Ancient Egyptian Linen —

The Role of Natron and Other Salts in the Preservation and Conservation of Archaeological Textiles —

A Pilot Study

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PLEASE NOTE

The greatest amount of care has been taken while scanning this thesis,

and the best possible result has been obtained.
“We talk glibly about textiles preserved in damp anaerobic peatbogs or the dry desert conditions of the Near East; but we still do not understand fully the reasons why textiles survive in archaeological contexts and therefore the treatment which they require for that survival to continue. Too often, the textile was safest before the archaeologist took it from the ground.”

(Wild, 1990, p. 4)
Dedication

This research grew out of a variety of experiences. At the National Library of
Australia my work in paper conservation gave me experience with the use of
alkaline salts in materials conservation. I acquired further experience with
salts as I treated salt affected artefacts at the Nicholson Museum of
Antiquities, University of Sydney. A decade later Mrs Patricia Cannon
Johnson, then Conservator of the Nicholson Museum, and Dr E. (Ted)
Robinson, then Assistant Curator of the Nicholson Museum (now Lecturer in
Classics at the University of Sydney) asked me to look at some of the textiles
from the Nicholson Museum of Antiquities’ Egyptian collections. This
experience led me to undertake research on the conservation of archaeology
textiles, which developed into this study of the role of salts in the
conservation and preservation of archaeological textiles.

I dedicate this work to Mrs Patricia Cannon Johnson. She has been a kind and
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DECLARATION AND PUBLICATIONS

I declare that this work has not been submitted for a higher degree at any other university or institution.

Glennda Susan Marsh-Letts

Parts of the work in this dissertation have been published, are currently in press, or have been presented as either a seminar or a conference paper:

- **Marsh-Letts, G. S.** (1999a). [Below the surface: Salts and textiles from ancient Egypt.] Thesis seminar presentation, April 28, 1999 at the University of Western Sydney, Kingswood, NSW.


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Glossary

This thesis is an interdisciplinary project, combining information from Archaeology, History, Egyptology, Textile Technology (History of Technology), Chemistry, Geology, and Biology. Specialist terminology used by each of these disciplines has been replaced whenever possible by Standard English in this thesis. However, the use of some key concepts and terms is necessary in order both to appreciate the philosophical basis of each discipline and to correctly identify specific materials. Some terms are defined below. Others, as appropriate, are defined within the text of the thesis.

**Artefact:**

1) **Archaeological artefact:** An object made by human activity or an object affected by human activity, which has been taken out of cultural use, i.e., discarded in some manner, so that it is no longer part of a living society (Schiffer, 1987, p.4).

2) **Historical artefact:** An object made by human activity or an object affected by human activity which has remained in cultural use, retained within living societies (Schiffer, 1987, p.3).
**Archaeological science:** A meeting ground for collaborations between archaeology and the full range of sciences. Main areas of collaboration have been on questions of dating, artefact studies, environmental studies (humanity and its environment), mathematical methods, remote sensing, and conservation science (Tite, 1991).

**Bast fibre:** “Fibre obtained from the stems of various plants” (McIntyre & Daniels, 1995, p. 21). “The bast fibres form bundles or strands that act as hawsers in the fibrous layer lying beneath the bark of dicotyledenous plants [plants which form two seed-leaves]. They help to hold the plant erect. These fibres are constructed of long thick-walled cells which overlap one another; they are cemented together by non-cellulose materials to form continuous strands that may run the entire length of the plant stem” (Cook, 1984 5th edition, p. 4). Plants containing bast fibres are often grouped together and called 'the bast fibres.' These plants include flax, jute, hemp, kenaf, urena, ramie, and nettle (Cook, 1984).

**Bleaching:** “A process for improving the whiteness of textile material, with or without the removal of natural colouring matter and/or extraneous substances” (McIntryre and Daniels, 1995, p. 32).
**Bleaching agent:** “A chemical reagent capable of destroying partly or completely the colouring matter present in textile materials, and leaving them white or considerably lighter in colour” (McIntryre and Daniels, 1995, p. 33).

**Buffering/ pH Buffering:** In Chemistry a buffer is “a substance or a mixture of substances, usu. [ally] of a weak acid or base and its salt, which stabilizes the degree of acidity or alkalinity of a solution.” (The Oxford English dictionary, 2nd ed. 1989, Vol. II, p. 623).

**Conservation profession:** The profession devoted to the preservation of cultural property for the future. Conservation activities include examination, documentation, treatment, and preventive care, supported by research and education (American Institute of Conservation, 1999, p.22).

**Conservation examination:** The investigation of the structure, materials, and condition of cultural property including the identification of the extent and causes of alteration and deterioration (American Institute of Conservation, 1999, p. 22).

**Conservation research:** “Conservation research produces new knowledge in the field of conservation. Using accepted research methodologies, it provides new information publishable in a peer reviewed publication. It is also an
activity aimed at systematic development of information to facilitate preservation decision making” (Daniel, 2000, p. 19).

**Conservation science**: An area of Archaeological Science concerned with “both the study of decay processes and the development of new methods of conservation” (Tite, 1991, p.141).

**Conservation stabilisation**: Treatment procedures intended to maintain the integrity of cultural property and to minimise deterioration (American Institute of Conservation, 1999, p. 22).

**Conservation treatment**: The deliberate alteration of the chemical and/or physical aspects of cultural property, aimed primarily at prolonging its existence. Treatment may consist of stabilisation and/or restoration (American Institute of Conservation, 1999, p. 22).

**Crystallisation**: The formation of minerals from a liquid through the cooling of magna (Mayer, 1976, pp. 33) or from the evaporation of a liquid.

**Degree of Polymerisation (DP)**: The degree to which a substance is made up of polymers, i.e. the degree to which it has a “molecular structure built up
largely or completely from a number ...of polyatomic units bonded together”

(The Oxford English dictionary Vol. XII, 2nd ed. 1989, p. 64).

Dehydration: “...the removal of water, its constituents, in a chemical combination” (The Oxford English dictionary Vol. IV, p. 402).

Deliquescence: “The process of deliquescing or melting away; esp. [especially] the melting or liquefying of a salt by absorption of moisture from the air” (The Oxford English dictionary Vol. IV, p. 420).

Fibre; fiber:

1) “Textile raw material, generally characterised by flexibility, fineness and high ration of length to thickness” (McIntrye & Daniels, 1995, p. 127).

2) “The fundamental unit in the fabrication of textile yarns and fabrics” (ASTM, quoted by Bellinger, 1950, [4]).

Fibre natural; fiber natural: “A fibre occurring in nature. Note: Fibres are found in all three sectors of the natural world, for example: animal (silk, wool); vegetable (cotton, jute); mineral (asbestos)” (McIntrye & Daniels, 1995, p. 127).
Flax:

“1. Plants of the species Linum usitatissimum cultivated for the production of fibre, or seed and fibre.

2. Fibre extracted from flax plants” (McIntyre & Daniels, 1995, p. 136).

“The plant Linum usitatissimum bearing blue flowers which are succeeded by pods containing the seeds commonly known as linseed. It is cultivated for its textile fibre and for its seed” (The Oxford English Dictionary Vol. V, 2nd ed. 1989, p. 1031).

Hydrate: “To combine chemically with water; to convert into a hydrate”


King: This title is often used in Egyptology to designate the sole or co-ruler of Egypt (Quirke, S., 2000, no page number given). An alternate title that is in common usage is pharaoh, which came into English from the Bible, where it is used in the stories of Joseph and Moses, and also in Kings II (Gardiner, 1961, p.52). The Egyptian original - Per-‘o - refers to the Great House or palace of the ruler (Gardiner, 1961, p.52). In the interests of consistency, the title king will be used in this thesis when naming the ruler or co-ruler, and the title queen will be used for the mother or a principal wife of the king.
Linen:

1. “Descriptive of yarns spun entirely from flax fibres.

2. Descriptive of fabrics woven from linen yarns.

3. Descriptive of articles which, (apart from adornments), are made of yarns spun from flax fibres. Note: Despite some usage of this term in non-technical circles as a generic one, e.g., linen department, baby linen, household linen, it does not apply to individual articles that do not comply with the definition” (McIntrye & Daniels, 1995, p. 194).


Lining: The strengthening of a painting on a fabric support or a textile through the attachment of another piece of fabric (Gettens & Stout, 1942, p.230). If this process is done through the use of glue and without heat it can be called Cold-Lining.

Mummy: “The body of a human being or animal embalmed (according to the ancient Egyptian or some analogous method) as a preparation for burial” (The Oxford English Dictionary Vol. X, 2nd ed. 1989, p. 97).
Mummy-cloth; mummy wrappings: “The cloth in which Egyptian mummies were wrapped” (The Oxford English Dictionary Vol. X, 2nd ed. 1989, p. 97).

Mineralized:

1. “Changed to a mineral.


Mineralization, mineralisation:

1) “The action or process of mineralizing, or the state of being mineralized” (The Oxford English Dictionary Vol. IX, 2nd ed. 1989, p. 807).

2) “The mineralisation of fibres is defined here as the combination and/or replacement of the organic matrix of the fibre with an inorganic one” (Gillard, Hardman, Thomas & Watkinson, 1994, p. 132).

Natron, natrun, or atrun: A natural compound of sodium carbonate and sodium bicarbonate in the proportion of one molecule of each, but generally found in its natural state with a large proportion of “impurities”, such as sodium chloride. (Lucas, 1912, p. 1).
pH; A numerical scale (0 – 14) indicating the number (concentration) of protons in an aqueous solution, with pH 7 representing neutrality between acidity and alkalinity. (Morrison, 1979, p.25)

Pharaoh: A widely used title in the Egyptological literature for the ruler or co-ruler of ancient Egypt. The title derives from the name of the residence of the ruler, and is analogous to the modern term “the palace” (Gardiner, 1961, p.52). Therefore the term “pharaoh’ will be used when referring to the position of ruler in the abstract. In the interest of consistency and clarity, the title king will be used when naming an individual who ruled, or co-ruled, in their own right.


Queen: A principal wife of a king, or the mother of a king. A queen may act as regent for a king who is a minor without assuming the title of king. If a queen reigns in her own right then her title changes to the masculine title of king (Quirke, Grajetzki & Shioda, 2000, no page number given).
**Replicate:** As used in Science, 1) to repeat (an experiment or trial) and obtain a consistent result 2) being a replicate (The Oxford English Dictionary Vol. XIII, 2nd ed. 1989, p. 247).

**Restoration:** “The protection of cultural property through minimal intervention to enhance its interpretation. Restoration may involve the reassembly of displaced components, removal of extraneous matter, or reintegration using new materials” (Australian Institute for the Conservation of Cultural Material, Inc., 1999, p. 6).

**Salt:** “One of the products resulting from a reaction between an acid and a base... the other reaction product being water. Salts may be either inorganic or organic, depending on the nature of the reactants” (Hampel & Hawley, 1976, p. 240).

**Selvedge; selvage:** “When used without qualification, the term refers to the longitudinal edges of a fabric that are formed during weaving, with the weft not only turning at the edges but also passing continuously across the width of the fabric from edge to edge” (McIntyre & Daniels, 1995, p. 298).
Twist / Direction of twist- S or Z- spun: “A yarn has S twist if, when held in a vertical position, the spirals conform in direction of slope to the central portion of a letter S, and Z twist if the spirals conform in the direction of slope to the central portion of a letter Z” (American Society for Testing Material, Designation D 123).

Warp:
2. The sheet of yarns laid together on a beam” (ASTM, cited by Bellinger, 1950, [p. 5]).

Weft: “Yarn running from selvage to selvage at right angles to the warp in a woven fabric. In England called ‘weft’ or ‘woof’, in America called ‘filling’ ”(Bellinger, 1950, [p. 5]).
List of Abbreviations

DP – Degree of Polymerization

ESEM - Environmental Scanning Electron Microscopy

EDXA - Energy Dispersive X-Ray Analysis

IC – Ion Chromatography

IMS – Industrial Methylated Spirits

PEG – Polyethylene Glycol


Conventions Used for Citations and References

The system of citations used was the Author-Date / Harvard System, as per the University of Western Sydney, Nepean (1991) *Style Manual*, Kingswood, The University. Revised 1995.

All published works cited in this thesis are referenced. Page references are given for specific information cited or for direct quotations. Personal communications, while cited in the text, are not included in References.
Ancient Egyptian Chronology

Adapted from Shaw & Nicholson, Eds. (1995, pp. 310-312), and Ellis (1992, pp. 5-6).

Predynastic Period 5500 - 3100 BC
- Badarian 5500 - 4000 BC
- Naqada I (Amratian period) 4000 - 3500 BC
- Naqada II (Gerzean period) 3500 - 3100 BC

Early Dynastic Period 3100 - 2686 BC
- 1st Dynasty 3100 - 2890 BC
- 2nd Dynasty 2890 - 2686 BC

Old Kingdom 2686 - 2181 BC
- 3rd Dynasty 2686 - 2613 BC
- 4th Dynasty 2613-2494 BC
- 5th Dynasty 2494 - 2345 BC
- 6th Dynasty 2345 - 2181 BC

First Intermediate Period 2181 - 2055 BC
- 7th-8th Dynasty 2181 – 2125 BC
- 9th - 10 Dynasties 2160 – 2025 BC (Heracleopolis)
- Re-unification 11th Dynasty 2125-2055 BC (Thebes)

Middle Kingdom 2055 - 1650 BC
- Post-unification 11th Dynasty 2055-1985 BC
- 12th Dynasty 1985 – 1795 BC
- 13th Dynasty 1795- after 1650 BC
- 14th Dynasty - partially contemporaneous with 13th Dynasty, ending c. 1650 BC

Second Intermediate Period 1650-1550 BC
- 15-16th Dynasty (Hyksos) 1650 – 1550 BC
- 17th Dynasty (Theban) 1650 – 1550 BC

New Kingdom 1550-1069 BC
- 18th Dynasty (Tuthmoside) 1550 – 1295 BC
- 19th Dynasty (Ramesside) 1295 – 1186 BC
20th Dynasty (2nd Ramesside) 1186 – 1069 BC

Third Intermediate Period 1069-747 BC
   21st Dynasty (Tanite) 1069 – 945 BC
   22-23 Dynasty (Bubasite/Libyan) 945 – 715 BC
   24th Dynasty (pre-Saite) 727 – 715 BC

Late Period 747-332 B.C.
   25th Dynasty (Kushite) 747 – 656 BC
   26th Dynasty (Saite) 664-525 BC
   27th Dynasty (Persian) 525 – 404 BC
   28th Dynasty 404 – 399 BC
   29th Dynasty 399-380 BC
   30th Dynasty 380 – 343 BC
   31th Dynasty (Persian) 343 – 332 BC

Ptolemaic Period 332 –30 BC
   Conquest of Alexander the Great 332 BC
   Macedonian Kings 332-305 BC
   Ptolemaic Period 305-30 BC

Roman Period 30 BC - AD 395
   Roman Conquest 30 BC
   Roman Emperors 30 BC – AD 395
      Theodosian Dynasty 379- 450 AD

Byzantine Period  AD 450-642
General Map of Ancient Egypt and Nubia

(British Museum, Department of Antiquities 1979 rev. ed., 1989 reprint, map 1).
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ABSTRACT

An understanding of the physical and chemical nature of archaeological textiles is an important prerequisite for their successful conservation treatment, display and storage. Ancient Egyptian linen textiles were examined through a combination of optical microscopy, environmental scanning electron microscopy (ESEM), ion chromatography (IC), and energy dispersive X-ray analysis (EDXA). These analytical techniques were used to distinguish between flax fibres, foreign matter present on and within flax fibres, and natron or other salts absorbed into the linen fibres in a form of partial mineralization.

The use of ESEM enabled the observation and recording of the movement of salts, in real time, during cycles of hydration and dehydration. Few studies have been undertaken to date on the dynamics of salt crystallisation within organic archaeological materials, and none previous to this has been published showing the dynamics of salt crystallisation within archaeological textiles.

Once the dynamics of salt crystallisation were viewed and recorded it became possible to investigate methods for the treatment of salt affected textiles.
through washing trials followed by alternative methods of drying. The release of salts from linen samples during washing in deionized water was monitored using IC and ESEM with EDXA, showing the pattern of salt removal and retention. The use of IC, ESEM and EDXA to monitor salt removal in textiles has not previously been reported.

A conservation treatment for ancient Egyptian linen was developed, incorporating a long water washing to remove salts, soils and organic deposits, followed immediately by carefully controlled freeze drying. This was effective in preserving the integrity of the ancient linen.

By combining archaeological, historical, and chemical data, this pilot study of the effects of salts upon and within linen textiles has widened our understanding of the role played by salts in both the deterioration and the preservation of these textiles.

Glennda Susan Marsh-Letts
This study is concerned with the conservation of textiles that have been recovered from archaeological sites in Egypt. Because to the naked eye much of this linen is apparently sound, it has sometimes been subjected to the same conservation treatment, and stored in the same environmental conditions, as historic textiles. At times this treatment has been successful, but at other times apparently sound textiles have disintegrated during treatment or become like "cardboard" (Wild, Personal Communication, 1999)\(^1\).

In order to begin to understand the chemical and biological reasons behind this practical textile conservation problem, it was thought necessary to first identify what is present within the textiles themselves, both chemically and physically, before going on to examine possible improvements in conservation treatments. In so doing an attempt has been made to distinguish the components that were present in the linen due to original manufacturing, usage, and cleaning processes from components that were introduced through interaction with archaeological environments or by storage in museum environments.

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\(^1\) For examples of the disintegration of fibres after conservation treatment see Appendix A: Samples: Mary Rose, MS1 and MS2.
This is an interdisciplinary study, drawing on evidence from the disciplines of History, Egyptology, Archaeology, Archaeological Science, Botany, and Materials Conservation. The overall structure of the study reflects this interdisciplinary approach. Chapter 1 is written primarily from the perspective of the disciplines of Botany, Egyptology, History, and Materials Conservation. Chapter 2 is written primarily from the perspectives of the disciplines of Archaeology and Egyptology. Chapters 3 and 4 are written primarily from the perspectives of Archaeological Science and Materials Conservation. Chapter 5 concludes this study through a synthesis of the evidence. Chapters 2 through 5 constitute the main body of this study.

The specific objectives of this thesis are to:

- Discover the chemical and physical nature of ancient Egyptian linen textiles;
- Discover the environmental factors that have contributed to the survival of ancient Egyptian linen, so that these factors can be taken into consideration in the treatment, display and storage of these archaeological artefacts;
- Distinguish between the natural fibre of the linen and any salts or other foreign matter the linen had absorbed from either its
usage in antiquity, from its archaeological environment, or from
its storage environment; and

- Validate improved methods of treatment, display and storage for
  archaeological linen textiles.

Chapter 1 discusses the chemical and physical nature of linen fabric,
describes the methods of manufacture, washing, bleaching and dyeing used
in ancient Egypt, and discusses the importance of linen both in Egyptian life
and in the rituals connected with death. The cultural importance of natron
and other salts in the washing and bleaching of ancient Egyptian linen is
shown. This historical background is essential for an understanding of the
chemical and physical nature of linen that has been recovered from Egyptian
tomb environments.

Chapter 2 concentrates on a description of the archaeological environments
from which ancient Egyptian linen has been recovered, and from which I
have obtained samples of linen for this study. Firstly it looks at general
environmental conditions in Egypt, and then it looks at the chief factors
present in Egypt which have contributed to the preservation of organic
materials; extreme aridity, extensive geological formations of limestone, and
the natural presence of natron and other salts in the environment. It identifies
natron and other salts as having a role in the preservation of linen in Egypt, through dehydration, mineralization, and alkaline pH buffering. Next it looks at specific sites in Egypt. Samples of the archaeological deposit directly associated with some of the linen samples are examined using X-ray diffraction (XRD). The environments of specific archaeological sites are discussed, as are the implications of this study for both provenancing studies and the environmental monitoring of archaeological sites.

Chapter 3 firstly sets out the hypothesis, based upon evidence set out in Chapters 1 and 2, that textiles from ancient Egypt have often undergone a form of partial mineralization through either (a) treatments involving natron, and possibly other salts, in antiquity and/ or (b) environmental conditions where the linen has come into contact with natron, possibly in conjunction with other salts, and that this mineralization has contributed to their survival.

An examination of the cellular structure of the fibres to determine whether or not full or partial mineralization has occurred, combined with identification of salts present, would then influence the choice of appropriate conservation treatment(s) of the textiles.
Chapter 3 next cites relevant previous studies and describes the research design and methodology employed for this pilot study. The role of natron and other salts in the preservation and conservation of ancient Egyptian linen is demonstrated through the examination of provenanced samples of Egyptian linen that have been correlated with their archaeological environments. The samples are examined and described using a variety of analytical techniques. Analytical techniques employed in this study are optical microscopy, scanning electron microscopy (SEM) with energy dispersive X-ray analysis (EDXA), ion chromatography (IC), and environmental scanning electron microscopy (ESEM) with EDXA. While it is found that optical microscopy and SEM are able to identify fibres, and both ESEM with EDXA and IC are found to be useful in recording the chemistry of each sample, it was found that only with ESEM is it possible to demonstrate the processes of salt movement (deliquescence and crystallisation) within fibres.

Washing trials, monitored by Ion Chromatography and ESEM with EDXA were designed in order to show the release of salts during washing with deionized water. It was found to be possible to demonstrate clearly the rate of release and also the rate of retention of salts within the fabrics. Samples used in the washing trials were also used to investigate methods of drying.
Samples were air-dried, slowly air-dried, vacuum freeze dried, and slow freeze dried. The physical structures of the dried samples were then compared using optical microscopy and ESEM.

In the interest of obtaining brevity and clarity within Chapter 3, the detailed experimental data have been located in appendices. Graphic or pictorial data that can be printed is presented in Appendix A. The data is printed in a format that shows relevant details to advantage, but without taking up unnecessary space. Therefore, there may be some variation in the size of photographs and graphs, and they cannot be used for accurate sample measurement. Data that cannot be printed consists of dynamic studies recorded on videotape. This data is available on computer disc, and is referred to as Appendix B.

Chapter 4 is a discussion of the results set out in Chapter 3, Appendix A, and Appendix B, in conjunction with background given in Chapters 1 and 2. Specific objectives of the study are discussed in detail before conclusions are made and recommendations are given.

Chapter 5 concludes the study with an assessment of the validity of the hypothesis that textiles from ancient Egypt have often undergone a form of
partial mineralization through either (a) treatments involving natron, and possibly other salts, in antiquity and/or (b) environmental conditions where the linen has come into contact with natron, possibly in conjunction with other salts, and that this partial mineralization has contributed to their survival.
CHAPTER 1
The Artefacts in their Historical Context

1.1 Introduction

Ancient Egyptian linen artefacts are a significant part of the historical record. In order to be able to read that record accurately we need to carefully place these artefacts in their historical context. In order to do this we need, firstly, to be very clear about our definition of “ancient Egyptian linen”. Then, secondly, we need to understand the place of linen in the economic and cultural life of ancient Egypt. Lastly, we need to understand just how this linen, upon its archaeological excavation, has often become part of a museum collection, and, thus, part of our historical record, as well as part of the museum’s on-going cultural and economic life.

Firstly, the term ‘linen’ is defined in terms of botanical classification. This definition is followed by a brief description of the historical distribution of flax and its introduction to ancient Egypt. Next, the role of linen in ancient Egyptian life is discussed, including the production of the flax fibre, the processing of the fibre into fabric, and the uses of linen fabric in daily life, as well as the uses of linen in the mummification process and as grave goods. Special attention is paid to evidence for the care of linen in ancient Egypt, particularly to evidence for the methods used for the washing and bleaching
of linen with natron. Of pivotal importance to this study is this historical use of natron in the washing and bleaching of linen and in the preparation of the dead for burial.

Placing ancient Egyptian linens in their historical context includes not only a description of their original manufacture and usage in antiquity, but also a description of their usage in modern times. Methods used by both archaeologists and museum staff in the last two centuries for the archaeological recovery and preservation of ancient Egyptian linens are discussed in detail.

