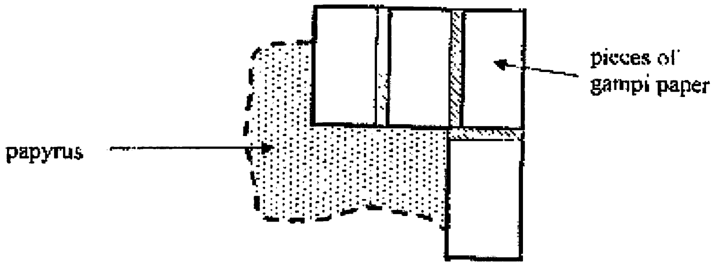


Fig. 20 Disposition of the pieces of paper for the facing (Menei, 1998)

3- Reline verso with Kozo paper (18g/m^2). Kozo paper is flexible enough and the surface is not too smooth, so the wheat-starch paste will be diluted to increase flexibility. This layer is composed of several squared pieces.

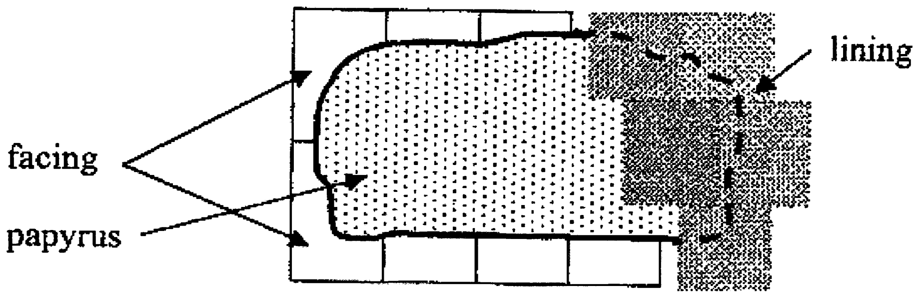


Fig. 21 The first pieces of lining (Menei, 1998)

4- Leave the papyrus to dry freely.
5- Remove the facing after generously wetting one piece of paper with the wet soft brush and tweezers.

The lining is flexible enough, well adapted to the papyrus and flattening to the papyrus (Menei, 1998).

10 The Use of Enzymes in Conservation of Papyrus

The enzymes are inanimate chemical compounds formed within all living cells. They are catalysts whose characteristic property is their ability of accelerating definite chemical reactions (1,000 billion times to 1 trillion times). The enzymes are proteins in nature having large molecules and composed by one or more amino acid chains. The enzymes are specific in that they catalyze only one chemical reaction. They are sensitive to factors that influence protein reaction such as pH, temperature, substrate, aeration metals, etc (Wendelbo, 1991). Proteinases are enzymes which hydrolyze protein into amino acids and are produced by animals, plants and microorganisms (Wendelbo, 1974).

The main uses of proteolytic enzymes in the field of conservation papyrus and manuscripts include, 1- Enzymatic separation of the waste papyrus and paper glued together by glue in the covers of old books to make stiff support for the cover, especially from the 16th century A.D., this waste papers and papyrus are some times of consider able importance as a literary source for books and manuscripts (Hey, 1979), 2- Removal of the defective restoration, 3- To removal unsuitable backing (poor quality cardboard) from papyrus, 4- To solve the problem of the extraction of old papyri documents from cartonnage.

Also enzyme was used to facilitate the removal of a backing attached with a starch or protein based adhesive. This was undertaken when it became evident that water alone would not successfully dissolved the backing adhesive. Many techniques were used, immersion, soaking, brushing or as poultice.

In Brooklyn Museum used 0.01% solution of alpha amylase in deionized water was brushed onto the backing during blotter washing of the papyrus piece. The piece was kept under a warm lamp to allow the enzyme to work within its optimum temperature range. After approximately 25 minutes the backing was mechanically removed and blotter washing was continued in order to remove excess enzymes, adhesive residues and discoloration (Owen and Danzing, 1993).

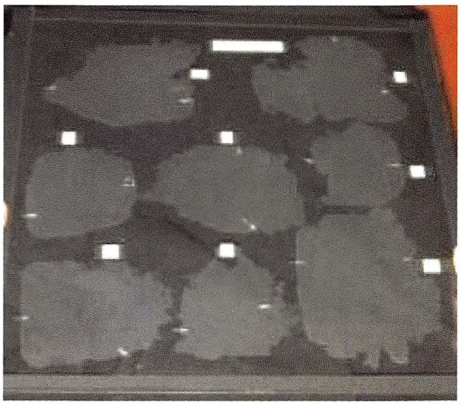
Wahba and Ramadan (2005) studied the effect of six enzymes on samples of papyrus, to recognize their characteristics and the factors that influence protein reaction. One of these enzymes was obtained from papain whereas the others five enzymes were extracted bacterial cultures isolated from Egyptian soils (aerobic sporeforming bacilli). It was obvious that the advantages of use of the enzymes as regard its ability to break the proteins with no harmful effect on the cellulose because it is composed of hydrocarbon material. Also among advantages of use of these enzymes that it can act it moderate temperature with rapid effect. General in all cases good results was obtained.

Proteolytic enzyme from papaya was used to reopen the stiff sealed heavy glued. Syriac papyrus compact as block, which may originally have been bounds in the form of a book. It was a delicate operation to separate these boards without any damaging the text through few seconds. After the enzymatic separation the blocks proved to contain 83 papyrus fragments. The main advantages for these enzymes are shape easy to use without delayed harmful effects, highly purified where some used in food processing. These enzymes preparation can be dissolved in water instead of buffer and used in room temperature.

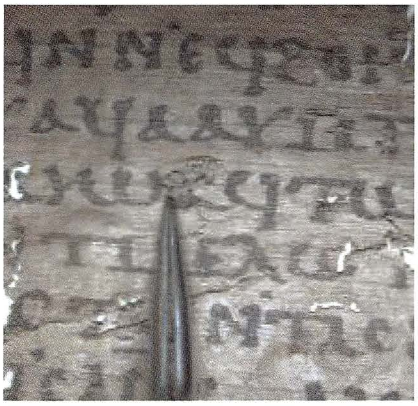
11 Removal of Salts

Deterioration of papyrus can also be caused by salts in the soil from which it was excavated. In a contaminated papyrus, these salts absorb moisture and can crystallize on its surface, causing it to decay (Parkinson and Quirke, 1995).

Sometimes mounted papyri show a "ghost" pattern or "halo" effect, on the surface of the glass that loosely follows the pattern of the fragment (Fig. 22). Previous analysis of the salt on one object confirmed that the deposit was composed mainly of potassium and sodium chloride, which is consistent with analyses of salt deposits on papyrus collections elsehere.



Salt on glass



Salt crystals on fibers

Fig. 22 Removal of Salts
(http://www.lib.umich.edu/papyrology-collection/papyrology-related-links)

The salts will appear more quickly in an atmosphere of fluctuating relative humidity, but it still happens in very stable environments.

To remove the salts, the mount may be opened and the bloom wiped away with a damp paper towel. These salt crystals embedded between fibers, destroy them and the ink writing.

Once the crystals have formed they can be picked out with fine tweezers under a microscope. If they only are too embedded for this they can be washed out, either by immersion in water or by laying the papyrus on damp blotting paper, followed by controlled drying. However, some salts are insoluble or only partly soluble; in this case the papyrus should be kept in a stable and relative low humidity to prevent the absorption of any moisture and the crystallization of more salts.

The conservators in Conservation Center, Grand Egyptian Museum, used 5g/L solution of calcium propionate dissolved in alcohol 95%, and applying antioxidant solution (Borane) which dissolved in alcohol 95%, and let the treated papyrus to dry between two sheets of blotter paper under light weight for approximately two weeks.

12 Consolidation of Papyrus

Ancient papyri exposed to many deteriorating factors, deterioration occurs through aging (the breakdown of constituents in the material itself), physical damage, insect attack, and mold growth. All these factors are closely associated with the conditions in which the papyri have lain for many years before discovery and the subsequent treatment they have received (Leach and Tait, 2000).

The ideal characteristics of consolidate are as follows. It should: -not affect considerably the color of the object not discolor with age (Leach, 1993), be non-toxic have at least short-term reversibility maintain stable mechanical properties with age have sufficient strength, flexibility and hardness, be cheap and readily available (Nakhla, 1986).

In some cases the papyrus appears brittle and also partially delaminating.