The specific objectives of this chapter are to:

- Define the term “ancient Egyptian linen”;
- Demonstrate the economic and cultural importance of linen and natron in ancient Egypt;
- Show how the artefacts analysed in this study were created, used, and disposed of in antiquity; and
- Review conservation treatments of ancient Egyptian linen in modern times.
1.2 Definitions

1.2.1 What constitutes “linen”?

The English word linen is derived from the Greek word for flax, written in
the Roman alphabet as linon, and the Latin linum, coming down through the
Old English linen or linnen (Brewer, Redford & Redford, n. d., p. 34; The
Oxford English Dictionary vol. VIII, p.985-986). In the following paragraphs
linen is defined in botanical and technical terms. This will suffice to identify
fibre and cloth woven or otherwise manufactured from plants within the flax
family. ¹

However, cloth woven from more than one fibre has existed from ancient
times. In Egypt this practice became particularly prevalent during the
Graeco-Roman period (c. 332 BC - AD 395). In order to address this
problem of classification, the system devised by the Textile Museum
(Washington DC) is used in this study. This system classifies fabric by the
nature of the fibre used for its warp, judging that the warp constitutes the
basic structure of the fabric. “Therefore the primary classification in our file
is made according to the material and preparation of the warp. A fabric with
linen warp is classified as linen no matter what fibres appear in the weft; one
with wool warp as wool, and so forth” (Bellinger, 1950, [p. 2]). Graeco-

¹ A modern usage of the term linen is to denote any fabric used for household purposes, particularly bed
sheets and coverings. The term is not used in that sense in this study.
Roman fabrics produced during the time of Roman rule, and especially in the later part of that period, as well as fabrics produced during the Byzantine Period (AD 450-642), are generally called Coptic textiles. These were woven using linen warps, with either wool or combinations of wool, silk, and/or linen as wefts. Such Coptic fabrics are classified as linen.

Linen fibre or fabric preserved as material evidence from ancient times in Egypt is “ancient Egyptian linen”. By Egypt I mean the geographical area corresponding to the present national state of Egypt (see General Map of Ancient Egypt and Nubia, and also Appendix A: Maps 1 through 6). By “ancient” or “ancient times” we mean any time prior to the Arabic conquest of Egypt in 642 AD (see the section Ancient Egyptian Chronology and also Table 2.3 Chronology of Ancient Egypt, Showing Periods, Dynasties, Kings, Sites and Samples, for relevant dating of ancient Egyptian history).

In this study, I deal exclusively with fabric or fibre made from true flax. In Australia and New Zealand, the common term “flax” has been applied to the plants Phormium tenax (New Zealand flax) and Gymnostachys anceps (Australian “Settlers’ flax”), because they could be used for the production of fibre. However, they have no botanical relationship to the flax of the Northern Hemisphere, and are not discussed in this study.
1.2.2 Botanical Classification

Flax is a flowering plant (see Figs 1.1 and 1.2, and also Appendix A: Sample Linum usitatissimum) and it is from the stem of the plant that the fibres are obtained to create linen fabric. The English work "flax" comes from the West German/ Old English fleax (Brewer, Redford & Redford, n. d., p. 34; The Oxford English Dictionary vol. V, pp. 1031-1032). Flax is of the subclass Dicotyledonae, the group Thalamiflorae (receptacle flowers), the Order Geraniales (Geranium Order), and the family Linaceae (Flax family).

The family is worldwide in distribution. It is most commonly found in temperate regions, but there are some varieties found in the tropics. The genus Linum, of which there are 230 species, is mainly found in the Mediterranean region (Chant, 1990, pp. 557-8).

The most economically important species of the genus Linum has been Linum usitatissimum (in English "most useful"). This is an annual herb that has been cultivated both for its stem fibres, which are strong and durable, and its seeds, from which linseed oil is extracted.
Figure 1.1 Botanical Illustration of a Flax Plant. *Flax Linaceae: Linum* from Krutch (1965, p.81). This is an illustration taken from life, and shows all parts of the flowering plant. The long stems are used in the production of linen fabric, while the flowers produce seeds used for linseed oil.

Figure 1.2 Drawing of a Flax Plant. This drawing of a flax plant shows the flowers of the plant, the leaves, and the seed bolls in greater detail than Figure 1.1 (Lutz, 1923, p. 4).
Cultivated *Linum usitatissimum* is divided into two main varieties, the white and the blue flowered. The white flowered variety produces coarser fibres and more seeds, while the blue flowered variety is favoured for fine fibre production. However, this current distinction may be the result of modern selective breeding, as we do not find mention of this distinction in ancient records.

Flax is classified as a soft fibre and a bast (phloem) fibre, because the fibres run around the woody core of the stem of the plant, between the core and the outer bark, forming the mechanical tissue of the stems. The fibres are attached to the woody, hollow core by pectins. It is the thick middle layer of the phloem that is used for linen fibre (see Appendix A: Sample *Linum usitatissimum* for a photomicrograph of a stained cross section of a flax stem, showing the phloem). While the outer and inner layers have a Z twist, the middle layer has an S twist. This is important for fibre identification in the processed linen thread (see Appendix A: Textile Analysis for further explanation of Z and S twist).

The length of the stem of a flax plant varies greatly. In the modern cultivated plant the stem length can range from 60 to 120 cm, longer stemmed varieties generally being grown for fibre and the shorter for seed (Benson, 1957;
Cook, 1984; Florian, 1987a; Landi, 1992). The stem is made up of many individual fibre cells, which, in the modern, commercially grown flax plant, vary in length from 6-65 mm, with a mean diameter of about 0.02 mm. (Cook, 1984, p.10).

The stem of the plant is topped by short-lived flowers, which then form seedpods (see Figs 1.1, 1.2 and Appendix A. Sample *Linum usitatissimum*). The seeds are important for linseed oil and linseed cake production, and were used in the ancient Middle East for oil (Barber, 1991, p. 11).

1.2.3 Historical Distribution of Flax

Zohary and Hopf (1993) correlated the archaeological evidence for the distribution of wild flax (*L. bienne*) and its subsequent domesticated form (*L. usitatissimum*). Wild flax, as *L. usitatissimum subspecies bienneis*, is native to a wide area, having occurred over western Europe, the area between the Caspian and the Black Seas and the Persian Gulf, and also in the Mediterranean coastal areas, including North Africa. Zohary and Hopf (1993, p. 120) have plotted its introduction into Egypt from the Near East in the 6th and 5th millennia BC, first in the Delta of Lower Egypt and in the Faiyum (also known as the Al Faiyum Oasis, or simply as El Faiyum), a fertile area southwest of ancient Memphis/modern Cairo, then later in Upper
Egypt (for maps showing these locations see the General Map of Ancient Egypt and Nubia, and also Appendix A: Maps 1, 5 & 6, and Figure 3.1 in Chapter 3).

The appearance of flax in Egypt may considerably predate the first piece of textile found, as the plant may have been used for its oil before its fibre. Also, the technology associated with the production of fibre and weaving may have had a long development. Woven cloth made of linen appeared later in Egypt than in Anatolia and Palestine, so speculation has been that the domestication of flax and the development of weaving using flax spread from Anatolia and Palestine to Egypt (Barber, 1991, pp. 10-15).

The earliest linen fabric archaeologically recovered in Egypt is from the Faiyum area (for maps showing these locations see the General Map of Ancient Egypt and Nubia, and also Appendix A: Maps 1, 5 & 6 and Figure 3.1 in Chapter 3). Caton-Thompson and Gardner (1934, pp. 46-9) excavated the linen fabric and dated it, on the strength of associated grave goods, to the Neolithic, some time in the 5th millennium BC (see Fig. 1.3 for a photograph of the linen as recovered, and also Table 2.3 Chronology of Ancient Egypt, for the dating of the linen). The linen was found within a pottery bowl, in a
sandy deposit in the desert. The bowl may have protected the fabric, which may have been part of a burial offering.

![Image of Predynastic Linen](image3)

**Figure 1.3** Predynastic Linen. The earliest linen fabric recovered to date from the area of present day Egypt. It was found in Badarian Culture levels (5500-4000 BC) of the Predynastic Period, 5500-3150 BC (Photograph from Caton-Thompson & Gardner, 1934: Photograph Number 3, reference to p. 46).

This evidence is also significant when linked to evidence from archaeological excavations at Buto in the Delta, where a very early level yielded a pottery shard with an impression of fabric (Köhler, 1996). The fabric from the Faiyum is in the collection of the Petrie Museum, University College London as University College London No. UC2943. (Barber, 1991, p. 146).
Egyptologist A. Rosalie David (1986, pp. 228-229) has summarised this early evidence:

Of the four major natural textile fibres: linen, cotton, wool and silk, linen and wool were known in Egypt from earliest times. And, whereas the wool of prehistoric Europe has disappeared, leaving only a partial picture of textile activity, Egypt's dry and sterile soil has preserved both animal and vegetable material, giving evidence of wool and of vegetable fibres like linen, rush, papyrus and palm - fibre, dating from about 5500 B.C. A number of Predynastic sites have provided indications of cloth production.

In 1913 Petrie discovered, in the dwellings of a small farming village at Abydos of about 5500 B.C., spindle-whorls of ground -stone and bone, loom-weights and needles, pointing to domestic civity. The Predynastic settlements of Omari, south-east of Cairo, and investigated between 1944 and 1952 by Debono but not yet published, yielded skins, flax seeds (*L. usitatissimum*), mats, spindle-whorls, bone needles and cloth. Even earlier is the Neolithic site of Kom W. in the northern Fayoum [Faiyum], dating from 6000 B.C. and excavated by G. Caton-Thompson in 1924-6. Whorls and signs of flax-growing were found on this site, dating from the long transitional phase of climate changes between c.7000 and 6000 B.C., when hunter-gatherers were altering their lifestyle, first to seasonal settlements, then to village and mixed farming communities.

The incidence of textiles on archaeological sites in Egypt increases greatly from the Neolithic period onward. As pioneering textile historian Geijer (1979, p.268) has written, “... the most abundant source of textile finds is Egypt, where the arid climate has preserved vast quantities of the most varied textiles...”
1.3 The Cultural Importance of Linen in Ancient Egypt

Evidence for the importance of linen in ancient Egypt is abundant in the language, religious rituals, and cultural materials of the ancient Egyptians (Hall, 1986). The written language (as preserved in ancient Egyptian papyri, inscribed on stone monuments, and carved and painted on tombs) demonstrates this in the frequency of signs associated with flax, linen, rope, twine and clothing. All of the following examples of hieroglyphics either standing for linen fibre or fabrics, or objects related to the production and use of linen fibre and fabrics, are taken from Gardiner’s Egyptian Grammar (3rd edition, 1994 reprint, pp. 27, 484, 506-507, 520-527, 617, 619, 626), unless otherwise cited. They come from Middle Egyptian, the vernacular language of Dynasties IX – XI, which then became the literary language of ancient Egypt, surviving in monumental and literary forms down through Graeco-Roman times (Gardiner, 3rd edition, 1994 reprint, p.5).

Collier and Manley, in their best selling book How To Read Egyptian Hieroglyphs, have summarized the earlier work of Gardiner in their table of signs that can stand for a single sound value. These are the most important signs in the language.
Table 1.1 Consonant Signs for a Single Sound Value.

Of these important single sound signs, the sign for the emphatic  also is
used for a wick of twisted flax. The signs for  also are respectively used for

1) folded cloth and 2) bolts of cloth.

Flax is shown as flax bundles with seed , and flax bundles without the
seed or . Tools associated with the production of linen thread and cloth
are the netting needle , a spindle , and the warp , shown stretched
between two uprights, as it would be when it was being prepared for
weaving.
For linen cloth there are different symbols, including a piece of cloth with a fringe —, a strip of cloth with a fringe combined with folded cloth, \( \top \), and a strip of cloth with two strands of fringe \( \downarrow \), as well as several different combinations of symbols for simply linen \( \chi \top \) or for fine linen \( \chi \top \). This linguistic distinction may be interpreted as showing that cloth was graded or classified as to fineness or other criteria.

There are separate symbols for pieces of linen or clothing, such as for a bag of linen \( \odot \), a mummy bandage \( \circ \), different garments \( \mathcal{C} \) (perhaps a folded garment), \( \mathcal{A} \) (this is called an apron and may represent a man’s kilt), \( \mathcal{\nabla}, \mathcal{\Lambda} \), \( ^2 \), a band made of string or linen \( \mathfrak{R} \), strips of knotted cloth \( \mathfrak{M} \), and a girdle knot \( \mathcal{S} \).

Linen was the clothing of choice for all Egyptians, and they also clothed their statues of the gods in fresh linen robes each day (Hawass, 1998, p. 150). Herodotus, in a frequently quoted passage, told how the priests must wear only linen clothing at their religious duties. He also made the point that the linen cloth is kept clean by frequent washing (Herodotus, trans. 1972, p. 142).

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\(^2\) This sign was used during the First Intermediate Period and the Early Middle Kingdom (Landi & Hall, 1979, p. 142).
143). Diodorus Siculus, Strabo, and Pliny also mentioned linen and its importance in Roman times. Pliny, in particular, waxed lyrical about its economic importance, not only to Egypt, but also to the whole of the Roman Empire (Pliny [the Elder], trans. 1963-1971, Book IX). Linen was produced through much of Egypt's history, not only for domestic use, but also as an important export product.

Nnpnt is named as the goddess of flax and linen in the Pyramid Texts (Lutz, 1923, p. 5). She has been considered a form of the goddess Nut and was associated with the creation of flax (Lutz, 1923, p. 9). Although Tayt (also spelled Taye or Tayet), is named as the ancient Egyptian goddess of weaving, and is present in some versions of the ancient mythology and stories, such as The Memoirs of Sinuhe, she is not represented in the tomb paintings (Faulkner, 1962, pp. 292-293). Her name in hieroglyphs, \[\text{glyph}\], contains symbols also used in the words for cloth and shroud (Gardiner 3rd edition, 1994 reprint, p. 626). Lesko considered that she is specifically identified with linen as mummy wrappings, which were called “wrappings from the hand of” Tayt, and that she was exhorted in prayers to gather together the bones of the deceased and to protect the body (1999, p. 275)
Figure 1.4 Neith. A painting of the ancient Egyptian goddess Neith in the Tomb of Queen Nefertari at Thebes (Hawass, 1998c, p.171).

Neith was an important creator goddess of Ancient Egypt. One of her many important roles was as a goddess closely associated with the invention of weaving. The symbol on her head is the hieroglyph 'd', which is thought to represent a spool, reel, or netting needle filled with twine (Gardiner 3rd edition, 1994 reprint, p.525). This symbol may indicate that Neith is depicted in her role as the goddess responsible for the provision of funerary linen.

Queen Nefertari was the chief wife of Ramses II (the Great). Her tomb dates to the 19th Dynasty, 1295 – 1186 BC.
However, the Ancient Egyptians believed that other goddesses also had close associations with weaving, and these are sometimes depicted with symbols of their association with weaving or the use of linen. Neith, an ancient creator goddess and one of the major goddesses of Ancient Egypt, is also credited with inventing weaving (Shaw & Nicholson, 1995, p. 200). One of her many roles was to look after funerary linen. Her name contains the hieroglyph 'd, which is thought to represent a spool, reel, or netting needle filled with twine (Collier & Manley 1998, p. 143). She is sometimes depicted with that hieroglyph upon her head (see Fig. 1.4). Other goddesses, such as Isis and Nephthys, also had various roles associated with weaving (Nicholson & Shaw, 1995, p. 200), but their names do not appear to contain hieroglyphs directly related to weaving.

Material evidence of linen in Egypt comes both from artistic works, such as wall paintings and statues, and from the surviving fabrics themselves. Colourful paintings and beautifully carved statues depict clothing, tapestries, household furnishings, and sails on boats. Fabrics exist from all periods of Egyptian history, though they come largely from burial contexts (both human and animal burials) and are only rarely found in settlement sites. There not only are fragments extant, but also whole
garments, grave offerings of flat textiles, some household furnishings, and boat sails.

The reasons why most of the linen that has been found in Ancient Egypt has come from a burial or tomb environment are partially cultural and partially environmental. Dwellings in Ancient Egypt were largely built of mud brick, which was recycled back into agricultural land when dwellings were abandoned. They were also subject to periodic flooding from the annual inundation of the Nile. Consequently, few dwellings (palace or village houses) have been excavated in Egypt, and when they have been excavated the environmental conditions have rarely been conducive to the preservation of organic materials.

On the other hand, temples and tombs were constructed of stone, as they were meant to be dwellings for eternity. Tombs and mortuary temples were located away from the Nile Valley, in dry desert areas which could not be used for agricultural production and which were conducive to the natural mummification of bodies buried there. In these tombs the deceased were supplied with all they would need for their future lives, including linen clothing (often in large quantities), in addition to the wrappings, clothing,
and/or shrouds placed on the bodies. Often these garments and pieces of linen were stored in the tombs in chests, boxes, or woven baskets.

Ancient Egyptian tomb linen had often been used prior to burial. Evidence for this comes from laundry marks on the garments and also from crease marks created by wear. This is true also for the mummy wrappings, which literary sources report were often made from used linen sheets or garments supplied by the household of the deceased (Vogelsang-Eastwood, 2000). If the garment or household linen had been used it had probably also been washed. The ancient Egyptians placed great emphasis on personal cleanliness, and most garments that were placed in the tomb appear to have been placed there in a laundered/clean condition.

Of great interest is the discrepancy between some garments which appear to be female tunics or dresses found in tombs, which are opaque and made to naturally fit the body (see Figs 1.5 and 1.6), and the female garments depicted on tomb walls, which are often shown as transparent or semi-transparent and clinging so tightly to the body as to leave little room for movement.
**Figure 1.5 First Dynasty Dress.** Ancient Egyptian tunic or dress from Tarkhan (U.C. 28614B.), dated to the reign of King Djet, c. 2800 BC, First Dynasty (Hall 1986, p. 27). The photograph is by the Petrie Museum, University College London.

**Figure 1.6 Fifth Dynasty Dresses.** Ancient Egyptian dresses from Deshasheh (UC 31182 and UC 31183), Fifth Dynasty, 2494-2345 BC. The dresses, which have undergone conservation treatment, are on display at the Petrie Museum, University College London. Photograph by the author.

Permission to photograph the dresses on display was granted by the Petrie Museum, University College, London.
This discrepancy suggests that the depiction of clothing as transparent might have a religious or symbolic meaning, rather than being a literal depiction of clothing worn in the lifetime of the tomb owner. This discrepancy also suggests that the tomb depictions may be idealised and conservative compared to the life of the times. Thus a close study of the remaining examples of clothing and other textile goods is of historical importance, as they may more accurately reflect the actual clothing of the ancient Egyptians than do the statuary and paintings from ancient Egyptian tombs and temples.

1.4 Linen Production

1.4.1 Introduction

Probably the most extensive descriptions of the process of linen production in Ancient Egypt are found in the work of Lutz (1923), Lucas (1948), Tata (1986), Hall (1986), Barber (1991, 1994), and Vogelsand-Eastwood (1992a, 1992b, 2000), though most general histories of Egypt include a small description of the process, since it was such an economically and culturally important part of life in ancient Egypt.

A thorough understanding of the processes of linen production and use is a prerequisite to an understanding of the physical and chemical composition of ancient Egyptian linen. These processes include the process of plant growth,
the processing and grading of flax crops, the production of linen fabric through the manufacturing processes of spinning and weaving, the grading and distribution of the resulting linen. The crucial processes also include the washing and handling of linen during its useful life, and the final use of linen in the Egyptian burial ritual.

1.4.2 Production Methods

Available information about the production and manufacturing of flax in Ancient Egypt comes from both pictorial and literary sources - chiefly wall paintings and papyri of various periods (Forbes, 1964, pp. 29-31).

Tata (1986, Tables 2 and 3) lists twelve reliefs representing flax cultivation dating from the Old Kingdom and seven reliefs from the Middle Kingdom. Pliny the Elder described the whole process as he knew it in the 1st Century AD (Pliny *Natural History XIX*).

Flax that will be used for fibre production is pulled out of the ground by its roots (in order to get as long a stem as possible for fibre production). Perhaps the best depiction in ancient Egyptian art of flax in the field being pulled as it is harvested is found in the tomb of Sennedjem at Deir el Medina, which
dates from Nineteenth Dynasty (see Figures 1.7 and 1.8). In the painting the flax is standing straight and relatively tall.

**Figure 1.7 Detail of a wall painting from the Tomb of Sennedjem at Deir el Medina.** This tomb is dated to the Nineteenth Dynasty, 1295-1186 BC. The third register from the top shows the tomb owner and his wife harvesting flax by pulling it up by the roots. Flax was harvested in this manner when the complete stem was needed for making linen textiles. The detail is from a photograph by Hesham and Mohamed Saad (2000).

![Wall painting from the Tomb of Sennedjem at Deir el Medina.](image)

**Figure 1.8 Wall painting from the Tomb of Sennedjem at Deir el Medina.** This tomb is dated to the 19th Dynasty, 1295-1185 BC. The complete painting depicts the tomb owner and his wife engaged in agricultural pursuits in the afterlife. The portion of the wall painting shown below includes the sewing of wheat and the harvesting of wheat by cutting, as well as the harvesting flax by pulling it up by its roots (Marks 1998, p. 99). The photograph below is by J. Morris, and has been edited to show the scenes of sewing and harvest.

![Wall painting from the Tomb of Sennedjem at Deir el Medina.](image)
However, it is worth remembering that it was a common convention in Egyptian art to show things in larger than natural size if you wished to emphasize their importance. As Sennedjem and his wife are harvesting in heavenly fields, the painting may depict an idealized field of flax, in keeping with the depiction of a prosperous afterlife for the tomb owner.

Evidence for the processes of spinning, weaving, and washing of textiles come largely from depictions of the processes found in tombs. The earliest evidence of weaving in Egypt comes from a Predynastic painted pottery dish (see Fig. 1.9), found in tomb 3802 at Badari (UC 9547) and now in the Petrie Museum, University College London (Brunton & Caton-Thompson, 1928; Hall, 1986, p. 2), but the most complete scenes showing the process in antiquity come from tombs of the Twelfth Dynasty at Beni Hasan, with scenes of spinning and weaving in Tomb 3, main chamber and west wall and scenes of what has been interpreted as washing (see Figs 1.10 and 1.11) from Tomb 2 (Newberry, 1893, reprinted 1975, plates XXIX and XI). A scene showing laundrymen at work (see Fig. 1.12) is found in the Nineteenth Dynasty tomb of Ipuy at Deir el-Medina (Davies, 1927, plate XXVIII). A very charming three-dimensional model of a weaving room from the tomb of Meket-Re at Deir el-Bahri, Eleventh Dynasty (JE 46723) is now in the Egyptian Museum, Cairo (see Figs 1.13 and 1.14).
Figure 1.9 Predynastic Dish. This is a photograph of a ceramic dish (UC9547) from Tomb 3802 at Badari, Egypt, dated to the Predynastic Period, 5500-3150 B.C. The drawing in the centre of the dish is thought to be the earliest depiction of the horizontal ground-loom in Egypt. The photograph is by the Petrie Museum of Egyptian Archaeology, University College London.
Figure 1.10 Drawing of the Washing Process from the Tomb of Baqt. This is a detail of a drawing of a wall painting showing men washing and drying cloth from the Middle Kingdom tomb of Baqt at Beni Hasan, c. 2055-1650 BC. It was taken from Newberry (1893 reprinted 1975, Plate XI).

Figure 1.11 Drawing of the Washing Process from the Tomb of Khnemhotep. This is a detail of a drawing of a wall painting showing men washing and drying cloth from the Middle Kingdom tomb of Khnemhotep at Beni Hasan, dated to the Twelfth Dynasty, 1985-1795 BC. It was taken from Newberry (1893, reprinted 1975, Plate XXIX).

Figure 1.12 Men Washing from the Tomb of Ipu. A photograph of a wall painting showing men washing cloth from the tomb of Ipu at Deir el-Medina, dated to the Nineteenth Dynasty, 1295-1186 BC. The photograph is by Andri Held, Lausanne (Boulanger, 1965, p.72).
Figure 1.13 Model Weaving Room. This is a photograph of a model weaving room recovered from the Tomb of Meket-Re at Deir el Bahri by H. Winlock and dated to the 11th Dynasty, c. 2125-1985 BC. The model is held by the Egyptian Museum, Cairo. (JE 46723). Photograph by the Egyptian Museum.

Figure 1.14 Drawing of Weaving Room. A drawing of the model spinning pots, spindles, pegging for holding linen thread, spun thread, and a ground loom, that were found in the above model. (Winlock 1955, figure 67).
Some artefacts connected with the production of linen in Egypt are rare, while others are common. Spindle whorls and loom weights, being often made of stone or pottery, are commonly found on archaeological sites. However, finds of the more perishable tools of spinning and weaving have only rarely been recovered.

Sir William Flinders Petrie found the finest set of weaving tools from an Egyptian site, perhaps the only complete set from Ancient Egypt, at Kahun and dated them to c.1890-1790 BC (1890, pp. 34-35). The set includes a very rare, perhaps unique, wooden flax stripper. The complete set was presented to the Manchester University Museum by Sir William Flinders Petrie, where it is currently exhibited.

It may be helpful to briefly review more recent methods of flax production as well as what we know about ancient Egyptian methods, as most archaeological commentary on the subject also refers to current methods in order to fill in gaps left in the ancient records. This method of interpretation has been commonly used as an anthropological method to attempt to understand ancient technology. For example, Nielson used the concept of “living tradition” among Kurdish weavers to construct models for

In modern times flax is sown from seed and cultivated much like wheat or other grass plants. It is commercially grown in Northern Europe and Great Britain, where it is sown from the end of April (Mitchell, 1993, p. 50) and in the Americas, where it is sown around the end of March. The plant blooms from the end of May through the Northern Hemisphere summer, depending on the area, and is harvested from August onwards. It is no longer grown in great quantity in Egypt, cotton having taken its place as a more economically profitable fibre plant.