In minor case this can sometimes be improved by gentle humidification or consolidate by very thin layers of papyrus pulp fiber ($6g/m^2$) on both sides (Wahba and Ramadan, 2005). In more extreme cases a consolidating must be introduced which will help readhere the fibers of the papyrus to one another.

In 2013 Abd el-Twab did some experiments to evaluate the effect of various consolidation material in fiber-form, Funori (0.5%), Isinglass (2%). Methyl cellulose (0.5%), Hydroxy propyl cellulose (2%), Starch (1%) by brush technique, evaluated them before and after aging, show that the use of cellulose ethers give the best results for both appearance and mechanical properties of papyrus (Abd el-Twab, 2013).

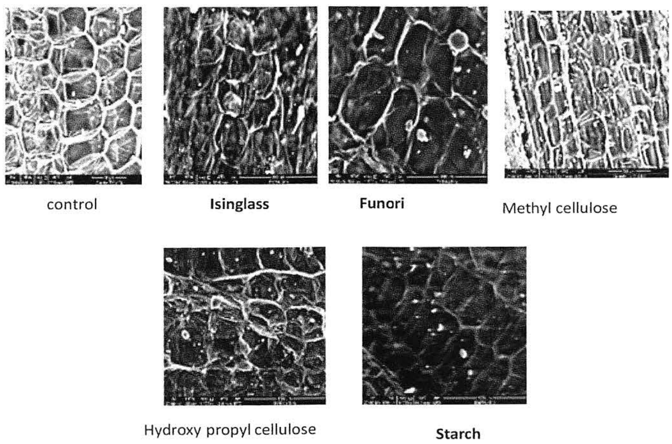


Fig. 23 Study of the surface morphology sheets with Scanning Electron Microscopy (SEM) before aging (Abd el-Twab, 2013)

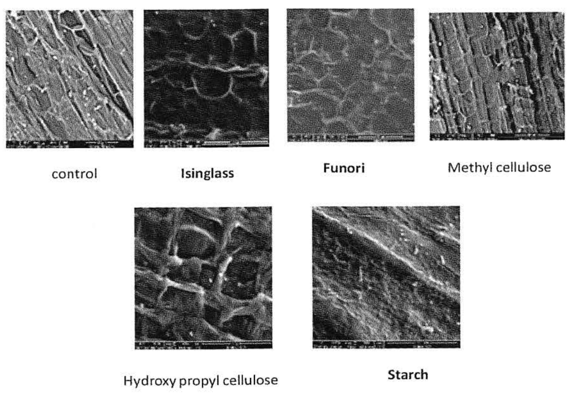


Fig. 24 Study of the surface morphology sheets with Scanning Electron Microscopy (SEM) after aging (Abd el-Twab, 2013)

13 Preservation: Rehousing and Mounting

After treatment was finished, the strong fragments can be stored between buffered blotting paper to prevent papyrus from sliding freely, and then they were placed inside folder. These folders keep inside fit standard boxes.

13.1 Mounting Papyrus

Fragile fragments should be mounted between two layers of glass, especially if they are used often by researchers and students or for exhibitions. The papyrus must be dry and everything is in the right place before place it between the glasses. They should be held in place with small strips of Japanese tissue, made to adhere to one side of the glass.

Glazed papyri need to be stored vertically, so the weight does not break it, or stored horizontally singly or in stacks of no more than three mounts with blotting paper cut as pads between them.

Oversize papyri also housed between glass (1/8-inch thick glass) they may be supported with an aluminum or wood picture frame cut to size (Lamb, 2005).

In some collections, Perspex has been adopted because it is lighter and less fragile; however, it is flexible, but static electricity can create problems if the frame of Perspex needs to be opened again. For these reason glass is still generally preferred (Parkinson and Quirke, 1995).

A fragment of papyrus may be hinged; with paste and Japanese tissue, into a mat of conservation or museum board. If the papyrus is on permanent (or long-term) display, ultraviolet's careening glass may help reduce light damage. Avoid placing UV-screening materials in direct contact with the papyrus, since it is not known what adverse effect these chemicals may have over time (Leach and Green, 1995).

14 The Recommended Environment for Papyrus Preservation

Condition for storage and display should aim to meet the criteria recommended for works of art on paper:

45-55% RH is satisfactory, and temperature of 19℃ (+2), rapid fluctuation of humidity and temperature must be avoided. Light levels 50 Lux (Brown, 1997).