The harvesting schedule in Ancient Egypt was different from the current harvesting schedule in countries that still grow flax on a commercial basis. That is because the growing season for flax in Egypt and much of the Near East was during their mild winter and warm to hot spring, their summer being too hot to grow flax efficiently. The seed was sown in October or November, and grown during the winter months to avoid the scorching heat of the Egyptian summer. Ancient Egyptian flax is pictured as growing quite tall and close together, to make for straight stalks (Barber, 1991, p. 12). The plant was harvested at various stages of development. Plants chosen for finer
fibre production appear to have been pulled earlier, before seeds were produced, while plants left to go to seed had much coarser fibres for spinning. The harvesting of flax differed from that of wheat in that it was pulled up by the roots, rather than cut, as can be seen in the wall painting from the Tomb of Sennedjem at Deir el Medina (see Figs 1.7 and 1.8). Linen is first “shocked” then threshed (if seed had been produced) in such a way that the stem or straw was not broken. The process of removing the seed is now called “rippling” (Mitchell, 1993, p.51).

A process that is now called “retting” separates the fibres from which linen will be made. In this process the fibre, which makes up only 15% of the total volume of the stem, is separated from the soft tissue (Landi, 1992, p. 22). This takes place either through exposure to rain in the field, called “dew retting”, or by soaking in water tubs or ponds, called “water retting.” Water retting is rarely used today because of its cost and the pollution it causes to rivers, and also because the rotting plants in a small river or pond use up oxygen and this kills fish (Mitchell, 1993, pp. 52-53). The retting process at the same time removes the gums and resins as well as softening the stems. This is because the retting (from the word rotting) dissolves/utilises the pectins surrounding the bast-fibre bundles through a natural enzymatic
process. When water retting is used the flax is given a pleasing blonde colour, a colour we associate as the colour of linen.

In the next stage of processing the stems are “scutched”, a process in which the fibres are mechanically separated from the stems. In present day manufacturing the layers of plants are passed through rollers and turbines. In the past, various implements were used to separate the fibres, the basic process being the same (Lutz, 1923, p. 11).

The fibres are currently classed into “fine” and “tow.” Only the fine is used to make cloth. There is a wide range of classes within fine, with fineness graded by diameter size. The fibres are then spun into thread and woven into cloth. Current practice is generally to spin fine fibres with water, while tow is dry spun.

Vogelsand-Eastwood, Barber, and other authorities on Egyptian textiles, believe that the Egyptians either spun the very long stem fibres by placing the ends of two lengths together, then rolling them on their legs, or they spun using a spindle in a variety of methods (Barber, 1991; Vogelsand-Eastwood, 2000, pp. 271-274). They also believe that the Ancient Egyptians spun with water or moistened the fibres with their mouth during spinning. Their
reconstruction of Ancient Egyptian spinning methods is based upon the evidence of the model weaving house in the Egyptian Museum, Cairo (see Figs 1.13 and 1.14), from tomb paintings, and from microscopic examination of the fibres of extant ancient Egyptian linen.

The ancient Egyptians also may have had a highly developed classing system for linen. The linguistic evidence cited above shows that they distinguished at least between common and fine linen. Vogelsang-Eastwood believed that marks found inscribed upon textiles now housed in the Egyptian museum, Cairo, indicate that fabrics were marked with their quality and that there may have been perhaps five grades of cloth recognized during the Dynastic period (2000, pp. 285-286).

A considerable amount of the available literature on ancient textiles is concerned with spinning and weaving, particularly as it is by close analysis of the resulting fabrics that differences in area, dating, usage, and class status can be deduced by the archaeologist (see Barber, 1991; Bellinger, 1950; Bowen, 1999; Crowfoot, 1931; Emery, 1994; Geijer, 1979; Hall, 1982, 1986; Kybalova, 1967; Lutz, 1923; Tata, 1986; Trilling, 1982; Vogelsang-Eastwood, 1987, 1992a, 1992b, 1992c, 1993, 2000; Walton and Eastwood, 1988).
1.4.3 Methods of Washing, Bleaching, and Dyeing

1.4.3.1 Introduction

Available knowledge of Ancient Egyptian textile washing practices comes from tomb paintings, literature from papyrus or rock inscriptions which mention washing practices, letters and laundry lists from the workman's village of Deir el Medina, and from the writings of foreign observers (Hall, 1986, pp. 48-56). The scholarly consensus based upon the above evidence is that linen was washed in water, either directly in the Nile or in pots alongside the River. It was washed either by professional washermen or in some household arrangement, perhaps by the female members of the household. The water used could be cold or heated. Either natron, potash, or a vegetable derivative called soapwort (*Saponaria officinalis*) was used to clean the clothing, or some combination of these substances could be used on the same garments (see Figs 1.10-1.12, which were painted within ancient Egyptian tombs depicting washermen at work).

1.4.3.2 The Processes

Both Middle Kingdom and New Kingdom texts describe the miserable life of the professional washerman, but they are not specific about his methods or materials (*Papyrus Sallier* II.8.2 translation by Wilson, cited by Forbes,

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3 While women may have washed for their own families, the linen of well-to-do families was washed by professional washermen (Hall, 1986, pp.48-56).
1964, p. 83; Hall, 1986, pp. 55-56). However, a letter from the reign of Ramses II found at the workman's village of Deir el-Medina, from a Scribe of the Tomb to the Scribe Amenemope, is more descriptive.

As for Nakht-Sobki, I found no natron (i.e., ‘soap’) in his possession- you (shall) give him [... some...] ...When you know the [amount] that's short, they can seek out natron for the cloths, and you shall not (further) [allow] this failure to supply natron. For Pharaoh has assigned natron to you - it just cannot be that he has not allotted it! ...(Kitchen, 1982, p.197).

Two notable Biblical references to the use of natron, potash and Saponaria officinalis can be cited.

Jeremiah 2: 22. For though thou wash thee with nitre and take thee much borith-alkali, yet thine iniquity is marked before me.
Job 9: 30. Though I wash myself with seleg water, and cleanse my hands with bor-alkali.

According to Lutz (1923, pp. 74-75), “The me seleg is probably a solution of a certain soap-plant, or some marine plant such as salsola, triglochia, salicornia, or atriplex, all of which on incineration yield sodium carbonate, although more potash than soda” and “The nitre is derived from the Egyptian Nitr a term which was applied to carbonate of soda. This carbonate of soda (natron) was used as early as the 5th dynasty period in Egypt for purposes of cleansing.” Lutz makes reference to Papyrus Wnys 18 N 243a, 243b; W. 19
N245a, 246a; W21, 22, 23, 24, N248, 249, pp. 74-75. Though Biblical references are to practice in Palestine, the reference to nitre indicates that its use was known in a wider area than present day Egypt. The use of natron may have been a cultural practice of the inhabitants of the area we now know as Palestine/Israel. However, it is useful to remember that the Egyptian Empire once extended to Mesopotamia and included the present lands of Palestine/Israel. If we consider the use of natron as an Egyptian cultural practice, then it was most probably carried into other areas in the present day Middle East with the Egyptian army. The composition of natron is discussed in detail in the following section (1.4.3.3).

Newly woven fabric was washed and then might be either left unbleached or bleached, or it might be dyed. It is common to think of all Ancient Egyptian cloth as plain white or natural linen colour, but some dyed linen, and also dyed wool, was produced. While wool is easy to dye using vegetable dyes, linen is very difficult to dye. Evidence has been found that suggests that the Egyptians used alum as a mordant to fix madder in some of the textiles found in the tomb of Tutankhamen (Lucas & Harris, 1999, pp. 150-154). Sodium chloride (NaCl) and other salts may also have been used to fix dyes, and hydrated or slaked lime, Ca(OH)$_2$, has been suggested as a source for the calcium found in some 12th Century colourfast yellow mummy linens as
well as coloured linens in Tutankhamen's tomb (Barber, 1991, pp. 236-267).

Further information about Pharaonic Egyptian dyes may be found in a standard reference on the subject, Die Textilfärberei und die Verwendung gefärbter Textilien im Alten Ägypten by R. Germer (1992).

Natron could also have been deliberately used for bleaching the cloth, or the bleaching could have been an unintentional side-effect of the laying out of the washed cloth on grass fields where dew formed, the impurities in the natron catalysing the oxidation process.

Lutz (1923) observed:

The monuments show us only the process of obtaining the fibres, but do not depict the method of bleaching. Two modes of bleaching must have been in existence, i.e., bleaching of the fibre and bleaching of the cloth, in case a white cloth was desired..."Unfortunately our knowledge at the present time regarding alkalies in use among the Egyptians, Babylonians and early Syrians, is still very imperfect. We know, of course, that these peoples must have had a practical knowledge of the chemical action of certain alkalies, and that they had made use of them in their textile industry, but the mere names of chemicals which have come down to us in the most elucidating instances tell us only in a general way to which class they belong (pp. 73 -74).

The state of our knowledge about these processes has not advanced much from Lutz's time.
If natron or other materials were used in the washing and bleaching process then possible residues may have remained from these cleaning aids in the cloth, and their use may have changed the fabrics chemically/and or physically.

With the coming of the Romans to Egypt there came a change in washing methods, as the Romans brought the use of soap, as we know it, made with fat and lye, with them. The first mention of soap may be Pliny, H.N., XXVIII, 51, 2:

"Fit ex sebo et cinere. Optimus fagino et caprino, duobis modis, spissus ac liquidus: uterque apud Germanos majore in usu viris quam femis". "This substance is prepared from tallow and ashes, the best ashes for the purpose being those of a beech and yoke-elm; there are two kinds of it, the hard soap and the liquid, both of them much used by the people of Germany, the men, in particular, more than the women." Pliny says that it was a Gallic invention, but best made by the Germans, and used for dispersing sores (Pliny quoted and translated in Lutz 1923, p.73).

1.4.3.3 Natron

As natron was a substance of much cultural and economic importance in ancient Egypt, being not only the most important additive or laundry aid for washing, but also used for a variety of other purposes over a long period of time, it gathered a variety of names over time, first in ancient Egyptian and
then in Coptic. The word natron comes from the Egyptian word, transliterated as ntr. Lutz (1923) on pp. 75-76 cited below, gives hieroglyphs for the Wadi Natrun, and a natron god worshiped in early dynastic times, as well as for common natron, red natron, and natron obtained by the ancient Egyptians from areas other than the Wadi Natron.

![Figure 1.15 Hieroglyphs for Natron.](image)

Source: Lutz (1923, pp. 75-76).

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4 These pages were photographed by the author in the library of Chicago House, Luxor. The out-of-print book (Lutz, 1923) was too fragile to be photocopied. Therefore the quality of the reproduction is the best that can be achieved at this time.
The word for natron was written in Middle Egyptian either as $\text{\textcopyright{}}$ or $\text{\textcopyright{}}$, according to Gardiner (3rd edition, 1994 reprint, p.619). The first form of the word cited above has within it hieroglyphs for a twist or wick of linen and for cloth, as well as folded cloth and water, all of which may point to its association with the washing of linen. The second form of the word has the determinative for a mineral, and three strokes representing the plural, thus representing grains of minerals or sand (Collier & Manley, 1998, p. 138).

From Coptic the word for natron passed into Arabic. The translation of Arabic terms into English is not a precise process, and variations of spelling are a common result. Thus both natron and natrun occur in the literature, and on English language maps of Egypt both Wadi Natrun and Wadi Natron, or sometimes Atrun, are found. The Greek word was nitron and the Latin word was nitrum or natrium. It is from the Latin natrium that the internationally accepted symbol for the element sodium, Na, is derived (The Macquarie Dictionary, 1981, p. 1152).

All the terms refer to the same natural soda, ideally an equimolar mixture of sodium carbonate and sodium bicarbonate. Generally it contains in nature a
large proportion of “impurities”, often including sodium chloride (Lucas, 1912, p. 1). The formula for natron that was used by Arthur Lucas (1912, p. 17) is \( \text{Na}_2 \text{CO}_3 - \text{NaHCO}_3 - 2\text{H}_2\text{O} \).

Arthur Lucas undertook as a major project the analysis of natron from Wadi Natron in the first decades of the 20th Century. Lucas had held the position of director of the Chemical Department of the Egyptian Government, and also had been conservator for Howard Carter's excavation of King Tutankhamen's tomb (Carter, 1954, reprinted 1972, p. 44). His interest in natron was part of the larger problem of the rediscovery of the ancient processes of mummification - to which study Lucas made a major contribution. He found that natron was a mixture of sodium carbonate and sodium bicarbonate, which also contains impurities, in various proportions. He found that in Egypt, sodium chloride and sodium sulfate are always present in natron, sometimes in large proportions (Lucas, 1932a, p. 66). For instance, in 14 specimens from Wadi Natron (or Wadi Natrun) the percentage of sodium chloride varied from 1.9% to 26.8% and the percentage of sodium sulphate from 0.8% to 39.3%. In three specimens from El-Kab the sodium chloride varied from 12.4% to 54.6% and the sodium sulfate from 11.4% to 70.2%. In samples of ancient natron from Egyptian tombs from the 11th dynasty and the 18th dynasty he reported that sodium chloride “impurities” ranged from 0.5
to 51.1% and sodium sulfate from 5.5% to 33.0%. Also present are magnesium chloride, magnesium carbonate, and oxides of iron and aluminium (Lucas & Harris 1999, pp. 493-494).

Magnesium is a natural component of dolomite (calcium-magnesium carbonate, CaMg [CO$_3$]$_2$) a major component of limestone in Egypt, found in almost all areas of the Nile Valley (Aston, Harrell & Shaw, 2000, p. 40). The presence of Mg in natural Egyptian natron, indicated in Tables 2-5 of Lucas' analysis of natron (1912), is especially relevant to this study as it might indicate that natural Egyptian natron, when used for washing, paralleled the action of magnesium bicarbonate in modern commercially produced solutions used for the deacidification of paper.

Modern baking soda (sodium bicarbonate NaHCO$_3$), washing soda (sodium carbonate Na$_2$ CO$_3$), and anti-acid powders (mixtures of sodium bicarbonate and sodium carbonate with flavours) consist of the same basic ingredients as natron, but are refined and purified. They are also used for many of the same purposes as natron. In Ancient Egypt natron was used in purification ceremonies (including purifying the mouth and daily cleansing), for washing cloth, for making incense, in the manufacture of glass, glaze, pigments, and cosmetics, for cooking, for medicine, and in the mumification process.

1.4.3.4 Natron: An Egyptian Laundry Aid?

Lutz (1923) cites ancient Egyptian literary references to the washing of textiles. The most widely cited references to the weaving and washing of linen come from The Satire on the Trades, a document that appears to have been used for the instruction of junior scribes. The earliest surviving copy is from the New Kingdom (1550-1069 BC). Presumably a scribe wrote it, as it depicts the offensive aspects of every trade and concludes that the only occupation to aspire to is that of scribe. In fact, as opposed to biased literary fiction, the position of washerman ⁵ was a well-known and widespread profession, with the position of Superintendent of the Washermen having a relatively high position in the household of Pharaoh (Hall, 1986, p. 48).

There is one clear documentation of the use of natron by the washermen of Ancient Egypt in a letter found among the ostraca (informal letters on slips of limestone and potsherds) found on the site of Deir el Medina (1500 - 1100 BC), quoted above by Kitchen (1982, p. 197).

⁵ Our evidence is that only men were professional washermen, and they worked for families who could afford to have their washing done professionally (Hall 1986).
Natron is better known in Egyptology as an important ingredient in the mummification process than as a washing agent. Samples of natron were found in Canopic jars and residues of natron were found among used bandages, upon the beds used for mummification and on some mummies (Lucas, 1932b, pp. 125-140; Peck, 1984, pp. 11-28). However, the actual use of natron (and whether it was used in liquid or solid form) was the subject of some scholarly/scientific debate early in the 20th Century. The question was resolved after some experimentation. It has generally been accepted that solid natron was used at certain periods to pack around and inside the body to encourage desiccation (David & Tapp, 1992; Lucas, 1932b).

Much of the written information from historical times about the use of natron in mummification rests on writings of Herodotus (trans. 1946; trans. 1972), Strabo (trans. 1932), and Diodorus Siculus (trans. 1968). Herodotus was a Greek, and therefore a foreign observer, and he is now known to have accepted some unreliable information from his Egyptian informants. Therefore, his evidence is currently suspect on many question of Egyptian history. Strabo and Diodorus Siculus, though also foreign observers, have a higher reputation for accuracy on matters Egyptian.
In the Ptolemaic and Roman periods mummification actually became more common, but with the increase in quantity the quality of the mumification declined. At the same time you find some burials conducted according to strictly Greek or Roman burial customs, instead of Egyptian ones. (Quirke, et.al. 2000, no page number given).

In the Christian period full mumification was practiced less often. Bodies were often buried with large quantities of salts (natron or rock salt) packed among the folds of the body’s tunic or shroud (Kybalova, 1967). Ordinary clothing and shrouds, or sometimes especially fine linen and garments decorated with woollen tapestry work, replaced linen mummywrappings (Quirke, et. al., 2000, no page number given).

The practice of some sort of mumification using natron only came to an end with the Arabic conquest. The Quran gave specific instructions on how to treat the dead; the body was to be ceremonially washed (Ghusls), covered with a cloth, laid out during prayers, and then buried quickly (Quirke, et. al., 2000, no page number given).
1.5 The Survival of Linen in Egypt

The survival of large amounts of textiles from ancient Egypt is a remarkable occurrence. In Egypt, textiles have been found in large quantities in tombs cut into limestone and in dry, sandy deposits. By contrast, almost no linen fabric has been recovered from ancient Mesopotamia or Asia Minor, been recorded as only dye in dust (Wooley, 1950) or as badly oxidized pieces (Harris, 1993; Mellaart, 1967; Ryder, 1965). Some textiles have, however, been recovered from dry caves or tombs in limestone in Palestine (Negnevitsky & Schick, 2000), with exceptional preservation being found of organic materials at Jericho (Wheeler, 1956).

1.5.1 Archaeological Recovery Methods

As the first "archaeologists" excavating in Egypt during the 19th and early 20th Centuries were largely concerned with finding and obtaining objects of high intrinsic and artistic value, such as jewellery and statues, the more humble and perishable items, such as basketry, textiles, and undecorated wooden items were often dumped, sometimes even burned.

With increasing acceptance of the careful stratigraphic analysis of archaeological excavations pioneered in Egypt by Sir William Flinders Petrie, more care came to be given to recording all evidence from
excavation, not just looting for a few precious finds. However, Petrie's collection of the humble textile-related objects from Kahun and Gurob was an exception to their general neglect (David, 1986; Petrie, 1890).

It was not until the pioneering work in Egyptian textiles by Hall was published (Landi and Hall, 1979; Hall, 1986), and comparable work on early textile history was published by Geijer (1979), Ryder (1983), Wild (1988), and Barber (1991, 1994), that a wider interest was regenerated in archaeological circles in textile history. The use of the term regenerated seems appropriate, as considerable interest in things Egyptian, including textiles, had been generated by the discovery of King Tutankhamen's tomb in the 1920s (Carter, 1954, reprinted 1972), and a small number of archaeologists had long been interested in ancient textiles that had been excavated in the Near East and Europe as well as Egypt (Burnham, 1965; Crowfoot, 1931; Lucas, 1948; Lutz, 1923; Thurman & Williams, 1979; Wooley, 1950; Zohary & Hopf, 1993).

1.5.2 Improvements in the Recovery and Analysis of Textiles, Wood and other Organic Materials

As studies of textiles from many parts of the world began to be compiled, and as new methods of analysis, particularly organic analysis, were
developed after World War II and increasingly used in the study of archaeologically recovered materials (Orna, 1996), scientific analysis began to be used on ancient textiles for a variety of purposes. These purposes included the identification of dyes, the identification of residues left in the fibres, the identification of manufacturing techniques, dating studies, studies of mineralization, and studies of bio-deterioration. Of particular interest to archaeologists and conservators were investigations into the reasons for the preservation of ancient Egyptian textiles and other ancient Egyptian artefacts made of organic materials.

The survival of organic materials within archaeological sites was attributed to beneficial environmental conditions. Pioneering work in this subject was carried out as part of the educational program of the Institute of Archaeology, University of London. Dowman (1970) described environmental conditions necessary for the formation and preservation of the archaeological record. Later manuals of field conservation have given less consideration to environmental conditions, instead concentrating on specific treatments for various categories of artefacts. These manuals give little consideration, in general, to organics and even less consideration to textiles.
Edwards (1974), also at the Institute of Archaeology, dealt with the environmental conditions necessary for the preservation of textiles in archaeological deposits, as well as with methods for the conservation treatment of archaeological textiles. However, this study remains unpublished, and is available only in the Institute's Library in London. It gives an overview of the general environmental conditions necessary for the preservation of textiles and focuses on textiles in the United Kingdom.

1.5.3 Archaeological Textiles: Specialist Studies

Specialist studies in archaeological science have concentrated on the mechanisms of deterioration of textiles under controlled conditions, on possibilities for the use of textiles for dating artefacts, and on studies of the mechanisms of mineralization of textiles⁶.

1.5.3.1 Biodeterioration

Research into the general factors affecting the preservation of textiles in an archaeological deposit has been undertaken through simulations or “experimental archaeology.” However, almost all of these experiments have been conducted in environmental conditions quite different from those of Egypt. The best known studies have been conducted as part of the

⁶ For a definition of mineralization please see the Glossary.
experimental earthworks at Overton Downs and at Morden Bog in the United Kingdom by the British Association for the Advancement of Science (Crabtree, 1990; Evans & Limbrey, 1974; Jewel & Dimbleby, 1966; Ryder, 1996).

The United States Government, as part of its defence program, has conducted experiments into the biodeterioration of textiles at its DSCP (Defence Supply Center Philadelphia) Laboratories (DSCP, 2002). Such studies have been concerned with the durability of modern materials (i.e., defence forces’ textiles) and as a consequence, are not directly relevant to studies of ancient materials.

Peacock (1996a, 1996b) conducted studies of the biodeterioration of textiles in wet or waterlogged conditions. The results have relevance to the preservation of Egyptian textiles that have been immersed in salt solutions or have been affected by saline ground water.

The role of sodium chloride as a preservative for textiles has rarely been dealt with in the literature, though there are occasional references to textiles having been found in mines (covered with salts), or on the edges of oceans or estuaries (current work in Antarctica on the preservation of explorers'
huts). The general prognosis is that sodium chloride inhibits bacterial action, and so helps to preserve textiles. Florian (1987a, 1987b) made some particularly relevant observations on the effects of salt water on organic materials, including ropes and textile sails. Also, some interesting articles by Hegeman (1985) and Hungate (1985) on the nature of salt-tolerant versus salt-intolerant bacteria have relevance to the question of biodeterioration of textiles in solutions of salts. That there are salt tolerant bacteria suggests an exception to the general rule that salt(s) will inhibit bacterial action in textiles.

Less attention appears to have been paid to fungi than to bacteria in studies of the effects of sodium chloride in the inhibition of the biodeterioration of textiles. Fungi do live upon ancient linens in Egyptian tombs if there is enough moisture present to permit fungal growth. Carter (1954, reprinted in 1972) found evidence of fungal growth in the tomb of Tutankhamen, dating from periods when moisture had entered the tomb. Jones and Oldfield (2001) believe that they have identified fossilized fungal hyphae in heavily resinated textile fibres from Burial 16 in the HK43 cemetery at Hierakonpolis in Upper Egypt (situated on the West bank of the Nile, near Edfu). In a preliminary report on their findings (2001, p. 14) they are not able to determine whether the fungal growth is of “human or textile origin”, but they
are certain that it is confined to the layer of textile mummy wrapping next to the body. An EDXA analysis of the textile fibres confirmed the presence of sodium chloride (J. Jones, personal communication by e-mail, dated 31.1.2002 on the EDXA examination of early textiles found at Hierakonpolis).

Kanawati (1993, p. 21) found evidence of damage to linen mummy wrappings when the mummy Hag. 89.C5 may not have been completely dehydrated before being wrapped, moisture from the body affecting the linen, and leaving large liquid stains. In such a situation fungal spores already present (air-borne and landing upon the cloth prior to entombment of the body) could be activated and fungal growth could consume the linen, until growth was halted, probably by dehydration in the tomb environment.

Landi (1992) gives an example of the activation of long dormant fungal spores in an Egyptian textile that she began to wash at the Victoria and Albert Museum. The growth was so rapid and extensive that immediate measures were taken to fumigate the textile and kill the fungi.