References:

1 Allen, K. W., Papyrus: Some Ancient Problems in Bonding, International Journal of Adhesion and Adhesives 16 (1996), pp. 47-51.

2 Abd el-Maksoud, G., and A. El-Amin, The Investigation and Conservation of a Gazelle Mummy from the Late Period. Mediterranean Archaeology and Archaeometry, Vol. 13, No. 1 (2013), pp. 45-67.

3 Abd el-Twab, A., Experimental Study of Materials and Methods Used in Consolidation and Removal Archaeological Papyri from Unsuitable Linings Applied on Some Selected Papyri, Cairo University, Faculty of Archaeology, Conservation Department (2013), pp. 108-112.

4 Bloom, J., M., History of Paper, Saudi Aramco World, May, Vol. 50, No. 3 (1999).
https://www.saudiaramcoworld.com/issue/199903/revolution.by.the.ream-a.history.of.paper.htm

5 Brown, A., The Conservation of Illustrated Papyri Artifacts, Conservation Journal, No. 24 (1997), 40-45.

6 Dimarogonas, A., Pliny the Elder on the Making of Papyrus Paper, The Classical Quarterly, New Series, Vol. 45, No. 2 (1995), pp. 588-590.

7 Dobrusskin, S., H. Singer, and G. Banik, Humidification with Moisture Permeable Materials, IADA (1990), pp. 1-12.

8 Effendi, A., Experimental and Applied Study on the Factors Damaging the Papyrus Manuscripts and the Methods of Treatment, Conservation and Restoration, Cairo University, Faculty of Archaeology, Conservation Department (1999), pp. 108-112.

9 Erman, A., Life in Ancient Egypt, London: Macmillan and Co. (1894), p. 447.

10 El-Hadidi, M., Distribution of *Cyperus Papyrus L.* and *Nymphaea Lotus L.* in Inland Waters of Egypt, Mitt. Bot.: Staatssaml. München (1971).

11 Franceschi. E., G. Luciano, F. Carosi, L. Cornar, and C. Montana, Thermal and Microscope Analysis as a Tool in the Characterization of Ancient Papyri, Thermochimica Acta, 418 (2004), 39-45 (2003). Available online, 2 March (2004).
http://www.sciencedirect.com/science/article/pii/S0040603104000358

12 Gilmour, S., Paper: Its Making, Merchanting and Usage, Longmans, Green And Co. Ltd., London (1956).

13 Hey, M., The Washing and Aqueous Deacidification of Paper, Journal of Institute of Paper Conservation, Vol. 4 (1979), pp. 66-77.

14 Hepper, F. N., and T. Reynolds, Papyrus and the Adhesive Properties of its Cell Sap in Relation to Paper-Making, Journal of Egyptian Archaeology 53 (1967), 156-157.

15 Hunter, D., Papermaking: The History and Technology of an Ancient Craft, Pleiades Books, 2nd ed. (1974).

16 Lamb, L., Advanced Papyrological Information System Guidelines for Conservation of Papyrus, University of Michigan (2005).

17 Leach, B., Papyrus Conservation at the British Museum, Papyrologica Lupiensia, No. 3 (1993), p. 137.

18 Leach, B., and L. Green, Removal of Unsuitable Linings from Illustrated Papyri: An Investigation into Suitable Consolidants and Facings, Conference of the United Kingdom Institute for Conservation, London (1995), pp. 29-35.

19 Leach, B., and J. Tait, Papyrus, in Ancient Egyptian Materials and Technology, Cambridge University Press (2000), p. 239.

20 Menei, E., Use of Japanese-Style Techniques in Conservation of Egyptian Papyrus, Spider Webs and Wall Papers: International Applications of the Japanese Tradition in Paper Conservation, ICCROM (1998), pp. 55-67.

21 Murrell, V., Some Aspects of the Conservation of Wax Models, Studies in Conservation, 16 (1971), 95-109.

22 Nakhla, S., Comparative Study of Resins for the Consolidation of Wooden Objects, Studies in Conservation, Vol. 31, No. 1 (1986), p. 38.

23 Neate, S., et al., An Investigation of the Extent and Causes of Salt Migration in the Papyrus and Related Collections in the Bodleian Library, Restaurator, V. 32, 2011.