1.5.3.2 Mineralization

When organic materials, such as wood or textiles, come into contact with metal salts in solution, then the organic materials may become mineralised.
The definition of mineralization used is that of *The Oxford English Dictionary* (1989 2nd edition, pp. 807-808), where “mineralised” is defined as being “impregnated with minerals”; or “containing mineral substances”, and “mineralization” is defined as “The action or process of mineralising, or the state of being mineralised”. I believe this broad definition of “mineralization” to be consistent with Gillard, Hardman, Thomas, and Watkinson’s definition of mineralization as “the combination and/or replacement of the organic matrix with an inorganic one” (1994, p.132).

More narrow definitions have been used by K.A. Jakes and her associates in regards to differing forms of textile “mineralization. The term “pseudomorph”, which means “false form”, is a term commonly used in Geology. This term has been used by Jakes and others to describe a situation where the whole of a fibre has been replaced by minerals, called “positive pseudomorphs”, or where only a cast of the fibre remains, called “negative pseudomorphs” (Jakes & Sibley, 1984; Jakes & Howard III, 1986; Coho, 1997, no page number given).

However, the term “pseudomorph” appeared to be going out of favour by the late 1990s, and instead “fibre mineralization” was becoming the more commonly used term (Chen, Jakes & Foreman, 1998). The descriptive definition “partial mineralization” came to also be used, to describe those fibres or fabrics where the process of mineralization has only just begun or
has only replaced part of the fibre structure (Jakes & Sibley, 1989; Cameron, 2002; Shearman, 2002; Watson, 2002).

Salts of copper, and to a lesser extent silver, have been the metal salts which effect the most obvious changes to textiles, and so, to date, textiles mineralised with these metal salts have been the object of the most interest among archaeologists and conservation scientists (Burnard, 1994; Hardman, 1994). This study of mineralised textiles is a form of textile analysis that developed largely in the United Kingdom and in the United States. It has been concerned with those textiles referred to as mineralised fibres or textiles and as partially mineralised fibres or textiles.

Work on textile mineralization from Reade and Potts (1993) is particularly interesting as it is concerned with linen recovered from a third millennium site in the United Arab Emirates. It is unclear from the evidence whether this linen was manufactured near its site of recovery near the coast of the Persian Gulf, or whether was imported, e.g. from known areas of linen manufacturing in southern Mesopotamia or Egypt.

While it has been noticed that textile fibres have been preserved through mineralization or partial mineralization with copper or silver salts, the introduction of techniques for the preservation of textiles through the use of these metallic salts has not been advocated by textile conservators. This may be because textile fibres heavily mineralised by contact with these metals have their texture changed, becoming hard and brittle.

1.5.3.3 Preservation and Deterioration: The Role of Salts

Though very little has been written on the role of salts, other than of copper or silver, in the preservation or deterioration of organic materials from archaeological sites, there has been some work done on the role of sodium chloride and other salts in the deterioration of parchment and papyrus (Leach & Tait, 2000, pp. 227-253), and also in the deterioration of dry wood (Blanchette, Haight, Koestler, Hatchfield, & Arnold, 1994). Indeed, the
research that was found to most closely parallel the concerns of this study comes from investigations into the preservation of archaeological wood. This may be because linen, like wood but unlike cotton, has a small but significant component of lignin. The research into archaeological wood may also be more relevant because it approaches wood as a botanical material, alike in many chemical and physical ways to flax and other plants used in basketry and weaving, rather than as a manufactured product (e.g. paper or textile). The work of Blanchette et al. (1994) shows the effects of salts upon the preservation of wooden (coffin) material from Egypt, with definite applications to this study of linen. Indeed, some of the linen samples examined in this study may once have been in close contact with such wood.

Early examination of papyrus recovered from soil deposits showed the presence of chloride salts of potassium and sodium. Speculation centred on whether the salts had been taken up into the plant from the soil and ground waters during the growth of the papyrus plants, or had been absorbed by the papyrus artefact from salts in the sand or soil. (Bridgeman, 1973, cited in Leach & Tait, 2000; Nielsen 1985 cited in Leach & Tait, 2000, pp. 241-243 Rathgen, 1905, cited in Leach & Tait, 2000).
Wallert (1996), working on the Dead Sea Scrolls at the J. Paul Getty Conservation Institute and Museum in Los Angeles, produced a highly significant study of the action of salts in organic materials. In this study salt crystals were photographed in the process of deliquescence and recrystallization upon the surfaces of parchment and papyrus. Wallert found that the effects of the salts were different in the two substances; the parchment tended to gelatinise, while salts on the papyrus led to a mechanical disruption of the surface through breaks in the cell walls. The action of salts in papyrus suggested to me how salts might also act upon and within linen fibres, and helped me to formulate my research design for this study. Banik and Stachelberger (1987) reported work on salts in papyrus held in museum collections. In addition, there have been a few studies of the intake of salts in both papyrus and flax plants growing in natural conditions and in special field trials. Papyrus, growing in marshes or on riverbanks, appears to take in a significant quantity of salts naturally.

The information for flax appears to be more problematic, but it does take in salts, and these salts are stored differentially in leaves and stems (Moraghan & Hammond, 1996).
1.5.3.4 Analytical Studies of Egyptian Linen: Chemical Composition, Physical Description, and Possibilities for Dating

Investigations into the chemical composition of Egyptian linen have concentrated on an assessment of the degree of polymerisation (DP) of cellulose in order find a dating technique for the samples (Edwards, et al., 1996; Kouznetsov, Ivanov & Veletsky 1994, 1995, 1996a, 1996b; Stoll & Fengel 1981a, 1981b, 1985, 1988). Stoll and Fengel were measuring the degree of polymerisation of cellulose in ancient Egyptian linen samples from German museums when their investigations revealed the presence of salts. They concluded that the linen had been washed with natron during its historic use.

Microscopic analysis of ancient textiles has been carried out by Cooke (1990) at the University of Manchester. He has published studies of fibre damage, particularly studies showing the effects of wear on textiles and of oxidation on fibres under a variety of environmental conditions (Cooke, 1990; Cooke & Lomas, 1990).

Some mummy wrappings have been analysed to ascertain the substances used in the process of embalming, substances used to attach the bandages, and the substances poured onto the mummy by priests after the body had
been wrapped. These investigations have been concerned with the gums or resins used for embalming and have not been concerned with the nature of the linen itself, beyond simple identification of the textile fibres (Benson, Hemingway & Leach, in A. R. David, 1979, pp. 119-131; Colombini, Modugno, Silvano & Onor, 2000).

1.6 Conservation Treatment for Egyptian Linen

The following quote shows in how little esteem pieces of linen were held by at least one of the early conservators working on finds from Egypt:

When Quibell came over on behalf of the Museum, I sent up the bracelets by him. The arm [of King Djer’s Queen] - the oldest mumified piece known - and its marvellously fine tissue of linen was also delivered to the Museum. Brugsch [assistant conservator in the Cairo Museum] only cared for display; so from one bracelet he cut away the half that was of plaited gold wire, and he also threw away the arm and the linen. A museum is a dangerous place. Petrie (1931, pp. 188-189).

Thankfully, attitudes have, in general, changed. Egypt now has its own specialist textile conservators. In addition, textile specialists from other countries have been invited to many sites in Egypt where textiles have been found, and many specialist studies of Egyptian fabrics have been published.

The often fragile nature of textiles, both before and after excavation, makes their recovery and treatment on-site potentially difficult for the archaeologist.
and/or site conservator. Furthermore, after excavation, textiles generally go to the site “store” with the rest of the artefacts, sharing the same storage conditions. Access to archaeological stores for any follow up by archaeologist or archaeological conservator has become difficult in Egypt, since increased measures intended to improve security have been imposed by the Antiquities Department within the last decade. Therefore textiles might be examined only once by their excavator before they are locked away for years. This explains the temptation to clean objects on-site, for description and photography, even if the conditions, equipment and personnel are not available on site for the safe cleaning of objects.

Indeed, rarely are field conditions suitable for the safe, careful examination and treatment of fragile organic objects. Many archaeological sites have no electricity or running water. Supreme Council of Antiquities’ restrictions on taking any artefacts off site during an excavation mean that the on-site conservator sometimes works in extremely “primitive” conditions, as did the early excavators. This is not always the case, and there have been and continue to be well established and funded projects with good facilities for the care of objects in Egypt. Furthermore, the Supreme Council of Antiquities in conjunction with the Institute of Nautical Archaeology has begun a specialist-training program for Egyptian conservators, covering
textiles, metals and papyrus, to begin in 2002 at the Egyptian Museum in Cairo. During the program conservation laboratory facilities at the museum will also be renovated and improved (D. Haldane, personal communication in e-mail on the program to be run through the Institute of Nautical Archaeology, February 18, 2002).

Most reported conservation treatment of textiles has been carried out within museum, gallery, or university conservation laboratories. These institutions are generally examining textiles from their storerooms or from clients. Often the textile will be needed for display. The textiles may be separate pieces collected as examples of weaving, or they may be part of a larger archaeological artefact, e.g., mummy wrappings or part of a tomb offering. In these circumstances the display requirements often dictate the type/extent of conservation treatment.

1.6.1 Relevant Previous Studies

This survey of published studies of the treatments undertaken on Ancient Egyptian linen concentrates on English language material, though an attempt has been made to access material in other languages through a search of various computer data bases and through both computer and non-computer based bibliographic aids. The studies are presented in chronological order, in
order to show the development of a philosophy for the treatment of
archaeological textiles, as well as to show changes in treatment methods over
the 20th Century.

1.6.1.1 Conservation of Archaeological Textiles: 1900-1940

The earliest report on the conservation of Egyptian linen was in the form of a
letter from Dr. Margaret Murray to a P.M. Evans (Sept. 1, 1908), as reported
by Hann and Janaway (1990, p. 31). Dr. Murray was a pioneer in the
scientific study of mummies, or paleopathology, at Manchester University.

Hann and Janaway quote in its entirety the correspondence from Dr. Murray
that was found with a box labelled "Mummy Cloths, Inv. no. 47-50
Fragments" in the Clothworkers Library Special Collection, University of
Leeds. Dr. Murray evidently sent the fragments of mummy cloths to P. M.
Evans at the Clothworkers Hall in response to a request for samples of
ancient weaving. One of Dr. Murray's letters contains both the earliest
reference in this survey to the conservation treatment of Egyptian linen and
also contains a reference to the question of salts in ancient linen. It is
addressed from University College, London W.C., and dated September
1, 1908.
Dear Sir,

I send herewith the pieces of mummy cloth which I wrote about last year. These have all been soaked for at least 24 hours in a weak solution of Jeyes Fluid [a common household disinfectant] and then ironed. I don't think you will be troubled with salt in them, but if they should get moist, soak them in plain water for a few hours. Salt is the worst enemy of all Egyptian things. It utterly destroys them and can only be got rid of by soaking. ... (Hann & Janaway, 1990, p. 31)

It is interesting that the evidence mentioned of the cloths being affected by salt is that they "get moist". This suggests that when salt-affected mummy cloths left the dry Egyptian air and encountered the moisture-laden air of England they took up moisture. This point, and the effectiveness of Dr. Murray's treatment of the linen, is discussed further in this study.

One would have hoped that conservation reports of the first treatments undertaken of some of the great tomb discoveries would have been published, especially on the conservation of the objects from the tomb of Tutankhamen. Original conservation records are to be found in the Griffith Institute at Oxford, filed with the records of Arthur Mace, Conservator from the Metropolitan Museum of Art, New York. Notes were also made at the time by Arthur Lucas on note cards and filed away; with the details of each treatment each object had received (Carter, 1954, reprinted 1972, p. 72). However, formal published reports of those conservation treatments are not currently available for study. Instead, some interesting observations are
found in the published works of Howard Carter, the archaeologist in charge of the excavation.

Carter himself valued the textiles, and wrote about their condition as he had found them.

The condition of textiles varies. Cloth in some cases is so strong that it might have come fresh from the loom, whereas in others it has been reduced by damp almost to the consistency of soot. In the present tomb the difficulty of handling it was considerably increased, both by the rough usage to which it had been subjected [during the ancient robbery attempt and the less than careful "straightening" of the tomb contents by the priests prior to resealing the tomb], and by the fact that so many of the garments were covered with a decoration of gold rosettes and beadwork...

This question of cloth and its treatment was enormously complicated for us in the present tomb by the rough usage to which it had been subjected. Had it been spread out flat, or neatly folded, it would have been a comparatively simple matter to deal with it.... In dealing with all these robes there were two alternatives before us. Something had to be sacrificed, and we had to make up our minds whether it should be the cloth or the decoration. It would have been quite possible, by the use of preservatives, to secure large pieces of the cloth, but, in the process, we should inevitably have disarranged and damaged the bead ornamentation that lay below. On the other hand, by sacrificing the cloth, picking it carefully away piece by piece, we could recover, as a rule, the whole scheme of decoration. This was the plan we usually adopted. Later, in the museum, it will be possible to make a new garment of the exact size, to which the original ornamentation - beadwork, fold sequins, or whatever it may be - can be applied. Restorations of this kind will be far more useful, and have a much greater archaeological value, than a few irregularly shaped pieces of preserved cloth and a collection of loose beads and sequins (Carter, 1954, reprinted 1972, pp. 71, 75-76).
Quite recently these robes have been copied, although a restoration of the type Carter envisioned has not taken place. Gillian Vogelsang-Eastwood of Leiden University, The Netherlands, and Christina Rinaldo of the Institute of Hand Weaving in Boras, Sweden, created an exhibition consisting of copies of the textiles and clothing found in the tomb of Tutankhamen (Ciszuk, 2000, pp. 20-21). Vogelsang-Eastwood had begun a catalogue of the textiles in 1991 (Vogelsang-Eastwood, 1992c), and then began planning an exhibition of reproductions of the textiles with Rinaldo in 1994. During the year 2000 the exhibition was seen in Sweden, Poland, The Netherlands and England (Ciszuk, 2000, pp.20-21). Landi (1992) also recently reported on the conservation, examination, and treatment of some of the textiles from the tomb of Tutankhamen.

Lucas, who had been involved with the removal of objects from the tomb of Tutankhamen, worked for many years among the antiquities of Egypt, holding several positions, including Chemist for the Department of Antiquities. In 1924 he published a manual entitled Antiques: Their Restoration and Preservation, which was quite popular, coming out as a new edition again in 1970 and in 1972. The following quote is from the manual, and is found in a section devoted to woven fabrics.
Ancient woven fabrics vary very much in their state of preservation, some being in excellent condition and others being badly decayed and falling to powder. The reason for the disintegration is not fully understood, but the factors that appear to be of importance are air, warmth and humidity, and it seems probable that the changes are partly chemical and partly biological, the chemical action being in the nature of oxidation and the biological effects being brought about by bacteria and fungi (moulds). Sunlight, too, produces disintegration of fabrics, but cannot be one of the causes when the fabrics have been shut up in a tomb (Lucas 1924, new edition 1970, p.215).

....

When fabrics are in a good state of preservation, but contain salt, as may happen in wrappings or garments on bodies that have been treated either with natron (which always contains salt) or with salt, and which often occurs in the case of Coptic garments on account of their frequent burial in damp and salty soil, the salt may be removed by soaking in repeated changes of pure water, but this treatment cannot be applied to fabrics that are in poor condition (Lucas 1924, new edition, p. 217).

Discussing his experiments with natron as an embalming agent, Lucas also mentioned his observations of the effects of natron on linen, in response to contentions that natron placed on the body had a corrosive effect on the bandages.

The writer has failed to find any evidence that dry natron corrodes linen in such a manner as to account for the appearance of the bandages in question and he is unable therefore to agree with the statements quoted respecting the cause for the corrosion. That there may be a slight tendering of linen cloth by natron is not denied, but that the characteristic blackening and disintegration of mummy wrappings is due to natron is most improbable. As some proof that linen is not always, if ever, corroded by natron, it may be mentioned that none of the linen, seen by the writer, that was used as wrapping for the small parcels of natron found
by Winlock at Thebes among refuse embalming material, some of which dates to the Eleventh Dynasty, was either blackened or decayed (Lucas, 1932b, pp1 39-140).

This blackening effect has since been shown to result from a use of resins, applied hot, on late period mummies. For an excellent discussion of the process see Colombini et al. (2000, pp. 19-29, but especially p. 20).

Lucas (1924, new edition 1970) described treatments for fabrics in a good state of preservation. The following points are paraphrases of his treatments, taken from pages 215-220. However, in certain cases I have quoted Lucas directly, and these direct quotes are enclosed in quotation marks. The treatments recommended go through the following stages:

1) Removal of loose dirt by a vacuum cleaner (using a small machine with a weak suction).

2) Washing, using soap and warm water, without rubbing, to remove dirt.
   a. The fabric is immersed in cold water.
   b. A small amount of soap added.
   c. “The whole is slowly heated, almost to boiling, and left for some time”.
   d. The fabric is taken out of the hot water and transferred with
clean warm water and “gently and carefully moved about”.

e. Treatment (d) is repeated with fresh water.

f. The fabric is removed from the water, placed on a clean white
cloth, and allowed to drain.

g. It is then placed between white cloths or white blotting paper,
pressed gently, and allowed to dry slowly.

Caution is advised about handling the fabric when wet, as the water
makes it heavier and more liable to damage.

3) “Merely ironing a fabric, with or without slight dampening, will
often considerably improve and strengthen it.”

4) Bleaching is recommended for stained linen or cotton fabrics through
   a. Wetting in water and then exposure to the sun for several hours
   b. Hydrogen peroxide
   c. Bleaching powder or sodium hypochlorite
   d. The removal of oil or grease stains is advocated through soaking
      in petroleum spirit and the removal of other stains is discussed.

5) Backing with another fabric is recommended for tapestry and fabrics
   in a fragile condition.

6) Display or storage in cases with insecticide is recommended.

7) To strengthen disintegrated fabrics, “a dilute solution of celluloid
   (1 per cent) dissolved in acetone gave the best results and ... a
similar dilute solution of cellulose acetate, also in acetone, gave the next best results.”

But Lucas found cellulose acetate more stable than celluloid and he recommended its use.

8) For fabrics found wet, drying slowly in a warm room was recommended.

9) For fabrics so dry they cannot be unfolded, damping with benzine (petrol) or alcohol was recommended before attempting to unfold them.

The next report of treatment of Egyptian textiles was from Midgley (1928, p. 64), who described the separation of layers of pre-dynastic textiles through “floating in water or a little dilute alcohol” followed by efforts to “flake off the layers and transfer them, by floating, to stiff paper sheets. After drying, some were preserved by coating with a very dilute solution of celluloid, but the microscopic analysis was made on untreated fragments” (p.64).

1.6.1.2 Conservation of Archaeological Textiles: 1940-1970

There is a large gap in the conservation literature between the work of the 1920s cited above and the next reported conservation of archaeological
textiles. In Egypt archaeological work was either suspended or slowed, because of World War II and subsequent political events.

Conservation science, as we now know it, began to develop in British, European and American museums in the immediate post-World War II years. Greater attention began to be paid to a scientific approach to the examination of art and artefacts, as well as to the care and conservation of museum objects.

One of the first institutions to show an interest in the conservation of Egyptian linen was the Textile Museum of the District of Columbia, Washington DC, USA. During the 1950s this museum published a series of *Workshop Notes*, dealing with questions of curatorship (identification, recording, history of technology) and conservation of archaeological textiles.

*Workshop Paper no. 1* in this series makes the bold statement, “We have come to the conclusion that most textiles can be washed and that modern scientific methods of cleaning can be applied to nearly all ancient textiles as satisfactorily as to modern ones if the proper support and protection are given to the textile” (Greene, no date, circa 1950, no page).
There follows the description of a process whose primary objective appears to be the removal of all dirt and stains. The textile examined and washed is a Coptic tapestry, with a woollen weft. Photographs show the use of netting (called lumite) to support the fabric during cleaning. The fabric is kept flat, washed in shallow trays, and gently towelled. The use of brushes, called tamping, during this process appears rather vigorous, as do the degreasing and enzymic treatments. These might be interpreted from the description as routine treatments instead of exceptional ones, as they now would be considered by many textile conservators.

Other works in the Textile Museum series of *Workshop Notes* that are of relevance are *Principles of Practical Cleaning for Old and Fragile Textiles* (No. 14), and Rice's series *Principles of Textile Conservation Science*, especially No. XIV *The Alkalies and Alkaline Salts*, and *The Control of Oxidation in Textile Conservation* (Rice, 1970b; The Textile Museum, 1956).

1.6.1.3 Conservation of Archaeological Textiles: 1970-1980

Rice's work also appears as an article in Leene's very important work *Textile Conservation* (1972), published by the International Institute for the Conservation of Cultural Materials and the Smithsonian Institution. This
appears to be the first book devoted to the subject of textile conservation for a museum or specialist audience. Though in English, it brings together articles from leading practitioners and scientists interested in textile conservation from America, England and Europe.

Leene's volume contained one article specifically on the conservation of archaeological textiles, by Jedrzejewska from the National Museum, Warsaw. In this article the author discussed the conservation of Coptic textiles, treating them as "woollen objects". She set out an important set of "basic principles of conservation" for archaeological textiles, which clearly stated the philosophy underpinning the treatment of archaeological objects:

1) The technique of conservation has to be maximally reversible, and this means that the materials applied or the technical additions can be again separated from the original without causing any detrimental effects.
2) Where chemicals are applied, the quantity used should be kept as low as possible.
3) The actual physical properties of the textiles (pliability, texture, sheen, transparency, colour) should be impaired as little as possible by the applied procedures. The restoration of these properties is another, different, problem.
4) The reverse of the textile has to remain open for inspection by specialists studying the weaving techniques.
5) The authenticity of the original must not, in any way, be impaired by the applied treatments (Jedrzejewska, 1972, pp. 235-236)
The rest of Jedrzejewska’s article is largely concerned with mounting
techniques for textiles, based both on sewing and using small amounts of
adhesives.

Another book on the conservation of textiles appeared slightly later in the
1970s. First appearing as *Caring for Textiles* (1977) it reappeared in a new
USA edition). Written by Finch and Putnam, it has remained a standard in
the field of textile conservation. However, it is concerned with the
conservation of historic textiles and not with archaeological textiles, and so
is not discussed in detail here.

In England, at the Institute of Archaeology, London, Edwards (1974) was
doing work specifically on the conservation of archaeological textiles. Her
work largely concentrated on textiles recovered from Northern Europe and
on the recovery and examination of mineralised fibres. Her study (The
Preservation of Textiles in Archaeological Contexts, 1974) contains an
interesting chapter entitled “Some Conservation Methods.”

Concerning cleaning, Edwards wrote:

> The layer of soil can be gently removed using a pin vice fitted with a fine
> needle and a fine soft paintbrush. Sometimes a little acetone or I.M.S.
Industrial Methylated Spirits] is useful for loosening the soil. Any stones should be cleared of soil and very carefully removed as they may be adhering to the surface of the textile, and hasty removal may damage it. If there are any hard encrustations obscuring the weave it is sometimes possible to remove them without damaging the underlying threads. To do this it is safer to use a vibrotool than a pin vice as any pressure may crack threads which appear to be strong but are in fact hollow. This cleaning should be done at a magnification of x20 to x40 as at this size individual threads can usually be clearly seen, and if they are being damaged the treatment can be halted. ... The vibrotool should be fitted with a fine needle so that threads can be avoided, and if possible the type of weave should be ascertained before starting the cleaning to avoid damaging or changing it. The threads can sometimes be cleaned by using the side of the needle, but no pressure must be put on them.

...Although some replaced textiles can be cleaned extensively by this means, there is really little that can be done to make soft replacements on iron and those on bronze any clearer. The best method to deal with them is to brush gently with a fine soft paintbrush moistened with acetone, but if this causes too much damage, cleaning will have to be abandoned (Edwards, 1974, p. 25).

Concerning water cleaning she wrote:

If drying from water seems too risky or if the process needs to be speeded up the textiles can be soaked in acetone and dried from that as is done at the Guildhall Museum. It must also be noted that drying from water may result in cellular collapse of old and fragile textiles of plant fibre. For safety, liquids of lower capillary action are used (Edwards, 1974, p. 34).

Also, when writing about possibilities for consolidation and mounting she observes that:
'Lubrication'/ glycerine appears to lubricate and strengthen, but is not a 'permanent' solution to the problem of brittleness. Also, a 10% solution in water used on fabrics softened them but did not prevent the shedding of fibres. 

Although some textiles may need much protection the destruction of the feel of the fabric must be avoided if at all possible (Edwards 1974, pp.37-39).

Important work on Egyptian textiles was taking place around Gordon Square, University College London, where Assistant Curator of the Petrie Museum, R. Hall, was actively collaborating with textile conservators from other London based institutions to look at the textiles in the Petrie collection. The results of this collaboration included Hall’s popular and useful book *Egyptian Textiles*, the discovery by Hall and Landi of what is thought to be the world’s oldest dress or tunic? (U. C. 28614B), from what had been thought of as a bundle of linen rags put away in storage, and the successful conservation of that dress or tunic as well as other Egyptian dresses or tunics (Hall, 1986; Landi & Hall, 1979). (See Figs 1.5 and 1.6 for photographs of these ancient Egyptian tunics or dresses, after conservation treatment, on display at the Petrie Museum, University College London.)

The publication of the conservation treatment of U.C. 28614B was a major achievement for several reasons. It involved the close collaboration of

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7 Dated by Hall to the reign of King Djet, also known as Djor, in the First Dynasty, c. 2800 BC (Hall, 1986, p.27)
curator and conservator, with their work presented as a joint project. It also involved a recognition that the textile could yield information, and that the evidence of wear/use on the textile was of value and should be retained. Furthermore, dirt was not removed from the garment at the cost of the fabric.

Cleaning consisted of light spraying with industrial methylated spirits (IMS) alone or with a small amount of water in order to separate layers. A test area was washed to removed dirt, but:

The application of enough water to wash out the mud from one area proved that it would be unwise to continue further. The individual warps and wefts tended to become a soft pulp, lose their identity, and break up under the slightest strain. Therefore the attempt was abandoned and reliance placed on the mechanical removal of the small cakes of mud still adhering to the fabric by brushes, spatula and gentle movement. Much of it dropped away during the course of work, the rest is still there (Landi and Hall, 1979, pp. 148-149).

1.6.1.4 Conservation of Archaeological Textiles: 1980-90

The 1980s, a relatively prosperous and peaceful period for Western nations, saw a tremendous growth in the practice and popularity of archaeology, a boom in the building and staffing of museums, growing interest in scientific conservation, and an increased understanding of the nature of archaeological artefacts. These trends are evident in the literature on the conservation of archaeological textiles. Attempts were made to develop a deeper
understanding of the nature of the cleaning process for all historic textiles (Landi, 1992; Wentz, 1986). Attention was also paid to methods of storage and display (Leene & Von-Comis, 1982; Morrison, 1987) and excellent work was done by Cooke and Lomas (1990) to show “use wear” in textiles, i.e., evidence of use prior to archaeological deposition: such as creases, folds, stains, and abrasion of the surface of clothing, and the presence of particles of the contents of a bag to show the previous usage of the bag.

At the end of the 1980s a new book on textile conservation made its appearance, Flury-Lemberg’s *Textile Conservation and Research* (1988). This brought to a wider audience the results of the work done at the world famous Abegg-Stiftung, Bern. The methods employed at ‘The Abegg’ differed substantially from those employed at some textile conservation laboratories in England and America. For example, the Abegg-Stiftung became well known for advocating washing with pure water (using no detergents) whenever possible.

At the Victoria and Albert Museum in London, Landi (1992) worked with some important archaeological textiles, including several from the tomb of Tutankhamen. (Her work with Hall at the Petrie Museum has already been cited.) Landi’s general procedures and her specific treatments of Egyptian
archaeological textiles were outlined in her book *The Textile Conservator’s Manual* (1992). She refrained from any treatment of a textile if that would endanger the stability of the textile and/or remove evidence of usage, such as creases. In an attempt to remove some sharp creases caused by storage one of the textiles was humidified, within a polythene tent, up to 95% RH, then the fabric manipulated to ease the creasing (Landi, 1992, p. 313).

Dealing with washing procedures for archaeological textiles, Landi described a procedure similar to that used by the Textile Museum in the 1950s, but it was much more carefully applied (no harsh brushes, enzymes, or degreasing solutions, and no detergents unless they were absolutely necessary and could be rinsed out). She was also concerned with the chemistry of the process and made some important observations (Landi, 1992, pp. 104-105):

1) Care should be taken to ascertain the pH of the textile before any decision to wash. A pH under 4.0 may indicate the object is too acid to wash. “When rinsing it is helpful to add a percentage of I.M.S. [Industrial Methylated Spirits] to the water, increasing the amount until it is almost totally I.M.S. to finish. This shortens the drying time and helps to prevent degraded cellulose, which cannot be fully washed out, from gathering at the edges, leaving the textile more flexible”.
2) If glycerol is to be used (Landi indicated that up to 50% may be used in solution) there may be some benefits during the washing process in the release of dirt and discolouration and some benefits immediately afterwards in the texture of the fabric, but the glycerol will volatilise away in time.

3) Humidification as an alternative to washing was also explored.

The conference *Textiles for the Archaeological Conservator* at York during April 1988, held by the United Kingdom Institute for Conservation Archaeology Section, brought together leading curators, conservators and scientists who had worked with archaeological textiles. The conference proceedings were published as *Archaeological Textiles* (O'Connor & Brooks, 1990). In his introductory remarks to the conference papers in *Archaeological Textiles* (1990, p.4), Wild wrote, “We talk glibly about textiles preserved in damp anaerobic peat-bogs or the dry desert conditions of the Near East; but we still do not understand fully the reasons why textiles survive in archaeological contexts and therefore the treatment which they require for that survival to continue.” Articles in this collection dealing with the examination and conservation of Egyptian linen are by Hann of the University of Leeds and Janaway of Bradford University, Hillyer of the Victoria and Albert Museum, and Lochhead of the North West Museum and
Art Gallery Service. The observation made by Murray about salts in Egyptian mummy cloths, and the description of her treatments, comes from Hann and Janaway's article (Hann & Janaway, 1990). Lochhead (1990) examined four Egyptian tunics in great detail, and then washed them all. She first soaked them in deionised water for long periods (16-45 hours), then washed them using a detergent and carbooxymethylcellulose in the water. Finally she rinsed and air-dried the garments. Hillyer (1990) advocated a cautious approach to the wet cleaning of archaeological textiles, describing some of the information which could be obtained using SEM in fibre examination which would be lost if the textile was washed. She also observed that:

The overriding consideration during the washing process is, however, the most basic one - the impact of water on desiccated and fragile fibres that have been protected by a dry stable environment for many hundreds of years. It is quite obvious that sudden swelling on wetting of a fractured fibre and equally vigorous contraction on drying is a procedure that can only be approached with great caution. The degraded linen fibre is, for example, far less resistant to the impact of water than its modern counterpart. This increased porosity is due both to the breakdown of the interultimate binder between the fibres and to the formation of transverse cracks in the fibres. In a highly degraded fibre, the sudden impact of water will lead to splitting not only of the fibre bundles into ultimates but also to defibrillation of the fibres and ultimately complete hydrolysis" (Hillyer, 1990, pp. 19-20).
In the above excerpt Hillyer attributed the breakdown of the fibre to the sudden impact of water upon the fibre. The mechanisms involved in the breakdown of linen fibres during treatment involving water are discussed at length in this study.

1.6.1.5 Conservation of Archaeological Textiles: 1990-2000

Conservation of archaeological textiles in the last decade of the 20th Century continued the trends towards a deepening of scientific scrutiny of methods and materials, and towards greater caution in the treatment of the textiles. However, perhaps because changes in the economic environment put greater workloads on textile specialists engaged in full-time work at Universities or within Museum Conservation Laboratories, there was less research published in this decade than during the 1980s.

Cooke, Babakhani and Hillyer, (1996) published an interesting study on the cleaning of degraded linen, but it was confined to an examination of a piece of historic linen. In this study they concluded “the simple immersion of degraded linen in de-ionised water produces irreversible changes in the crystallinity of the cellulose and the dimensions of the textile”(p. 9).
Morgan and Cruickshank (1995), of the British Museum, described an interesting treatment of an Egyptian painted linen shroud. In this treatment they first humidified and then cold-lined [lined without using heat] the shroud. An appendix to the main report, written by Shashoua of the Conservation Research Section, discussed experimental work done with samples of linen to determine the effects of humidification, heat and pressure. All the samples appeared to have been affected (in various ways) by the treatments, and the decision was made to employ the least invasive treatment, humidification and cold mounting (pp. 1-9).

Krasuski and McKay (1993), at the Royal Ontario Museum, also treated an Egyptian painted linen shroud. They confined their treatment of the linen to removing creases and realigning weave through dampening with blotters and mechanical manipulation. Most of their conservation work consisted of the removal of previous (modern) patches and the formulation of a method for the display of the shroud.

In their excellent review of the conflicts in conserving archaeological textiles, Brooks, Lister, Eastop and Bennett (1996) of the Textile Conservation Centre, outlined a cautious approach to the treatment of archaeological textiles, suggesting that if more than one fragment of a textile
is recovered from a site then one might be left untreated, to preserve the maximum amount of information for future analysis and comparison.

While fewer articles on archaeological textile research were published in the 1990s than the 1980s, the publication of Chemical Principles of Textile Conservation (1998), the product of collaboration between Timár-Balázs of the Hungarian National Museum and Eastop of the Textile Conservation Centre, London, combined up-to-date textile chemistry with descriptions of practical textile conservation. It immediately became an essential reference for the working conservator. It does not deal directly with the topic of archaeological conservation, though its coverage of conservation examination and treatment methods is extensive.

1.6.1.6 Deacidification: 1980-2000

Landi’s statement (1992, p. 104) that:

If the [pH of the textile to be treated] reading indicates acid conditions, below pH 4, it may be safer not to wash it at all. Not enough is yet known about the effects of trying to buffer the washing water to prevent hydrolysis. Alkalinity is not so commonly found...
is interesting when compared to the work of several other conservators at this time regarding the potential for the application to textiles of deacidification solutions used in paper conservation.

Work on the potential for deacidification of textiles took place at a time when there had already been considerable work on deacidification of library materials. Libraries around the world were faced with a huge crisis: collections made up of modern newsprint, made from chemically treated wood pulp containing lignin, were literally crumbling. Earlier books, in which the paper had been made from cotton and linen rags, remained in excellent condition. For centuries paper had been made from cotton and linen textile rags, whose main constituent was cellulose. By analogy it could be argued that what preserved cellulose based paper would also preserve cellulose-based textiles.

The whole question of the pH buffering/deacidification of paper has become of great economic importance to the paper industry worldwide, and also of great cultural significance to libraries worldwide, whose collections currently are largely composed of paper-based documents. Therefore much time has been invested in research into deacidification methods. The literature covering the development of paper deacidification in the United
States of America, and discussions of its viability, runs to well over 700 citations within Conservation Science alone, and may reach the thousands if industrial publications are also considered (Barrow, 1967/68, cited in Morrison, 1979; Robertson, D.D., 1981; Morrison, 1979; and a computer search using Canadian Heritage Information Network's Research and Reference service, 1999).

The processes of cellulose degradation are now well documented. Research into the nature of cellulose, the basic constituent of all plant fibres, has been extensively pursued since the middle of the 19th Century, and there is consensus on the nature of cellulose and its reactions to different acid and alkaline treatments. Garner (1996), in his multi-volume work *Textile Laboratory Manual*, covers the nature of cellulose and describes in detail the effects of the major agents of chemical and physical deterioration/change in the structure of cellulose, namely hydrolysis, including acid hydrolysis, and oxidation. Garner refers to important studies by Himmelfarb in 1957, Roche in 1964, and Slack in 1957. In the conservation literature the work of Feller, Lee & Bogaard, (1986) and Feller & Wilt (1990) on the kinetics of cellulose degradation is frequently cited.
The process of cellulose degradation within cotton fibre is straightforward, as cotton is almost completely cellulose, compared to the process of cellulose degradation in linen. This is due to the presence of a significant quantity of lignin within the untreated flax plant. As the process of cellulose degradation within linen is more complex than within cotton, work appears to have often been carried out using "models." Hardman (1994) and Edwards, Ellis, Farwell and Janaway (1996) give lucid summaries of the degradation process within linen.

As linen consists largely of cellulose material (generally between 50% and 70%) degradation can occur in a burial environment largely through hydrolysis and/or through oxidation. Linen would be more susceptible to acid hydrolysis than alkaline hydrolysis, and appears most stable when its pH is mildly alkaline.

Important research into the effect of pH upon cellulose has been done by Grignon and Scallon (1980), which, though coming from research into wood technology, has direct application to a study of environmental conditions necessary for the preservation of linen. The issue of the swelling of the fibres due to a pH change appears to be significant in this study.
Work on the application of deacidification to textiles was headed by Kerr at the University of Alberta, and was also pursued for a time by Peacock at Queen's University, Canada. All of the work at the University of Alberta concentrated on the treatment of cotton, and was concerned with historic textiles. The team of Kerr, Hersh and Tucker (1982, 1984) reported that tests using cotton fabric that was treated with deacidification solutions and then heat-aged showed that alkaline buffering agents containing magnesium and calcium protected cellulose from degradation by slowing the oxidation process (Jennings 1985; Kerr, Hersh & Tucker, 1982, pp. 100-103; Kerr, Hersh & Tucker, 1984; Kerr, Jennings, and Methe, 1989; Peacock, 1983).

Peacock published the only paper during this period on deacidification of degraded linen. She concluded:

Deacidification decreased the rates of weight loss, acidification, and strength loss, increased the stiffness, and caused minimal colour change. In fact, magnesium bicarbonate increased the tensile strength. ... Naturally, the conclusions are valid only for the materials and methods investigated; however, these conclusions indicate that some historic or archaeological linen textiles, as well as linen painting supports, may benefit from a form of deacidification (Peacock, 1983, pp. 12-13).
However, by the 1990s Peacock's views on the wisdom of applying deacidification solutions to textiles had modified. In a personal communication, Peacock wrote:

I'll tackle the deacidification of linen first. I have not done further work. People who have done similar work at about the same time, albeit on cotton, are N. Kerr (Alberta) and Jane Hutchinscons (now working privately in British Columbia), and also Ira Block (Maryland, I think). Having a lot more first-hand experience with archaeological textiles than when I did the deacidification work, I now am very reluctant to apply anything to them. I would not deacidify actively - Kerr is of this opinion also - but if necessary, seek out a passive solution, e.g., some sort of deacidifying atmosphere. I do not know of recent work done on active deacidification, and this may well [be] a result of the trend away from interventive treatment (Peacock, personal communication, e-mail, March 30, 1998).

Further published research into the question of alkaline reserves being used with linen has been undertaken in relation to painted canvases, not to historic or archaeological textiles. Clements (1990) completed a research report into the question of alkaline reserves being used with linen canvases at Queens' University, Ontario. Hackney and Ernst (1994) reported on their research, which was part of a continuing project at the Tate Gallery. As some form of alkaline sizing agent or ground has been applied to both wooden boards and linen canvases for hundreds, if not thousands of years as the ground for paint, an investigation of the long-term effects of alkaline materials on these supports is of great importance to the painting conservator.
Clements (1990, no page number) concluded that "an alkaline buffering system in artists' canvas via calcium carbonate in acrylic gesso grounds does not seem possible...it is best attained by immersion or spraying the canvas with deacidifiers before applying grounds and paints."

Hackney and Ernst (1994, pp. 226) experimented with both dry and aqueous deacidification methods for linen painting supports. They concluded that:

Non-aqueous deacidification is established as an option to be considered in certain cases by conservators. However, it is not yet possible to offer a method that is free from practical and ethical problems and that can be applied routinely. Deacidification retards the deterioration of canvas, but cannot increase its strength...Although further experience and development work are required, concentrating on methods of application and identifying any side-effects, enough has been done to show that deacidification can work and that it is capable of providing considerable protection for canvas in the long-term.

1.6.1.7 Freeze Drying: 1980-2000

The freeze-drying of some wet organic materials, especially wooden objects and basketry, has become standard practice, but its use for wet textiles is less common. The use of freeze-drying of wet archaeological textiles was discussed by Tarleton and Ordonez (1995), who examined the effects of
freeze-drying on woollen samples buried in a temperate terrestrial site, by Jakes and Mitchell (1992), where a trunk of waterlogged textiles from an ocean wreck was freeze dried, and by Peacock (1990a), where textiles were freeze-dried which had come from cold and wet or frozen Scandinavian conditions. In Germany Elmer (1973) has reported satisfactory results with freeze drying of Neolithic textiles and braided work, after thorough cleaning and desalination. Peacock (1999) has also published a controlled study of the effects of freeze-drying on natural fibres, including linen.

In freeze-drying organic materials the use of additives, consolidants, or baulking agents is controversial. Many archaeologists and archaeological conservators oppose the addition of any consolidating materials to textiles as the consolidant may interfere with the identification of the textile, and may affect the use of the textile for dating or other testing purposes, and also because the consolidant may change the look, feel, and handling properties of the textile. Furthermore, they argue that consolidants are never completely reversible. Other archaeologists and conservators argue that if consolidation is the only method that can allow the textile to be excavated, and to retain its physical shape, then consolidant should be used. The ethical and practical problems are well summarised by Brooks et al. (1996, p.17):
The conflict between preserving a textile and the information it contains is particularly acute with waterlogged pieces. Drying methods may result in disruption to both fabric and fibre structure. However, unless the textile is dried, it cannot be easily studied, documented, displayed or stored. Accordingly, various modifying chemicals such as humectants, lubricants and plasticisers are used to reduce damage during the freeze drying process. In practice, these materials cannot be totally removed and may compromise future analysis.

1.6. 1.8 Observations on Previously Published Conservation Treatments of Ancient Egyptian Linen

In the majority of the above reports the presence or absence of particulate matter that may contain salts within the textile garments has been treated more as a question the removal of “dirt”, rather than being considered as a question of salts that might act as possible pH buffering agents or which might have been involved in the process of partial mineralization. The question of the effect of the removal of salts on the textile fibres has rarely been addressed. Only Florian (1987a) has considered whether to remove salts from textiles recovered from an underwater environment, and concluded that to do so would be detrimental to the stability of the textile.

1.7 Conclusions

- The term ‘linen’ was defined as fabric where the warp, or both the warp and the weft, of the fabric was made exclusively from the flax plant, *Linum usitatissimum.*
• Linen preserved as material evidence from ancient times in present day Egypt is defined as “ancient Egyptian linen”.

• It was demonstrated that the production and use of linen fabric was an important part of economic and cultural life in ancient Egypt—through numerous references to linen in the ancient Egyptian language, through the testimony of ancient historians, through pictorial and sculptural evidence, and through the abundance of the linen itself, preserved as grave offerings.

• It was demonstrated that natron was an important part of economic and cultural life in ancient Egypt, and was a widely used and highly valued cleaning agent.

• Evidence gathered from literary and pictorial sources showed how linen was created and how linen was used in antiquity. This evidence is of importance for an understanding of the physical and chemical characteristics of ancient Egyptian linen, as recovered from archaeological sites in Egypt.

• The treatment of ancient Egyptian linen in modern times was reviewed chronologically.
CHAPTER 2

The Materials in Context; The Artefacts in their Archaeological Environment

2.1 Introduction
In Chapter 1 historical evidence was cited which described the production of linen in ancient Egypt. Evidence was also reviewed for the use of linen in daily life, in the life of the temple, and in mortuary ritual. New and used linen placed into a tomb or used in the burial of a body in the sand of Egypt then entered into a new phase in its history. It became part of what the archaeologist would call the archaeological deposit. While artefacts remain in situ they are in a dynamic relationship with that environment.

It is this dynamic relationship between artefacts and their environment that is the theme of this chapter. Ancient linen that has survived in certain archaeological deposits will have achieved its remarkable level of preservation through certain chemical and physical attributes of the linen, through certain chemical and physical attributes of the environment in the deposit, and through the interaction of the artefact with its environment.

By grouping samples together by region and environment it may be possible to detail the evidence for a relationship between environment and the state of preservation of archaeological artefacts. In order to do this most effectively,
information on provenance, excavation, and the results of scientific analysis of the samples have been combined for each sample examined in this study. This information is to be found in Appendix A: Samples. Discussion of the implications of this data is undertaken in the main body of this study.

The remarkable state of preservation of many artefacts found in Egypt has long been famous, and may lead some to think that these artefacts are somehow unchanged. However, appearances are often deceptive. The appearance of solidity and stability in physical objects is deceptive: scientists are aware that physical objects are not actually static and do not have solid surfaces. They are instead made up of rapidly moving particles (molecules, atoms, electrons), with physical surfaces that are not solid but to varying degrees porous and permeable. These surfaces are the interface of the object and environment. Therefore all artefacts are the products of their past, reacting with their present.

The specific objectives of this chapter are to:

- Identify key elements in the environment of Egypt that may have acted to preserve linen artefacts.
- Describe the environment of those archaeological sites from which the archaeological linen samples used in this study were recovered.

- Identify environmental changes in the 20th Century, both in the general environment of Egypt and in the environment of archaeological sites from which the linen samples used in this study were recovered, which may have chemically and physically altered the linen artefacts in situ.

2.2 General Environmental Factors - Egypt

Egypt once formed the floor of an ancient sea covering much of present day North Africa. During the Eocene epoch, between forty and fifty million years ago, a tilting of the land caused the waters to recede into the present day Mediterranean Sea (Pregill & Volkman, 1999). The ancient seabeds, which had consisted of metamorphic and igneous rock overlaid by limestone, sand, clays and shales, thus became the surface of much of present day Egypt. However, a portion of the north of Egypt remained submerged longest, allowing for further limestone deposition before it was also raised. The second uplift, approximately eight million years ago, created the Nile River valley (Pregill & Volkman, 1999, pp. 59-60).

Since that time it has been a truism that Egypt is the Nile. The Nile Delta, built up of alluvial deposits from the river, and the Nile River terraces (below
high limestone cliffs from Edfu to Cairo), provided most of the agricultural land of Ancient Egypt. The annual inundation of the Nile, caused by rainfall much further south, provided the water for irrigation in an otherwise dry land and at the same time washed away salts from the soil (Pregill & Volkman, 1999, p. 77).

Linen samples analysed in this study are identified in Appendix A as having been recovered from either a pre-1960 or post-1960 archaeological deposit (if the excavation date is known), because this date represents the beginning of the building of the Aswan High Dam, which has widely been credited with increasing the salinity of both the Nile River and Nile Valley land (Abercrombie, 1977, pp. 336-337; Caputo, 1985, pp. 584-599). Though the Nile was dammed above the First Nile Cataract with the Aswan Dam in 1902, that dam did not control the river to the same extent as the Saad al-Ali, the High Dam 17 km south of Aswan (Logan, Cole, & Wayne, 1996, pp334-337).

The land of Egypt has been divided geographically, climatically, and some say culturally, into two major divisions since Pre-Dynastic times: Upper Egypt (Southern Egypt) and Lower Egypt (Northern Egypt, the Delta), the divide between the two major divisions being roughly at the site of ancient
Memphis.¹ Little remains of ancient Memphis, but its large cemeteries remain at Giza and Saqqara on the west bank of the Nile and at Helwan on the east bank of the Nile.

Though Lower Egypt has long supported a large population, and has seen magnificent cities rise and fall, its high rainfall and verdant growth mean that the preservation of these cities as archaeological remains has been less notable than in Upper Egypt. Buildings made of mud brick were broken up and the soft brick was spread on the fields, to be used as a rich source of soil for agriculture. Few artefacts remain from these Lower Egyptian sites, in comparison with sites in Upper Egypt, and preservation of archaeological artefacts made of vegetable fibres has been especially poor. It has been necessary, therefore, to examine the environmental conditions in those areas of Upper Egypt where linen has survived in abundance, isolating the factors that have contributed to its preservation.

Cornwall (1958), Jewell and Dimbley (1966), Dowman (1970), Edwards (1974), Wild (1988), and Stein (1992) have published general surveys of the environmental conditions that favour preservation of archaeologically

¹ Modern-day Cairo is believed to cover part of ancient Memphis, with another part of Memphis now under the Nile. (Jeffreys & Tavares 1994).
recovered textiles. These authors concluded that the factors that have led to
the preservation of archaeological textiles include wet, frozen, and dry
conditions, as well as salt-rich environments. They have also found that “all
decomposition is affected by environmental factors, especially temperature,
moisture, and available oxygen” (Stein, 1992, p. 198).

2.2.1 Chief Factors Responsible for the Preservation of Linen in Egypt

Conclusions from the surveys cited above are that important general
environmental factors which are conducive to the preservation of vegetable
fabrics (including linen) in Upper Egypt are (1) dry conditions, (2) a mildly
alkaline environment, and (3) protection from light.

2. 2.1.1 Desiccation

Dry conditions inhibit the growth of fungi and bacteria, which could use linen
and other vegetable fibres as an energy source (food). Fungi and bacteria are
present in most environments, but both need water in liquid form and some
source of energy, such as linen fabric, in order to multiply (Rodriguez-Valera,
1988, p. 4). As Leadbetter & Poindexter observed, “everything is
everywhere, the environment selects” (1985, p. 19).
A description of the effects of water upon fabrics in an Egyptian tomb comes from the archaeologist responsible for the excavation of the most famous tomb in Egypt, that of Tutankhamen. Howard Carter (1954, reprinted 1972, p. 218) wrote that water in the tomb was:

the main cause of deterioration and chemical changes among the objects in the Tomb. From every point of view it was a thousand pities that this tomb should have suffered from infrequent moisture filtering through the fissures in the limestone rock in which it was cut. This moisture saturated the air of its chambers, and caused a humid atmosphere to exist therein for what must have been considerable intermittent periods. It not only nourished a fungoid growth, and caused a peculiar pink film to be deposited everywhere, but it destroyed practically all the leatherwork by melting it into a black viscid mass. It also caused extensive warping to take place among the varied woods used in the construction of many of the objects. It dissolved all adhesive materials such as glue, so that the component parts of many of the articles fell apart. It also resulted in much deterioration of the textiles - an irreparable loss, for among them were rare garments and the like made of tapestry-woven linen fabric as well as of needlework.