24 Owen, A., and R. Danzing, The History and Treatment of Papyrus Collection at the Brooklyn Museum, the Book and Paper Group Annual, V. 12, AIC, 1993.

25 Parkinson, R., S. Quirke, et al., Papyrus, Egyptian Bookshelf, British Museum Press, 1995.
26 Pliny, E., Natural History Book XII-XVI, Translated by Rackham London, Cambridge (1968), pp. 143-147.
27 Ragab, H., A New Theory Brought forward about the Adhesion of Papyrus Strips, reprints of 4th Int., Congress of Paper Historians, Manchester (1978).
28 Ragab, H., Le Papyrus, Dr. Ragab Papyrus Institute, Cairo, 1980.
29 Wahba, W., and E. Ramadan, The Use of Proteolytic Enzymes in Restoration and Conservation of Syriac Papyrus and Arabic Paper, Conference of Archaeology in Syria: Reality and Perspectives, 12-14, September, Faculty of Architecture, Aleppo University (2005).
30 Wallert, A., The Reconstruction of Papyrus Manufacture Preliminary Investigation, Studies in Conservation, Vol. 34. No. 1, 1989.
31 Waly, N., N. Wafika, and A. Affendi, Comparative Study of the Sheets Similar to Papyrus, Manufactured from Different Plants, Papyrologica Lupiensia, No. 11 (2002).
32 Wendelbo, O., The Use of Enzymes for Restoration Purposes, Archives et Bibliothèques de Belgique, Numéro Spécial, 12 (1974).
33 Wendelbo, O., How Enzymes Work and when they can Be Used in Paper Restoration, Internationaler Graphischer Restauratorentag, Uppsala (1991).
34 Wiedemann, H. G., "Paper Technology from Egyptian, Chinese, and Many Cultures," The State-of-the-Art of Thermal Analysis, Gaithersburg, 1979.
35 Weidemann, H. G., and G. Bayer, Papyrus: The Paper of Ancient Egypt, Analytical Chemistry 55, No. 12, October (1983).

URL:

(1) Le Papyrus: La tige de Papyrus, structure anatomique:
http://www.snv.jussieu.fr/bmedia/papyrus/12-tige.htm
(2) Cyperus Papyrus: Rhizome Vermehren:
http://www.pflanzenblog-in.de/2008/04/19/cyperus-papyrus-rhizome-zur-vermehrung/
(3) Tutankhamun Papyrus Box:
http://www.egyking.info/2012/03/tutankhamun-papyrus-box.html
(4) Floral Collar from Tutankhamun's Embalming Cache:
http://www.metmuseum.org/toah/works-of-art/09.184.214-.216
(5) Tutankhamun's Sandal:
http://www.agefotostock.com/en/Stock-Images/Rights-Managed/FAI-18085
(6) Men Gathering Papyrus, Tomb of Puyemre:
http://www.metmuseum.org/collection/the-collection-online/search/544591
(7) Men Splitting Papyrus, Tomb of Puyemre:
http://www.metmuseum.org/collection/the-collection-online/search/544592

(8) Papyrus: Secret of the Egyptians:
http://www.brooklynmuseum.org/community/blogosphere/2010/06/23/papyrus-secret-of-the-egyptians/
(9) Papyrus Making 101: Rediscovering the Craft of Making Ancient Paper:
http://www.lib.umich.edu/papyrus_making/index.html
(10) Blank Papyrus Paper:
http://commons.wikimedia.org/wiki/File:Blank_papyrus_paper.jpg
(11) Looking for Adhesives and Identifying Binders in the Book of the Dead Using FTIR:
http://www.brooklynmuseum.org/community/blogosphere/wp-content/uploads/2011/01/Image-032.jpg
(12) Making Papyrus Paper:
http://farm7.staticflickr.com/6025/5960430916_2f35b28218_z.jpg
(13) Le Papyrus: Le Papyrus support d'écriture, étude microscopique:
http://www.snv.jussieu.fr/bmedia/papyrus/22-micro.htm
(14) Conserving a Papyrus from the Book of the Dead of Muthepti:
http://www.britishmuseum.org/explore/highlights/articles/c/conserving_a_papyrus.aspx
(15) Papyrology-Related Links:
http://www.lib.umich.edu/papyrology-collection/papyrology-related-links