The tomb of Tutankhamen had been cut into bedrock of lower Eocene limestone. During excavation by Carter the front and entrance tunnels were found to be free of water, but investigation showed that workmen on the later tomb of Merenptah, which is above Tutankhamen's tomb, threw their stone chips (debris) into a watercourse. When infrequent rain occurred in the Valley of the Kings the stone chips in the watercourse caused damming of rainwater. This water then flooded Merenptah’s tomb, as well as affecting the nearby
tomb of Horemhab. Finally the water entered into fissures in the rock and affected Tutankhamen’s tomb, particularly the western ends of the chambers and the annexe (Carter, 1954, reprinted 1972, pp. 221-222).

Tutankhamen’s tomb was affected because of a change in the drainage pattern. Ordinarily rainwater has not affected archaeological deposits in Upper Egypt as (a) it is extremely infrequent, and (b) when rain occurs it comes with such force and rapidity that the ground can absorb little of it: much runs off quickly.

Ground water, particularly ground water rising due to changes in agricultural use of the land, increased urban growth, and the damming of the Nile River, has been an important factor in the destruction of organic materials in burial grounds which were previously dry. For example there was seepage of water from the Nile into old burial grounds at Tura. The Tura burial grounds were excavated by Prof. Junker of the University of Vienna immediately prior to World War I. Tura (also called Turah) was a predynastic cemetery a few miles south of Cairo, on the east side of the Nile, between Cairo and the town of Helwan (for the location of Tura and of Helwan see Appendix A: Maps 2, 4 & 6). As Junker explained:
The graves had been dug in a mixture of sand and clay at the edge of the desert, and as the ground in the vicinity has since been under cultivation, they had suffered considerably from the water [irrigation water from the Nile used for agriculture] which had soaked the ground; and also probably from water coming across the desert from the hills during the occasional heavy rains which visit this part of the country in the winter months.

... As already mentioned much of the Turah material had been seriously damaged by water, and the actual number of skeletons obtained is too small to allow of any conclusions being drawn if only mathematical methods are employed (Junker, Kapitel & Derry, 1912, p. 87).

Contrast this situation with the reports of Brunton and Caton-Thompson (1928), where fibres and fabrics were found in good condition in predynastic burials made directly into the dry desert sands. There are also many other reports, such as that of Quibell (1909), where organic materials were found in good condition in a variety of dry burial environments. They bear out Dowman’s statement (1970, p. 39) that “where there is total aridity there should be no breakdown of any kind ...”

2.2.1.2 Alkaline Environmental Conditions

Mildly alkaline conditions have been found to be most suitable for preservation of vegetable fibres, with the zone between pH 6.5 and pH 10 generally considered safe for most vegetable based textiles (Timár-Balázsy & Eastop, 1998). Linen, as a vegetable based fibre with a high cellulose content,
can be adversely affected below pH 5 and can dissolve at about pH 3 or pH 2.5 (Edwards, 1974, pp. 325-6; Rice, 1970a, p. 55).

In Upper Egypt many tombs have been cut into limestone. This is the most prevalent rock in the area adjacent to the Nile. It is relatively easy to cut in order to form tombs, and also to cut into blocks for transport to another site. When a substantial tomb was constructed in Egypt in a limestone area it was generally constructed as a limestone lined pit with a superstructure, as a pyramid made up of limestone blocks, or it was cut into limestone cliffs.

Now, limestone is both alkaline and a carrier of various alkaline salts.² Calcium carbonate (CaCO₃) is the primary constituent of limestone, while calcium magnesium carbonate (CaMg [CO₃]₂) is the major component of dolomite limestones. In Egypt dolomitic limestone is found in six out of the seven geologic formations that have been identified as in use by the ancient Egyptians as quarries or tombs (Aston, Harrell & Shaw, 2000, pp.40- 42). Egyptian limestones also commonly contain quartz (chief component silica, SiO₂), iron oxides (haematite, Fe₂O₃ or goethite, HfeO₂), besides various clay minerals. (Aston, Harrell & Shaw, 2000, pp. 5-77).

² A common test for carbonates, including limestone, is the application of a mild dilute acid. A reaction of “bubbling” indicates the presence of carbonates.
Therefore in creating tombs from limestone the ancient Egyptians were
creating an alkaline burial environment, which would contribute to the
preservation of organic materials, including linen. However, as limestone also
is a carrier of various alkaline salts, there is potential for the movement of
salts within a limestone tomb with the humidification or dehumidification of
the tomb environment.

The walls of these tombs were often of carved limestone, or the rough walls
were smoothed and covered with a plaster made with lime before painting
(Siliotti, 1996). Wooden coffins, caskets and boxes were treated in like
manner, being covered with a smooth plaster then painted. Mummies were
sometimes covered in linen that had been dipped in plaster (for an example of
such a mummy see Moussa & Altenmuller, 1971, p. 43, Fig.40a and 40b p.
174) or, more commonly, covered with what is called cartonnage. Cartonnage
is a stiff material generally used as a support for painting and/or as a cover for
the mummy. It consists of a base of linen or papyrus, sometimes with glue
used as an adhesive between layers, and it was usually both plastered and
painted.

The tomb walls, coffins and other objects, including textiles, within the tomb
were often painted. Colour was used to convey symbolic meaning, and was
applied according to religious conventions (Wilkinson, 1994). Siliotti (1996, p. 27) listed the colours commonly found on tombs walls as: gypsum-huntite (white), cuprorivaite (blue) or Egyptian blue (a synthetic blue pigment), orpiment (yellow), coal (black), red ochre (red/brown), and copper wollastonite (a synthetic green pigment). A yellow produced using yellow ochres or oxides, was the more commonly used yellow, with yellow from orpiment only coming into use from the later New Kingdom onwards (Wilkinson, 1994, p. 106).

At the British Museum, Johnson, Head, and Green (1995) tested these same colours (with the exception of yellow), which had been painted onto an Egyptian coffin (c. 960 - 900 B.C.). Results reported below in their Table 1 confirmed that these same pigments had been used.

*The conservation of a polychrome Egyptian coffin*

<table>
<thead>
<tr>
<th>Colour</th>
<th>XRF</th>
<th>XRD</th>
<th>PLM</th>
<th>Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>Cu, Ca</td>
<td>Coarse pale blue particles, RI &lt; 1 66, PC: grey, CF: pale pink.</td>
<td>Egyptian blue</td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>Cu, Ca (Fe)</td>
<td>Green with blue (Egyptian blue) and yellow (isotropic varnish). Green, RI &lt; 1 66, PC: grey-green.</td>
<td>Green frit, traces of Egyptian blue and varnish</td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>Fe (Ca)</td>
<td>Fine particles strong red. RI &lt; 1 66, PC: dull orange-red.</td>
<td>Haematite, Fe₂O₃</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>Low counts (Ca, S)</td>
<td>Opaque particles of varying sizes, cellular structures characteristic of plant material</td>
<td>Carbon black, possibly plant charcoal</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>Ca (S)</td>
<td>Calcite, traces of gypsum</td>
<td>Calcite, CaCO₃, traces of gypsum, CaSO₄·2H₂O</td>
<td></td>
</tr>
</tbody>
</table>


**Table 2.1 Egyptian Pigments.** Source: Johnson, Head, & Green 1995, p. 79.
Painted textiles found within tombs and temple complexes include mummy shrouds as well as Books of the Dead and banners. I have viewed mummies with their complete funerary equipment intact, painted fabric shrouds (now displayed separately from the body), sections from Books of the Dead on papyrus and linen, and banners (honouring the goddess Hathor) in the collections of the Egyptian Museum, Cairo, the Ashmolean Museum, Oxford, the British Museum, London, the Nicholson Museum of Antiquities, Sydney, the Oriental Institute, the University of Chicago, and the Field Museum, Chicago. The practice of copying Books of the Dead for burial with the mummy became popular as more elaborate burials became possible for non-royal Egyptians. These documents could be written on papyrus or linen, and are found written and illustrated in plain black ink or in the typical Egyptian range of colours used for painting. While no evidence has been found that the pigments used to paint fabric mummy shrouds, Books of the Dead, or banners adversely affected the fibres they came into close contact with or were painted upon, some of these paints contain metals that act as catalysts for photo-oxidation or other chemical reactions (Timár-Balázsy & Eastop, 1998). Also, orpiment is a known poison (Gettens & Stout, 1942, reprinted 1966, p. 135), being the naturally occurring arsenic trisulphide (Wilkinson, 1994, p.106).
There is some evidence that the limestone tomb itself might also, in certain circumstances, have created carbon dioxide and methane and thus formed a self-contained atmosphere that could halt organic decay. This was the theory of Zeuner, based upon his examination of a remarkable find of intact organic materials in a tomb at Jericho (Wheeler, M., 1956, pp. 104-118). For a description of his examination of the tomb, his experiments conducted at the tomb, and his own arguments in favour of his theory see Zeuner (1955, pp. 118-128).

Thus conditions within the typical Egyptian tomb were largely alkaline; with walls of limestone, and alkaline plasters used both on the walls and on the surfaces of grave goods. This alkaline environment was highly suitable for the long-term storage of linen, as well as other vegetable materials.

2.2.1.3 Protection from Light

Light causes oxidation of vegetable fibres. The cellulose in vegetable fibres absorbs light at all wavelengths, but mainly in the far ultra-violet region. The absorbed energy activates photochemical reactions. These reactions are greatly accelerated if moisture is also present, and if catalysts such as heavy and transition metals are also present in small amounts. In this photo-oxidation process damage is done through the oxidation of the hydroxyl side
groups and through the rupture of the glycosidic ether bonds between the
cellulose units, shortening the polymer chain. Consequently, this process will
change the colour, polarity, solubility, and mechanical properties of the fibre,
resulting in a loss of strength and flexibility (Landi, 1992, p. 18; Tímár-Balázsy & Eastop, 1998, pp.25-26.). Therefore, while linen artefacts remain
in the tomb or burial environment they are protected from light and so from
photo-oxidation, but are again subject to potential damage from photo-
oxidation when taken from the tomb or burial environment, examined, and
displayed.

2.2.1.4 Presence of Salts

There is a great deal of circumstantial evidence that salts act to preserve
vegetable fibres, as long as the fibres are kept dry or any water present is
frozen (Tímár-Balázsy & Eastop, 1998: Ryder, 2000). They act as desiccants,
locking up moisture in their crystalline structures. They also discourage the
activity of most, though not all, bacteria and, perhaps to a lesser extent, fungi.
Examples of fabric and other organic materials preserved by salts are found in
salt mines (Ryder, 2000, p. 17). In the Durnberg mountain mine near
Saltzburg, corpses were found in the 17th Century with such well-preserved
clothing that the weave and colours were noted and recorded (Kurlansky,
2002, pp. 52-54).
Such conditions may also exist on the edges of bodies of salt water where the temperature is either extremely hot, as on the beaches of the Red Sea (Wild, 1999, personal communication by letter) or extremely cold, as in Antarctica (Ms Sarah Clayton, 1998 and 1999, personal communications). Bacteria and fungi could be discouraged if the textile was kept in very high heat (for example the 100-130°F common in Upper Egypt) to desiccate the fabric, as in the Red Sea coast examples cited by Dr. Wild (buried in dry sand).

Bacteria and fungi could also be discouraged in very cold conditions, as in the Antarctic example cited by Ms Clayton, where the moisture needed by bacteria and fungi is unavailable through being frozen. In both of these situations there may be a high level of salt present in the fabrics, but whether it is the presence of the salts or the extreme temperatures, leading to desiccation, which discourage bacterial and fungal activities is difficult to distinguish.

It may be that the movement of salts within fibres and fabrics is the same or similar to their movement within ceramics and stone. In the Discussion section of my own Master of Applied Science, Materials Conservation, Internship Report is a description of the movement of salts within ceramics.

It is generally concluded that the salts enter the fabric of the pot in solution (with the rain or ground waters), and remain undisturbed until excavation changes the
environmental conditions around the ceramic. With changes in temperature and relative humidity, the salts are carried along with the moisture in the ceramic. If the ceramic dries out, then moisture is carried to the surface, the salts crystallise upon drying, and in the process take up an increased space within the ceramic fabric, generally causing the surface of the ceramic to deteriorate (Marsh, 1985, p. 58).

Cronyn (1990, p. 103) has pointed out that particular damage is caused to porous objects through this movement of salts in solution because porous objects, such as ceramics, hold the moisture in vacant spaces (which he describes as pores or capillaries) within the body of the object.

Damage occurs when the porous archaeological object (artefact) dries out, either within the deposit or when excavated. If salts are all brought to the surface in solution they can be washed out before crystallising. If they can be brought to the surface (even if they dry out on the surface of the object instead of being removed through washing) the damage done will be minimal. However, if the object dries out so quickly that salts crystallise while within the body of the object, the crystals grow within the confined space of the pores of the object, causing physical damage. This damage can be so severe that the object is destroyed. Pottery can flake to pieces (for an example see Fig. 2.11), iron objects can break up suddenly and completely, stone can flake and powder, etc. (Cronyn, 1990; Marsh, 1985; Marsh-Letts, 1999).
If the movement of soluble salts into a porous object takes place within organic materials, instead of the inorganic materials discussed above, it may serve to discourage the growth of bacteria or fungi, which would normally use the organic material as a food source. If the fabric is in a temperate atmosphere, perhaps with variations of relative humidity and temperature, instead of an extremely cold or extremely hot atmosphere, then the salt content would need to be very high in order to discourage biodeterioration.

2.2.1.5 Salts Found in Egyptian Archaeological Deposits

Salts are found in Egyptian archaeological sites from two main sources. Firstly, they come from the natural environment, either originally in the geological deposit or carried by ground water. Secondly, they could have been deliberately introduced by the ancient Egyptians as part of cultural activities, including the artificial mummification of the body and/or the burial process, through the washing of textiles with natron, through a cleaning or ritual purification of the tomb with natron, or within the grave goods.

2.2.1.6 Salts in the Environment: Carried by Ground Water

Water-soluble salts that are most often found interacting with archaeological artefacts are chlorides, sulfates, nitrates and phosphates. Sodium chloride, which is highly soluble, is found naturally in both seawater and in arid or
semi-arid environments (in the soil). Higher than normal levels of nitrates are to be expected in archaeological sites where there has been decaying animal or vegetable material, and phosphates are found where there has been a large quantity of bone present (Dowman, 1970, pp. 28-29). Halite (NaCl), gypsum (CaSO₄·2H₂O), and potash are found in shallow lakes or along seashores.

Untreated ground water in the region of Cairo contains large concentrations of calcium, magnesium, sodium, potassium, chloride and sulfate (Shanta, 1988, cited in Maekawa & Agnew, 1996, p. 119; Sultan, Sturchio, El Sharkawi, El Maghraby, & Taher, 1996), which can be easily accounted for by the bedrock of limestone and other stone of marine origin, coupled with human occupation. Calcite, the chief constituent of limestone, is very pure CaCO₃, though it may also contain Mn, Pb, Mg, or Fe and traces of other elements. Certified “pure” commercially bottled water from the deep springs of the Kafir El Arbein Region of Egypt showed the presence of the same salts: calcium, magnesium, sodium, potassium, sulfates, chlorides; further the label lists bicarbonates, silica and total dissolved solids (Baraka label, 2000). This same range of salts was also present in another Egyptian brand of mineral water, Aqua (Aqua label, 2001).
However, mineral waters bottled in Europe and the United States of America differ from the Egyptian waters in the range and concentration of salts present in their spring waters (Crystal Geyser Natural Alpine Spring Water label, 2001; Evian label, 2001; SPA label, 2001).

There has traditionally been a distinction made between the soluble and insoluble salts. However, it should be remembered that the solubility of salts is a matter of relativity. As Dowman (1970, p.25) has pointed out:

The carbonates, sulphates and silicates of calcium are often referred to as insoluble salts. This can be misleading unless it is remembered that solubility is a relative term and that in time anything becomes soluble in water. A conservator, when trying to remove salts, will consider them to be insoluble for they are not readily dissolved by water, but they must have been in solution at some point to be present on an object at all. Calcium carbonate is converted into its soluble bicarbonate to become mobile but it will recrystallise back into the carbonate. ... While in solution the salts will have penetrated the object but they will come to the surface to crystallise out. As the process is very slow they will not break up the object internally as would more readily soluble salts with their greater ease of dissolution and recrystallization, but will simply form unsightly superficial whitish crystals.

Indeed, in the clear demonstration by Arnold and Zehnder (1991) of the movement of salts through porous building materials, chlorides, nitrates, sulfates, and carbonates were all found, by a form of chromatographic testing,

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¹ What the author may be referring to here is the fact that some materials that are relatively insoluble can be made soluble with the passage of time and large volumes of water.
to move through building materials that had been made into a test wall, although they crystallised out in different zones on the test wall, indicating differing rates of migration. Arnold and Zehnder’s observations reinforce the generally accepted view that chlorides and nitrates are more mobile than sulfates and carbonates.

Price and Brimblecombe used a computer program, PITZ93, to study multi-salt systems. The computer calculates “the relative humidity of air in equilibrium with any given mixed salt solution” (1994, p. 90). Their research has charted the complex behaviour of natural salt mixtures. They have found that mixtures of salts react to changes in relative humidity in a manner different from that of each individual salt in the mixture.

2.2.1.7 Salts in the Environment: Salts Introduced as Part of the Mummification/Burial Process

Also present in Egyptian burials are salts that were deliberately placed within the body or in proximity to the clothing or wrappings of the body. Evidence for the burial practices of the ancient Egyptians comes from contemporary tomb paintings, utensils found in the tombs, the mummies themselves, and from Egyptian written records.

The written evidence is quite late, and so has often been questioned as to its accuracy. It consists of British Museum demotic papyrus 10077 (British
Museum, 1979, Fig. 33) and Greek writings, particularly Herodotus (trans., 1946, trans. 1972) and Diodorus Siculus (trans., 1968). There are also scattered, brief references in Plutarch, Porphyry, Augustine, and the Book of Genesis (Genesis 50:2). We now have, however, extensive evidence of the development of the mummification process in Ancient Egypt, and of the nature of the materials employed, based upon the archaeological evidence and the work of archaeological scientists (Colombini, et.al., 2000, p. 19; David & Tapp, 1992; Lucas, 1932b, pp. 125-140; Peck, 1984).

Briefly, it appears that the first burials known to us were in hot, dry, sands that naturally desiccated the body (Peck, 1984, pp. 12-13). Later generations of Egyptians found that with the internment of the body in ever more elaborate tombs the body deteriorated. To replicate the earlier desiccation of the body a process of desiccation through the use of solid natron was developed. This might also have been inspired by the observation that animals that had drunk salt water from the salt lakes and died within the natron deposits were preserved from decomposition (I also observed the evidence of dead animals at the edge of salt lakes at Wadi Natrun during 1999).

This process of artificial mummification was relatively effective. At first mummification was confined to the highest levels of society, but as social and
religious restrictions on its use relaxed and as less expensive versions of the process were developed, the use of artificial mummification moved down the social scale. Later periods increasingly combined the active agent of natron with the use of various resins and spices, sometimes packed dry but also sometimes poured over the body in a liquid state. Colombini, et. al., (2000) analysed mummy balms from a Late Period mummy (7th Century B.C.) and found the main components to be “mastic resin from the genus Pistacia, an unidentified vegetable oil, beeswax, and bitumen” (Colombini, et. al., 2000, p.19). This latter process actually caused deterioration of the linen wrappings and the body through the re-introduction of moisture and the addition of fats, breaking down to fatty acids (Carter, 1954, reprinted 1972, p. 138).

Both cloth and natron were used in the mummification of bodies for burial. The natron was supposed to be removed from the body after the process of dehydration was complete and before the body was wrapped, but this did not always occur. Packets of natron have been found inside mummies recovered archaeologically, and other mummies in museum storage show evidence of the efflorescence of salts due to natron having been left inside the body (personal observation by the author at the Oriental Institute, Chicago, and personal communication with D'Alessandro, 2000).
In Late Antiquity, from the late 3rd Century A.D. to the middle of the 7th Century A.D., burial practices underwent considerable change.\textsuperscript{4} Firstly, Greek and then Roman influences were seen on the coffin and in the treatment of the body, but the body still was mummified and wrapped in linen. Then, it has been suggested due to the influence of Christianity, the practice of mummification decreased in popularity (Rutschowscaya, 1990, p. 14). Instead the deceased was buried, un-mummified, clothed in the garments worn in life, in special garments, or in a shroud. Many of these clothes were decorated with tapestry (usually wool weft on a linen warp), often of a high standard of workmanship and artistry. The burial often did not have a coffin; the body instead was buried on a wooden plank, in the desert sands, about six feet deep (Kybalova, 1967, p. 34). Sometimes the body was shrouded as well as clothed (Rutschowscaya, 1990, p. 4). Archaeologists also found many bodies packed with rock salt or common salt (NaCl) within the clothing or the shrouds. Reisner wrote that in the early Christian burials at Aswan the wrappings "were heavy and sticky with salt" (Reisner, G.A. \textit{Archaeological Survey of Nubia, Report for 1907-8}, p. 100, cited in Lucas, 1932b).

\textsuperscript{4} The term “Early Christian” has also been used instead of Late Antiquity for the same time period. It includes both Late Roman and Early Byzantine. Dating for these periods varies.
2.2.1.8 Temperature: The Variable Factor

Temperature is a factor in all considerations of preservation or deterioration. A high temperature combined with an absence of rainfall or a low average rainfall can maintain the low relative humidity necessary to create and sustain dry conditions. Uniformly dry conditions will keep salts in their crystalline state. A fluctuating temperature, combined with either rainfall or other sources of moisture, will tend to bring about fluctuations of relative humidity, and thus allow salts to deliquesce and recrystallise.\(^5\) Finally, an extremely high temperature, in the form of fire, may oxidise fibres quickly. This can act either to destroy fibres completely or it can preserve the fibres, albeit in a charred state.

2.3 Samples of Egyptian Textiles: Specific Environmental Conditions

In this study further discussion of environmental conditions will be limited to those archaeological environments associated with the samples of archaeologically recovered linen examined in this study. These will include environmental conditions at the cemeteries at Giza, Saqqara and Helwan,

\(^{5}\) Relative humidity is the amount of water in the air over the maximum amount of water that the air can hold at that temperature, times 100, and thus relative humidity is very dependent on temperature (Sage, 1992, p.3).
which were cemeteries of the ancient city of Memphis, and also environmental conditions at the cemeteries of provincial towns in Middle and Lower Egypt (for the locations of these archaeological sites see Appendix A: Maps 1-6).

The samples of linen that have been examined originated from different geographical areas of Egypt, different cultural areas of Egypt, different time periods, and different types of archaeological deposits (i.e. from ground burials, tombs, temples, or dwellings). An attempt was made to obtain as representative a cross section of material as possible, taking into consideration the range of materials available for examination within museum collections in Australia. This objective was largely achieved, as samples were obtained from the most important geographical and cultural areas of the Nile Valley, from all major periods of Egyptian history, and from a variety of types of archaeological deposits.  

For a summary of the dates of samples used in this study see Table 2.3 Chronology of Ancient Egypt. For the location of specific archaeological sites see the General Map of Ancient Egypt and Nubia, as well as maps of modern 

\[ ^6 \text{Samples were not obtained from the Nile Delta, from the Western Oases, or from the Red Sea Coast.} \]
Egypt to be found in Appendix A. More detailed maps of the sites themselves are included in the text as Figures.

2.3.1 Cemeteries of Ancient Memphis

The area surrounding present day Cairo contains important burial grounds dating from the Neolithic period to the present day. An important cemetery remaining from the Predynastic and Early Dynastic periods of Egyptian history is found on the east bank of the Nile, below the limestone cliffs, at Helwan. Memphis itself is now largely lost to agriculture, built over, or under the waters of the Nile, as the Nile has shifted since Memphis was the capital of a unified Egypt. Memphis reached a peak of cultural as well as political influence in the Old Kingdom (2686-2181 BC). It was then that the great pyramid tombs at Saqqara and Giza, on the Giza Plateau (west of the Nile) were erected, along with a host of smaller tombs for the nobility (for photographs and a map of Saqqara see Figs 2.1-2.3). These great cemeteries continued to be used by the local population into Late Antiquity (Lauer, 1976).

Appendix A: Maps 1, 2 and 4 show the location of these cemeteries. Map 1, Ancient Egypt, is a map of ancient Egypt, showing the site of Saqqara. Map 2. Helwan, shows the sites of Saqqara and Helwan in 1950, prior to the large-
scale expansion of the city of Cairo that has come after the completion of the Aswan High Dam. Map 4, *Around Cairo*, is a modern map of the Cairo area, showing the Wadi Natrun, the Giza Plateau (on the west bank of the Nile River) and the area from Ma’adi through Helwan (on the east bank of the Nile River).

![Figure 2.1 The Step Pyramid at Saqqara. Photograph by the author.](image1)

![Figure 2.2 The Cemetery of Saqqara, January 1999. Photograph by the author.](image2)
Figure 2.3 Saqqara. A map of the central area of the archaeological site of Saqqara, showing the step pyramid of Djoser and other pyramid complexes, including the pyramid complex of Teti, as well as mastaba tombs, catacombs, and the proximity of modern settlement (Shaw and Nicholson, 1995, p. 251).

2.3.1.1 Saqqara and Giza

Geologically, as well as geographically and culturally, Giza and Saqqara are so similar as to be part of a single large cemetery complex, which stretches down the Giza Plateau. Burials at Giza and Saqqara were: within the Royal Pyramids, within the stone lined tombs of the nobility and the wealthy, and directly into the desert sands for the poor. It was considered beneficial to be buried as close to the king as possible, to obtain some of his reflected glory or
grace, and so poor people were buried in all areas of the site after it ceased to be fashionable for the wealthy.

Giza, until recently, was considered to lie outside the city of Cairo. Now the city has come right up to the pyramids of Giza, bringing with it problems of environmental pollution and modern mass tourism. Cairo is now the largest city in Africa. Worries are growing that Cairo’s serious air pollution is making the city air more humid than only a few decades ago. The problems of environmental pollution, population pressure and mass tourism have raised serious environmental concerns at Giza, and necessitated the implementation of a new conservation management plan by the Supreme Council of Antiquities (Hawass, 1998, 1999, 2000).

Saqqara is located approximately 27 kilometres south of present-day Cairo, on the high Giza Plateau, on the West Bank of the Nile River, and outside the urban sprawl of Cairo. There is an abrupt demarcation between the valley floor, covered with the green of agriculture, and the high limestone plateau upon which the ancient Egyptians built the first pyramids, later covering it with tombs and burials of all classes of the population. At the site of the Step Pyramid at Saqqara sand and loose stones cover the area around the pyramids and tombs (for photographs and a map of the site of Saqqara see Figs 2.1-2.3). There the atmosphere is still extremely dry. No vegetation is visible on
the plateau, as opposed to the lush Nile Valley floor directly below it. In January 1999, when I tested the sandy surface soil, Merck pH test strips registered neutral pH. Though some air pollution (including acid rain) is now feared to be spreading from Cairo to Saqqara, the ancient cemetery is still relatively pristine in terms of visible environmental change. There is limited traffic (only tourist traffic, and that is generally escorted). Residence near the site is allowed only for those few archaeologists who have dug there for many years.

2.3.1.2 Helwan and the East Bank Cemeteries

The ancient cemeteries of Memphis once included areas now built over, (for both private housing and for industry), at Tura, Maadi, and Helwan, as well as near Giza and Saqqara. When Junker excavated at Tura just before WWI, the city of Cairo was just visible to the north in his photographs. Now housing and the Tura concrete factory cover the area. The factory processes limestone from the nearby cliffs, the same cliffs which were quarried to provide limestone for the pyramids of Giza and Saqqara, and probably also for the upper class tombs of Helwan.
Figure 2.4 Helwan. The archaeological site of Helwan, showing excavated tombs and the encroaching agricultural land next to the Nile. The view is looking to the west. The photograph was taken by the author during December 1998.

Figure 2.5 The Cliffs of the Nile Valley. This view of the cliffs was taken from the archaeological site of Helwan, facing the east. The photograph was taken by the author in December 1998.
Figure 2.6 Map Showing the Distribution of Predynastic Sites Around Cairo.
This is a map showing Helwan’s position on the Nile Valley floor, Helwan’s proximity to the Wadi Hof (that comes through the high limestone cliffs of the eastern plateau), and the relationship of Helwan to Saqqara (Hoffman, 1979, p. 193).
The large necropolis of Helwan is located between the villages of Ezbet Kamel Sidqi in the north and Ezbet el-Walda in the south. Parts of the site are now covered by the village of Muasasat Dewagen in the west and by a military camp in the east (Köhler, 2000, pp. 83-84). For photographs of the site see Figs 2.4, 2.5. For maps of the location of the site see Fig. 2.6, maps of Egypt to be found in Appendix A, as well as Map 2 Helwan, showing Saqqara and Helwan in 1950, at the time of Z. Saad’s excavations.

The cemetery of Helwan was excavated by Saad between 1942 and 1954, when he uncovered more than 10,000 tombs and more than 6,000 objects associated with these tombs (Köhler, 2000, p. 83). Among these objects were textiles. Saad (1969, p. 49) wrote:

In the Helwan tombs we found many kinds of linen, indicating a wide variety in clothing... Much of the cloth we found is even and straight, as well woven as the best modern machine-loomed material. The thread is so fine that one can hardly believe it was spun with a simple spindle. Some pieces of cloth are extremely thin and smooth (Plate 67), while others are heavy and coarse (Plate 68) [for photographs of the linen published by Saad see Fig. 2.6].

During his fifth season of work (1947) Saad found what he reported as a woollen fabric. “In tomb 36 H5 [we found the] remains of a skeleton wrapped
in a woollen [cloth] wool is not known to have been used in Egypt. This is ... a defunct [deceased man] rolled in woollen cloth." (1951, p.44) The remaining examples of “wool” are currently in the Agricultural Museum at Doqqi, Cairo. To date, Mrs. Jana Jones and myself have had great difficulty in obtaining permission to scientifically analyse or to photograph the wool in the Doqqi Museum, though we were able to view it. The sample varied in colour from light to dark grey, and appeared to be made of loose tufts of very fine hair-like wool, not woven. Possibly it is matted, or part of a fringe, or even raw fibre left as an offering in the tomb. Jones believes that it was a fragment/sample of the woven woollen blanket or shroud mentioned on page 44 of Saad's 1951 report (Jones, personal communication, 1999).

Saad found linen in excellent condition (for Saad’s photographs of the linen see Fig. 2.7). Most of the linen that he found has been stored in the Egyptian Museum in Cairo. These fabrics, along with the rest of Saad’s collection from Helwan, have been the subject of recent research by Dr. E. Christiana Köhler of Macquarie University, assisted by Mrs. Jana Jones. Mrs. Jones and myself examined samples of the linen.

7 Saad here may have meant that wool was not normally used in burial contexts in ancient Egypt, being considered, at least, in the later periods of Egyptian history, to be ritually unclean (see Herodotus, trans. 1972, p. 143; Tata, 1986, pp. 180-185). The use of wool for warm garments is attested to in finds from several other archaeological sites on display at the Agricultural Museum and the Egyptian Museum in Cairo. However, “wool was never as important as linen in terms of textile manufacture” (Shaw & Nicholson, 1995, p. 33).
Figure 2.7 Linen from Helwan.

a) This is a copy of Saad’s photograph of thick, coarse linen cloth from Helwan (Saad, 1969, plate 68, p. 148).

b) This is a copy of Saad’s photograph of fine linen cloth from Helwan (Saad 1969, plate 67, p. 147).
As it is known that the site previously had a very good environment for preservation (Saad wrote that he recovered bone, textiles, metals, and ceramics), one would be justified in thinking that it had a slightly alkaline pH, consistent with a sandy deposit and low rainfall. Since the area, as is normal along the Nile Valley, rests on limestone bedrock, ground water could be expected to carry a high level of soluble salts. An alkaline pH for the soil would lead one to expect a largely green/ carbonate patina on any copper based metals from the site. It was difficult to determine the level of patination on copper objects from black and white photographs in Saad’s reports and from the objects on display in the Egyptian Museum Cairo (for photographs of the objects see Figs 2.8 and 2.9), as many appeared to have been cleaned prior to being photographed and prior to exhibition. However, the fact that so many objects of pure copper did survive, including rare whole vessels, shows that corrosion of the metals was not extensive. Bone and ivory artefacts on display (for photographs of the objects see Fig. 2.10) appear to be in an excellent state of preservation. This is consistent with preservation in a mildly alkaline, archaeological deposit.
Figure 2.8 Pottery from Helwan. This is a detail from a photograph of artefacts from Tomb 722 H5, Helwan, taken during Saad's excavations (1969, plate 114).
Figure 2.9 Artifacts from Helwan in the Egyptian Museum, Cairo. The photograph shows the state of preservation of copper, bone, ivory and stone objects from Saad's excavations. This photograph was taken by the author in 1999.

Figure 2.10 Ivory and Stone Artefacts from Helwan. This photograph shows the state of preservation of ivory, stone, and ceramic artefacts from Helwan that are currently on display in the Egyptian Museum, Cairo. This photograph was taken by the author in 1999.
Figure 2.11 Pottery with Salts from Helwan. This is a photograph of a flake of pottery from Helwan showing small white salt crystals. It was taken before the desalination of Helwan pottery, in the 1998-1999 excavation season. The photograph is by the author.

Figure 2.12 A Sodium Chloride Crystal. This crystal was taken from a mud brick wall at the site of Helwan during the 1998-1999 excavation season by the Director of the excavations, Dr. E. Christiana Köhler. The photograph is by the author.
During re-excavation of the site of Helwan during the 1997-1998 and 1998-1999 seasons by Köhler, evidence of recent permeation of the site by salts was apparent in pottery recovered from the site and also upon the stones and mud brick of the tombs themselves (for photographs of the salt crystals see Figs 2.11 and 2.12). The uncovering of the tombs during archaeological excavations may act to draw the water up (Peacock, 1998, personal communication). Other important factors in the movement of water, and consequently soluble salts, on the site are the proximity of agricultural activity to the tombs, a changed drainage pattern in the area, and the quality of the water itself (Marsh-Letts, 1999). Following the damming of the river upstream, problems of salinity in the Nile River Valley have increased (Billard, Burns & Wilson-Young, 1982, pp. 111-113). In addition, it is a topic of ordinary conversation in Cairo that the climate is changing: rainfall and humidity are increasing.

2.3.1.3 Textiles Recovered from the Former Cemeteries of Memphis

Samples analysed in this study known to come from the former cemeteries of Memphis are MS1, MS2, MS3, MS4, MS5, L, U, MU546, and MU 2982.
2.3.1.4 *Analysis of Samples of Archaeological Deposits from Cemeteries of Ancient Memphis*

2.3.1.4.1 *Relevant Previous Studies*

X-Ray diffraction analysis (XRD) is widely used for the identification of materials through their crystal structure. This is achieved through the diffraction of an X-ray beam by the planes of atoms within a crystalline structure, thus producing a characteristic pattern of diffraction (Hodges, 1976, p.185).

XRD and polarising light microscopy are commonly used together for the identification of petrological specimens. Within the field of archaeological science XRD has been widely used in the identification of crystalline materials in samples of paints and pigments, stone, pottery, metals, and glazes.

In Egypt, important conservation work on the deterioration of the tomb of Nefertari (in the Valley of the Queens near Luxor) has used XRD (Corzo & Afshar, 1993, p. 57). It has also been used in investigation of the deterioration of stone monuments on the Giza Plateau (Hawass, 1998b, p. 34). Analysis
has shown that the limestone of Giza contains large quantities of gypsum and sodium chloride (Mackawa and Agnew, 1996, p. 119).

2.3.1.4.2 Examination of Samples

As the purpose of this analysis was to obtain information about the salt content of the archaeological deposits/environments from which textile samples had been obtained, samples were obtained of pottery affected by salts, of salt crystals which had formed on mud brick walls from the site of Helwan, and of debris within textiles excavated from a cemetery in the limestone area near Cairo. These samples were examined in Sydney at the University of Western Sydney, Nepean and at the CSIRO, North Ryde.

2.3.1.4.3 Instrumentation

XRD analysis was accomplished using a Phillips PW 1820 Automatic X-Ray Powder Diffractometer with PDS Data File Searchmaker at the University of Western Sydney and also using a Phillips Model PW1710 X-Ray Diffractometer at the Commonwealth Scientific and Industrial Research Organization, North Ryde, Sydney.
2.3.1.4.4 Data from XRD Analysis

Table 2.2 XRD Analysis of Inorganic Samples from Egypt

<table>
<thead>
<tr>
<th>Sample</th>
<th>Major Components</th>
<th>Minor Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pot flake OP3</td>
<td>Quartz, calcite, anorthite.</td>
<td>Illite/muscovite, gypsum</td>
</tr>
<tr>
<td>Large crystal, mud brick wall OP4</td>
<td>Sodium chloride (NaCl)</td>
<td></td>
</tr>
<tr>
<td>Small crystals, mud brick wall, P4</td>
<td>Sodium chloride (NaCl)</td>
<td></td>
</tr>
<tr>
<td>Large crystals, OP4 deposit</td>
<td>Sodium chloride (NaCl)</td>
<td></td>
</tr>
<tr>
<td>Loose deposit, OP4</td>
<td>Lime, calcite (CaCO₃)</td>
<td></td>
</tr>
<tr>
<td>Loose deposit in association with sample L.</td>
<td>Calcite (CaCO₃), quartz (SiO₂).</td>
<td>Gypsum (CaSO₄·2 H₂O) (Calcium sulfate)</td>
</tr>
<tr>
<td>Loose deposit</td>
<td>Gypsum (CaSO₄·2 H₂O).  (Calcium sulfate)</td>
<td>Calcite (CaCO₃), quartz (SiO₂).</td>
</tr>
</tbody>
</table>

The results were consistent with previous studies (reported above) on the limestone plateau areas adjacent to the Nile at Cairo and Thebes, showing the presence of sodium chloride or halite (NaCl), and gypsum. The analysis also recorded calcite consistent with a limestone area, and quartz, which was to be expected. Only the pottery flake (Fig. 2.11) showed the presence of anorthite and illite/muscovite. This might, therefore, be more relevant to the source of the clay used for fabrication of the pottery than to the mineralogy of the archaeological deposit.
The presence of sodium chloride and gypsum within pottery, mud-brick walls, and architectural stone shows that the salts had migrated into these materials (for photographs of the salts found on pottery and on mud brick at Helwan see Figs 2.11-2.12). The base rock of the whole of the Cairo area is limestone that was deposited in an oceanic environment, accounting for the presence of both the calcite and the salts observed by XRD. However, the movement of the salts from base rock or lower deposits to the artefacts and architectural stone demonstrates the movement of ground water, with the water level higher than in ancient Egypt.

Although the samples related to the Cairo area only, reports from Middle Egypt and Upper Egypt (Luxor) show that those areas too are beginning to experience the same problems as Cairo, where the ground water is rising (Billard & Burns, 1988, pp. 293-298; Billard, Burns, & Wilson-Yang, 1982, pp. 111-113; Corzo & Afshar, 1993; G. Gilbert, Personal Communication re his own archaeological sites in Upper and Lower Egypt, email letters 2000)). It has been postulated that this is due to changes in agricultural methods, including increased irrigation, and also to changes brought about by a greatly increased population, with its higher usage of water and the subsequent discharge of water either directly onto the ground or through drains into areas near the Nile.
2.3.1.5 Examination of Artefacts in Egypt from Cemeteries of Ancient Memphis

A comparison was undertaken of artefacts held by the Egyptian Museum from the site of Helwan that had been recovered before the building of the Aswan High Dam with artefacts newly recovered from the site of Helwan. This was done through visual comparison combined with an examination of original archaeological reports (for photographs of some of the artefacts examined see Figs 2.9 and 2.10).

Among the artefacts recovered from early excavations in the former cemetery of Memphis at Helwan, stone artefacts showed slight traces of what appeared to be gypsum on the surfaces, but no observable spalling due to salts. No other artefacts showed evidence of any salts. This absence of salts or salt-induced corrosion was especially notable in that (a) the copper utensils showed no signs of corrosion (though they may have been cleaned prior to exhibition at the Egyptian Museum, Cairo), (b) textiles had been preserved, often in excellent condition, (c) other organic materials were preserved, and (d) bone showed no signs of disintegration due to salts.

In contrast to the excellent condition of ivory, bone, metal, linen and other organic artefacts recovered from Helwan by Saad, recent excavations from
otherwise equivalent deposits at Helwan have recovered few organic materials (some bone and small slivers of wood) and almost no recognisable metals. Dr. E. Christiana Köhler has found no new textiles in recent excavations at the site of Helwan (Köhler 1998, 2000). Architectural stone and mud walls were full of salts, and the pottery was so full of sodium chloride and other salts that an extensive desalination program had to be undertaken in order to desalinate all pottery recovered (Marsh-Letts, 1999).

2.3.2 Tell el Amarna

The site of the ancient but short-lived city of Akhetaten, now most often referred to as Tell el Amarna, is in present day Middle Egypt, halfway between Cairo and Luxor, and 12 km southwest of the town of Mallawi. It is on the east bank of the Nile, in a crescent shaped plain, approximately 12 km from north to south and bounded by high cliffs and wadis (for a sketch map of the site see Fig. 2.13). The ground is sandy, alkaline from the limestone bedrock, and very dry.

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9 This evidence comes from previously unexcavated tombs in close proximity to previously excavated tombs, within the same geological strata, and is based on my own observations as Conservator for the 1998-99 excavations.
Figure 2.13 Sketch Map Showing the Site of Akhetaten on the East Bank and the Approximate Extent of Excavations (British & German) up to February, 1932
(Drawing by H.S. Smith, in Samson, 1972, p.9.)
The Egypt Exploration Society has held the concession (permit) to dig at Tell el Amarna for most of the 20th Century (with only one period when the concession went to another organization). Petrie excavated Tell el Amarna from 1891 onwards, in association with the London based Egypt Exploration Society, but among his published works available in Australia no descriptions of the recovery of Coptic textiles were found (Petrie, 1931). However, textiles were recovered from this site by an expedition funded by the Egypt Exploration Society, circa 1920-1930, and given to the Nicholson Museum of Antiquities, Sydney University, presumably because the Museum had contributed to the work of the Society. The Nicholson Museum has no records other than the labels on the boxes. The explanation for a lack of records may be that at that time excavators concentrated only on the Pharaonic period, with later periods not even recorded. However, Petrie was well known as one of the first to record his excavations in what has come to be accepted as a scientific manner.

To attempt to locate the exact area from which the Roman or Byzantine period textiles were excavated I made a search among the excavation records of Tell el Amarna held at the Griffith Institute/ the Ashmolean Museum Library at Oxford. During the time period 1921-1936, excavation by the Egypt Exploration Society began with the Eastern Village (the Workmen’s
Village), Maru-Aten, and the River Temple and then moved to the central city, the North Palace, and the North Suburb (Kemp & Garfi, 1993, pp. 20-21). The North Suburb contained late Roman and early Christian remains, including a large cemetery. Kemp and Garfi commented that several different excavators dug the cemetery, but that the excavations were unfortunately only published in preliminary reports (1993, pp. 49-50). A careful study by myself of the reports cited by Kemp and Garfi showed that this was indeed true; the reports were brief and of a preliminary nature. They did not discuss textile finds.

Of more help was an earlier report from Lepsius, who crossed the North Suburb in 1843. He described the whole site as a large cemetery with human bones; its tombs “dug into the sand, also mummy cloth and indeed woollens lie around” (Lepsius, Denk Text II, p. 126, as cited by Kemp & Garfi, 1993, p. 50).

Kemp and Garfi give a further description of the deposit of the Roman era levels in the areas of occupation in the North Suburb. Red brick, ashes and potsherds overlay yellow clay. Sand and gravel deposits are found to a depth of three metres (see Kemp and Garfi 1993, pp. 44-45 for the profile of excavation).
Woolley excavated at Tell el Amarna. While his excavation report of 1922 did not mention late Roman and Coptic textiles, it contained excellent photographs of the Workmen’s Village. These show that the preservation conditions for organic materials should have been excellent in the area, with photographs showing a room excavated with baskets in position and another room with a manger with the tether rope still in position.

The excellent preservation conditions for organic materials are further shown by the report on recently excavated basketry and cordage by Wendrich (1989, pp. 169-201) and by the report on recently excavated textiles by Eastwood (1985, pp. 191-204). Referring to these recently excavated textiles, Eastwood (1985, p. 191) wrote, “Due to the arid and sand conditions at the site, the majority of the textiles are well-preserved and have not suffered any serious distortion in their original colour”.

2.3.2.1 Results of Analysis of Linen Recovered from Tell el Amarna

Using standard textile examination methods and optical microscopy, I examined fabrics from Tell el Amarna in the collections of the Nicholson Museum of Antiquities, the University of Sydney. Of the two small collections initially examined, one collection was not used in this study since the fabrics had recently undergone conservation treatment. The other
collection was of considerable interest because it could be photographed and samples taken both prior and post conservation treatment. However, some textiles in this collection were later deleted from this study because the initial examination showed their warp and weft were both made from woollen fibre, not linen. These textiles were N67.34, N67.35, N67.37a, N67.37b, N67.40a, and N67.41. Textiles that were found to be linen and therefore included in the study were N67.36, N67.38, N67.39, N67.40b, and N67.42. Reports of the analysis of these linen textiles are found in Appendix A.

2.3.3 Textiles of Middle and Upper Egypt from the Museum of Victoria, from Private Collections, and Unprovenanced Materials

A Harvard Boston Expedition led by G.A. Reisner excavated the mummy of Tbj /Tjeby⁹ the Elder during the 1923 season. It was found in Tomb 5105 at Sheikh Farag, part of the Cemetery of Naga ed -Deir, in Upper Egypt. This cemetery was located on the East Bank of the Nile, opposite modern Girga, and which can be thought of as in either Middle or Upper Egypt (see Fig. 2.14 and Appendix A: Map.3 for the location of Girga, and Fig. 2.15 for a map of the tomb drawn by A. Rowe, an assistant to Reisner during the 1923 excavations). The tomb was cut into the limestone cliff of the Nile Valley. Conditions appear from published reports to have been dry. Rowe

⁹ In Ancient Egyptian Hieroglyphic inscriptions the vowels were not written (Gardiner, 3rd edition reprinted 1994 p.9), however they are commonly added to approximate the spoken language. Therefore the mummy was identified by inscriptions in the tomb as Tby. He may have been called Tjeby.
presented the coffin and mummy to the Museum of Victoria (then the National Museum of Victoria) in 1924. For further details about the excavation and subsequent examination, display, and conservation treatment of Tbj/Tjebly refer to Hope (1983-84, pp. 7-10); Marsh (1990a, 1990b); Stevens, Thomas, Bartlett, & McDougall (1978, pp. 35-36).

Figure 2.14 Girga. A map showing the location of Girga, near which the mummy of Tby/Tjebly was buried (Stevens, et. al., 1978, p. 36).
Figure 2.15 Tby/Tjeb’s Tomb. A copy of the drawing of the tomb of Tby/Tjeby originally drawn by A. Rowe in 1923 (Hope, 1983-1984, p.10).

Several textile specimens were recovered by a private collector from a desert deposit at a now abandoned site in Middle Egypt. These are identified as
samples of TK. The site from which these samples were recovered, and the
dry sandy conditions for the archaeological deposit, were noted and
photographed by the private collector. Other samples are unprovenanced as to
source, but can be roughly dated as Dynastic (three samples of Cartonnage, N
(Cartonnage Mask), BD (Book of the Dead), MU1545, MU1547, MU1550,
MU1551, MU1552), or Graeco-Roman (T, MU2469, MU2479, MU2485,
and MU2488).

2.4 Chronology of Textile Samples from Ancient Egypt, Showing Periods,
Dynasties, Rulers, and Sites

Linen samples used in this study come from specified locations and have been
identified as belonging to specific time periods. In order to relate the chemical
and physical properties of the linen samples to the historical and
archaeological evidence presented in Chapters 1 and 2, an outline of the
chronology of ancient Egyptian History is given in Table 2.3.

Within Table 2.3 the following conventions have been observed:

- Colour changes indicate the major divisions of Ancient Egyptian
  history.

- Commonly accepted divisions of rulers into Dynasties are given. Major
  kings are named in chronological order, but are included in the
  chronology only if we have discussed them in the text of the thesis or if
  they reigned during a time for which we have textile samples that are
  included in this study.
• Historical information has been combined with information about the linen samples analysed in this study.

• All linen samples examined in this study are identified either by their museum registration numbers or by a code using capital letters.

The chronology used in Table 2.3 is based upon dates given by Adams & Cialowicz (1988, p. 5), Clayton (1994), Ellis (1992, pp. 5-6), Kitchen (1982, pp. 238-239), Midant-Reynes (1992, trans. 2000, pp.25, 152-153), Quirke, S. (2000, no page numbers given), Schultz in Schultz & Seidel (1998, pp.528-531), and Shaw & Nicholson (1995, pp.310-312). There are scholarly disagreements about many of the exact dates and lengths of dynasties in Ancient Egyptian history. Therefore all dates before either 664 BC are approximate, and are based the most reputable sources available. It is not within the scope or purpose of this study to enter into questions of exact dates, and indeed, the exact dating of samples is not of major importance for this study.

Table 2.3 Chronology of Ancient Egypt, Showing Periods, Dynasties, Rulers, Sites and Samples.

<table>
<thead>
<tr>
<th>Period</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predynastic Period</td>
<td></td>
</tr>
<tr>
<td>c.5500-3150 B.C.</td>
<td>Sample U</td>
</tr>
<tr>
<td>Earliest known linen fabric in Egypt Found in Badarian Culture levels</td>
<td></td>
</tr>
<tr>
<td>Dynasty 0</td>
<td>c.3150- 3050/3000</td>
</tr>
<tr>
<td><strong>Early Dynastic Period</strong></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td></td>
</tr>
<tr>
<td>c. 3050/3000-2686 B.C.</td>
<td></td>
</tr>
<tr>
<td>The villages of Upper Egypt and of Lower Egypt may have come to be organized under regional leadership. Possible Kings were Crocodile, Iry-Hor, Ka, Scorpion and Narmer.</td>
<td></td>
</tr>
<tr>
<td>Sample TK</td>
<td></td>
</tr>
<tr>
<td>Samples which are Dynastic but otherwise undated: MU1545, MU1547 MU1550, MU1551, MU1552</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dynasty 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cemetery at Helwan in use. This period saw the unification of Upper and Lower Egypt.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dynasty 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kings included Hotepsekhemwy, Raneb, Ninetjer, Sekhemib, Peribsen, Sened, Weneg, Khasekhem, and Khasekhemwy.</td>
</tr>
<tr>
<td>Sample L</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Old Kingdom</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>c. 2686-2150 B.C.</td>
</tr>
<tr>
<td>Cemetery at Saqqara in use by Kings and Nobility</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dynasty 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>King Netjerikhet built the Step Pyramid at Saqqara.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dynasty 4</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Dynasty 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kings include Userkaf, Sahure, Neferirkare, Shepseskare, Neferefre, Niuserre, Menkawhor, Djedkare, and Unas.</td>
</tr>
<tr>
<td>MU2982</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dynasty 6</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Dynasty 7</th>
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</table>

<table>
<thead>
<tr>
<th>Dynasty 8</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th><strong>First Intermediate Period</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>c. 2150-2040 B.C.</td>
</tr>
<tr>
<td>Dynasties 9-10</td>
</tr>
</tbody>
</table>
This was a period of political disturbance. The dating of this period has been highly controversial in Egyptology. At various times Dynasties 7 through 8, and Dynasty 11 have also been included in the First Intermediate Period.

<table>
<thead>
<tr>
<th>Middle Kingdom</th>
<th>Tby/Tjeby Wrappings (X83758)</th>
</tr>
</thead>
<tbody>
<tr>
<td>c. 2040-1640 BC.</td>
<td></td>
</tr>
<tr>
<td>Dynasty 11</td>
<td></td>
</tr>
<tr>
<td>This period saw the unification of the Kingdom. Kings included Mentuhotep II, Mentuhotep III and Mentuhotep IV.</td>
<td></td>
</tr>
</tbody>
</table>

| Dynasty 12           |                               |

| Second Intermediate Period |                               |
| c. 1640 - 1550 B.C.      |                               |
| Dynasty 14              |                               |
| Country divided         |                               |

| Dynasty 15 and 16       |                               |
| The Asiatics ruled in the Delta |                       |

| Dynasty 17              |                               |
| The central government was restored |                      |

| New Kingdom            |                               |
| c. 1550/1570-1070 B.C. |                               |
| Dynasty 18             |                               |
The expulsion of the Asiatics from Egypt took place and was followed by a period of expansion and prosperity.


Tell el-Amarna was built and then abandoned.

### Dynasty 19
Kings included Rameses I, Seti I, Rameses II (The Great), Merneptah, Sety II, Amennesse, Siptah, and Tausret.

### Dynasty 20

<table>
<thead>
<tr>
<th>Third Intermediate Period</th>
<th>c. 1070 - 712 B.C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynasty 21</td>
<td></td>
</tr>
<tr>
<td>Egypt begins a decline</td>
<td></td>
</tr>
<tr>
<td>Kings included Nesbanebdjed, Amenemnisut, Pasebakhennut I, Amenemipt, Osorkon, Saamun, and Pasebakhennut II.</td>
<td></td>
</tr>
</tbody>
</table>

### Dynasty 22
Kings included Sheshonq I, Osorkon I, Takelot I, Sheshonq II and Osorkon II. After Osorkon II Egypt was no longer united; separate kings ruled in Thebes and Upper Egypt.

### Dynasties 23-24

<table>
<thead>
<tr>
<th>Late Period</th>
<th>c. 712 - 332 BC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynasty 25</td>
<td></td>
</tr>
</tbody>
</table>

Samples which are Late Dynastic, but otherwise undated are Book of the Dead, Mummy Wrappings (N), Cartonnage.
<table>
<thead>
<tr>
<th>Period</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynasty 26 (Saite)</td>
<td></td>
</tr>
<tr>
<td>Dynasty 27 (First Persian Period)</td>
<td></td>
</tr>
<tr>
<td>Dynasty 28-30</td>
<td></td>
</tr>
<tr>
<td>Second Persian Period</td>
<td></td>
</tr>
<tr>
<td>Greco-Roman Period c. 332 B.C. - AD 395</td>
<td></td>
</tr>
<tr>
<td>Macedonian Kings 332-304/5 B.C.</td>
<td>Alexander the Great</td>
</tr>
<tr>
<td>Ptolemaic Period 304/5-30 B.C.</td>
<td>Kings included Ptolemy I, Ptolemy II, Ptolemy III, Ptolemy IV, Ptolemy V, Ptolemy VI, Ptolemy VII, Ptolemy VIII, Ptolemy IX, Ptolemy X, Ptolemy XI, Ptolemy XII, Cleopatra VII, Ptolemy XIII, Ptolemy XIV (co-regent with Cleopatra VII) and Ptolemy XV (co-regent with Cleopatra VII).</td>
</tr>
<tr>
<td></td>
<td>MU2469, MU2479, MU2485, MU2488</td>
</tr>
<tr>
<td>Direct rule by the Emperor of Rome 27 BC to circa AD 395.</td>
<td>All Emperors of Rome were also King of Egypt from Octavian through Theodosius I the Great (ruling with Arcadius and Honorius).</td>
</tr>
<tr>
<td>Byzantine Period</td>
<td>This period is variously dated. It covered circa AD 395 to 641.</td>
</tr>
<tr>
<td>Arab conquest of Egypt</td>
<td>AD 639-642.</td>
</tr>
</tbody>
</table>
2.5 Conclusions

- The key elements in the environment of Egypt that may have preserved linen artefacts in situ have been identified as desiccation, alkaline environmental conditions, protection from light, and the presence of salts.

- Archaeological sites from which ancient Egyptian linen samples used in this study were recovered have been described. They were found to have: offered protection from light damage, had a dry environment at the time the textiles were excavated, had a base rock of limestone, and shown evidence of the presence of salts in the archaeological environment.

- Changes in the environment of Egypt which appear to affect the preservation of linen in archaeological sites are:
  
  o increased environmental pollution associated with a greatly increased population,
  
  o possible changes in weather patterns, bringing increased rain to some areas of Egypt,
  
  o changes in the water table in the Nile River Valley, possibly due to changes in land use, and
  
  o increased salinity of both the Nile and the Nile Valley, possibly due to the damming of the river.
CHAPTER 3
Experimental Demonstration of the Role of Natron and Other Salts in the Preservation and Conservation of Ancient Egyptian Linen—A Pilot Study

3.1 Introduction
Natron is a natural soda, ideally a compound of sodium carbonate and sodium bicarbonate in the proportion of one molecule of each Na₂CO₃- NaHCO₃-2H₂O, but generally found in its natural state with a large proportion of “impurities”, including sodium chloride and sodium sulfate (Lucas 1932a). Also present are magnesium, and other soluble inorganic salts.

In Chapter 1 evidence was presented that natron or other materials were used in the washing and bleaching process in ancient Egypt. It is possible that residues from these cleaning agents may have remained in the cloth. In Chapter 2 evidence was presented that natron and other alkaline salts are present in the archaeological environment on Egyptian sites. These salts may have interacted with ancient Egyptian linen in the archaeological deposit. If natron and other alkaline salts have remained in ancient Egyptian linen then they may have mineralised, or partially mineralised¹ the fibres, and in this manner contributed to their preservation. The occurrence of partial
mineralization in organic materials has previously been described and discussed by Jakes & Sibley (1989), Chen, Jakes & Foreman (1998). It has also been described and discussed for archaeological textiles by Shearman (2002), for archaeological leather by Cameron (2002), and for archaeological wood by Watson (2002).

An examination of the cellular structure of the fibres of ancient Egyptian linen to determine whether or not full or partial mineralization has occurred, combined with identification of salts present, would then be needed in order to determine whether or not a fabric had any inorganic materials within its cellular structure before appropriate conservation treatment could be determined.

Therefore the following hypothesis was formulated:

- That textiles from ancient Egypt have often undergone a form of mineralization\(^1\) or partial mineralization through either (a) treatments involving natron, and possibly other salts, in antiquity and/or (b) environmental conditions where the linen has come into contact with natron, possibly in conjunction with other salts, and that this

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\(^1\) For the definition of mineralization used in this study please see the Glossary.
mineralization or partial mineralization has contributed to their survival.

In order to test the above hypothesis a background study of other work in the area of salts in archaeological artefacts was conducted, then a research design was constructed, and experimental work was undertaken. It was recognized that this experimental work should be considered as a pilot study (i.e. work on a small scale designed to assess the viability of future experimental work), as the time, financial resources, and equipment available for the study were limited.

The specific objectives of this chapter are to:

- Place the study in context through a literature review;
- Formulate a research design which will test the hypothesis that textiles from ancient Egypt have often undergone a form of mineralization or partial mineralization through either (a) treatments involving natron, and possibly other salts, in antiquity and/or (b) environmental conditions where the linen has come into contact with natron, possibly in conjunction with other salts, and that this mineralization or partial mineralization has contributed to their survival;
- Identify suitable ancient Egyptian linen samples that may be tested in order to determine their level of mineralization;
• Test control samples of linen, natron, and ancient fibres as well as ancient Egyptian linen in order to determine whether or not they have undergone a process of mineralization or partial mineralization by natron and other salts;

• Test suitable ancient Egyptian linen samples for levels of alkalinity and acidity; and

• Observe the effects of hydration and dehydration upon linen test samples in order to observe the behaviour of natron and other salts which may be present in the fabrics.

3.2 The Context

This study is related to numerous other studies of the effects of salts within archaeological artefacts and within historic buildings and monuments. Most of these studies have been concerned with stone and other building materials (Arnold & Zehnder, 1991; Pessoa, Antunes, Figueiredo, and Fortes, 1996; Preussner, 1991), with pottery (Willey, 1995) and with metals (McLeod, 1981). This is due to the fact that the destructive effects of salts within these materials have been more obvious and have been seen to have a more economically important effect than in organic materials.
Considerable attention has also been given to the conservation of waterlogged organic objects, especially wooden ships (recovered from both salt and fresh waters) and wooden artefacts. Indeed, in the published preprints of the 1970 New York Conference of the International Institute for Conservation (IIC), *Conservation of Stone and Wooden Objects*, one half of the conference preprints was devoted to stone, with the conservation problems of salts in stone a recurring topic of discussion, while the other half of the conference preprints concentrated on problems connected with the conservation of wood, with the treatment of waterlogged wood a recurring topic for discussion (Thomson, 1971). Attention in studies on waterlogged wood has focused largely on techniques such as freeze-drying and baulking with materials such as polyethylene glycol (PEG) in order to prevent a collapse of the structure of waterlogged wood upon drying.

In contrast to the highly publicised work done on the conservation of shipwrecks, such as the Mary Rose and the Batavia (including their contents), which have been recovered archaeologically, there has only been one recent study of the effects of salts in a dry environment upon wooden artefacts in Egypt. This has been the excellent article on Egyptian (coffin) wood by Blanchette, Haight, Koestler, Hatchfield and Arnold (1994). A reason for the different emphasis in the conservation literature on these two classes of
wooden artefacts may be that, in contrast to the grave and dramatic problems which waterlogged wood presents to the conservator, wood which has been affected by salts in dry conditions is relatively stable.

Studies of the conservation of textiles from shipwrecks have been less numerous than wooden artefacts studies. Those studies that have been published have considered the effects of salts upon textiles. Notable among these studies have been those of Florian (1987a) and Flury-Lemberg (1988). The study of Ancient Egyptian linen by Stoll and Fengel (1988) was the only published study on archaeologically recovered Egyptian linen that chemically identifies salts on the fibre surfaces, prior to my own work.

While conducting ageing studies of cellulose on archaeologically recovered Egyptian linen obtained from museum collections, Stoll and Fengel (1988) found evidence of salts on the surface of linen fibres, which could have been residues from natron washing. In that study they used energy dispersive X-ray analysis (EDXA) to identify the composition of extraneous materials found associated with the linen fibres, and were successful in using scanning electron microscopy (SEM) to reproduce images of salt crystals on the surface of fibres. However, they did not demonstrate the presence or otherwise of crystals within the fibres. As the role of natron in the
preservation of linen was not the primary focus of their work, they did not pursue the subject of salts in ancient Egyptian linen any further.

Studies showing the association of salts with papyrus are small in number (Banik & Stachelberger, 1987, cited in Leach & Tait, 2000; Bridgeman, 1973, cited in Leach & Tait, 2000; Nielsen 1985, cited in Leach & Tait, 2000; Rathgan 1905, cited in Leach and Tait, 2000; Wallert, 1996), but have direct relevance to this work. This is because both papyrus and linen were created from plant fibres and because both have been found preserved in similar archaeological deposits in Egypt. However, the papyrus plant and the flax plant differ botanically, and papyrus and linen differ both in methods of manufacture and in usage.

Descriptions of the conservation treatment of Egyptian linen have appeared in a small number of publications (Brown, Macalister & Wright (Eds.), 1995; Landi, 1979; Landi, 1992; O'Connor & Brooks, (Eds.), 1990) and these are discussed in greater detail in the later sections of this chapter. There are no reported studies of the presence of natron and other salts within the cellular structure of ancient Egyptian linen fibres previous to this study, and there have been no attempts previous to this study to investigate the effects of sodium chloride and other salts upon ancient Egyptian linen fibres under variable environmental conditions.
3.3 Research Design

In order to test the hypothesis that textiles from ancient Egypt have often undergone a form of mineralization or partial mineralization through either (a) treatments involving natron, and possibly other salts, in antiquity and/ or (b) environmental conditions where the linen has come into contact with natron, possibly in conjunction with other salts, and that this mineralization or partial mineralization has contributed to their survival, I considered it necessary to examine a number of linen control samples and samples of ancient Egyptian linen.

All samples needed to be examined in order to record both their physical condition and all chemical elements present. The focus of this examination was to identify the chemical elements present in the natural linen fibres and to distinguish them from elements added either through washing with natron or through contact with an environment containing soluble inorganic salts. It also appeared to be important to be able to determine the physical form of these introduced elements. Once this distinction was made, and the introduced elements identified, then the behaviour of the introduced elements could be monitored during cycles of hydration and dehydration, in order to record the effect of the introduced material upon the linen fibres.
Based upon a review of the literature cited above, I chose to use the following techniques to examine the linen samples: optical microscopy, scanning electron microscopy (SEM), environmental scanning electron microscopy (ESEM), energy dispersive x-ray analysis (EDXA), x-ray diffraction (XRD), and ion chromatography (IC). The work of Blanchette, Haight, Koestler, Hatchfield and Arnold (1994) demonstrated the use of transmission electron microscopy to view extraneous material within cell lumina of wood samples from ancient Egyptian artefacts, although that extraneous material was not identified. Transmission electron microscopy was considered as a potentially useful analytical technique for the examination of linen fibres, especially if it could have been combined with EDXA so that salts in the lumen of fibre cells could have been directly viewed and identified. However, the use of a transmission electron microscope was not available to me during this study. Each method of analysis was considered to have its limitations, but each could yield important information. The information obtained through all of the techniques chosen could be coordinated in order to obtain a comprehensive picture of the chemical and physical nature of the samples.

3.3.1 Sequence of Methods Employed
1) Before any experimental work could take place it was necessary to obtain the appropriate samples:
i) Control samples were created. These consisted of (a) new linen, (b) new linen washed in natural natron, to replicate as closely as possible the pre-deposit state of ancient Egyptian linen, and (c) new linen washed in the deacidification solution used by paper and textile conservators to buffer against acidity.

ii) A sample of an archaeologically recovered textile from an ocean environment was obtained, for comparative purposes.

iii) Samples of both unprovenanced and provenanced ancient Egyptian linen, as excavated and without any prior treatment, were obtained. However, sampling had to be limited to those suitable samples available from Australian museums and collections, due to both constraints of time and the difficulty of obtaining provenanced samples from Egypt.

To obtain samples from Egypt has become more difficult in recent years than it previously had been. Samples of textiles are rarely allowed out of Egypt (this is government policy), little sampling is allowed in the country for analytical purposes, and there are limited facilities in Egypt for textile analysis.

2) Textiles were examined and described using recognised methods. They were also photographed and, in some cases, drawn.

3) Textile samples were examined using optical microscopy in order to identify the type of fibre and its state of preservation.
4) Textile samples were in some instances spot-tested for the presence of lignin using the phloroglucinol test\(^2\).

5) Some textile samples were examined using SEM with EDXA.

6) Samples of salts collected from archaeological environments associated with some of the textiles were examined and identified using X-ray diffraction analysis (see 2.3.1.4 Analysis of Samples of Archaeological Deposits from Cemeteries of Ancient Memphis).

7) Anions present in water extracts from some samples of linen were determined by ion chromatography.

8) A small number of samples of linen were initially examined using ESEM coupled with EDXA. The first results indicated that this method was able to give the desired information, as it was possible to use this technique to examine and identify the chemical and physical nature of the fibres, and also to observe and record the kinetic processes of salt hydration and deliquescence. Therefore this method became the preferred experimental method. A wider range of samples was then tested using ESEM, and the results recorded using a computer file and a videotape (edited footage from the videotape is included in this thesis as Appendix B).

9) Further IC analysis was undertaken on the same samples examined by ESEM and EDXA, then the two sets of results compared.

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\(^2\) To test a fabric or paper for lignin a solution of 2% phloroglucinol in ethanol is used to spot test a fibre. If a red colouration appears then lignin is present. Some variations of the test also use a small amount of
10) A treatment process was developed for linen that contained salts within its fibres that would otherwise make conventional treatment problematic. This treatment involved testing using both vacuum freeze drying and freezing followed by slow drying processes. The samples obtained were then examined using optical microscopy and ESEM with EDXA.

11) Analysis done at the University of Technology Sydney using the ESEM combined with EDXA was coordinated with IC and X-ray Diffraction analysis done at the University of Western Sydney in order to clearly document (a) the presence of inorganic salts in the samples, (b) movement of salts during cycles of hydration and dehydration, (c) in some samples a comparison of salts identified from within the textiles and the salts present in samples of the archaeological deposits from which they were recovered, and (d) the effectiveness of conservation treatments for the removal of salts from textiles.

3.4 Samples Used In This Study

A description of the sampling strategy used in this study is given below, followed by a brief description of each class of sample. A complete description of every sample used in the study is given in Appendix A.
3.4.1 Sampling Strategy

Stoll and Fengel (1988, pp151-168) wrote that:

In spite of the great store of woven fabrics only little analytical research using physical and chemical methods has been done on them up to date. [Referring to their own studies of more than 50 fabrics with ages between 1000 and 4000 years] ... The investigations suffered from lack of knowledge about the environmental conditions of the tissues during their long stay in the Egyptian tombs or even in the cellars of the museums.... The systematic investigation of the inorganic substances being present in the old Egyptian linen is complicated by the fact that many of the finds [finds] have been washed with water after the excavation. Some of them are labelled accordingly ... others are not. Thus all analytical data are subjected to the uncertainty whether or not some of the water-soluble salts have been removed.

Taking note of the work of Stoll and Fengel (1988) cited above, a priority was the acquisition of samples from clearly provenanced fabrics whenever possible, and also the acquisition of the conservation "history" of the fabrics which were sampled, i.e., the treatment history. Especially important was information on whether samples had been water washed or treated in any other manner.

It was difficult to formulate what would be an adequate number of samples for this study, especially when it was taken into consideration that these were "real" objects with natural variability, not standardised test samples. A further complication was that they were archaeologically recovered objects whose
survival was in some degree arbitrary, being dependent upon environment and historical chance. Every attempt was made to obtain a wide range of samples in that small linen samples were obtained which would give dated material from all eras of ancient Egyptian History and which at the same time would come from a wide range of archaeological environments. While it was possible to obtain samples from different eras of Egyptian history and different types of archaeological deposits, it proved impossible to find from Australian museum collections samples from all geographical areas of Egypt, especially samples from sites in the Delta (where environmental conditions are not conducive to the preservation of organic materials).

Taking the example of Stoll and Fengel (1988), a sample of between 50 and 100 would have been appropriate. However, the emphasis in this study on provenanced material meant that the choice of suitable material available from museum collections in Australia was severely limited (most museum collections in Australia consisting largely of partially provenanced or unprovenanced Egyptian textiles). Even Stoll and Fengel, with the range of ancient Egyptian linen available to them in the much larger museum collections of Germany, had difficulty obtaining provenanced material and had included unprovenanced material in their study. Therefore it was determined that this pilot study would test a smaller number of samples than
Stoll and Fengel did in their study, but would test them with a wider range of techniques than were used by Stoll and Fengel, in order to extract the maximum amount of information from the samples.

An initial survey of textiles in museum collections and private collections within Australia was undertaken. Small samples were collected from museum collections and private collections of well provenanced ancient Egyptian linen. Ancient Egyptian textiles in collections outside of Australia were also visually examined, but samples from these collections could not be taken to Australia for analysis.

The total number of ancient Egyptian textiles initially included in the pilot study was fifty-one. Of this original selection some were found, upon later examination using optical microscopy, to have a woollen warp as well as a woollen weft, and therefore these were unsuitable for this pilot study. The remaining thirty samples of ancient Egyptian linen were retained in the study. These samples were examined using fibre analysis techniques and optical microscopy and the results recorded. Their complete records can be found in Appendix A.
3.4.2 Samples

Fresh *Linum usitatissimum* fibre, for use as a reference sample, was obtained from an Australian nursery. Due to Australian quarantine regulations, it was not possible to obtain fresh flax in Egypt for scientific testing in Australia. As *Linum usitatissimum* is rarely grown in Australia it was difficult to obtain samples of either living flax plants or flax seed from commercial supply houses. However, with the assistance of the Royal Botanic Gardens, Sydney, a single supplier was located in Tasmania. Six living plants were obtained from Island Herbs, Snug, Tasmania. Photographs and records of the examination of these samples are found in Appendix A. 1. *Linum usitatissimum*.

Natron was collected from the Wadi Natrun (also called the Wadi Al-Natrun and the Wadi Natron or The Natron Valley). The Wadi Natrun is a depression in the Libyan Desert, approximately 95 km northwest of modern Cairo via the Cairo-Alexandria Desert Road. Lutz writes that (1923, p. 75)

The salt and soda (natron) deposits of the Wadi Natron ... in the Libyan desert west of Cairo, appear to have been worked by the Egyptians from the earliest time, and as now were used for bleaching, and in the manufacture of soap and glass... The Natron Valley contains ten salt lakes, which dry up almost completely during the summer months, leaving deposits of salt, and the surrounding soil yields both salt and carbonate of soda ...The Copts used to call this district 'the salt mountain'.
Samples were collected from one of the lakes in January 1999 (for maps describing the location of Wadi Natrun and photographs of the site where samples were collected see Figs. 3.1 – 3.4 and Appendix A: 7. Natron).

**Figure 3.1 Around Cairo.** This is a modern map of the Cairo area, showing the Wadi Natrun, the Giza Plateau and the Al Faiyum Oasis on the west bank of the Nile, and, on the east bank of the Nile, Maadi and Helwan (Logan, et al., 1997, p. 219).
Figure 3.2 *Wadi Natrun*. A map of the salt lakes of the Wadi Natrun (Lucas, 1912, no page number).
**Figure 3.3 Wadi Natrun Lake.** A photograph of natron salt on the edge of the evaporating lake, taken by the author January 1999.

**Figure 3.4 Natron Sample.** A photograph by the author of a sample of natron collected, January 1999.
It might have been useful to test soapwort and potash, and to test linens washed with soapwort or with potash, for comparative purposes. These are the other laundry aids that might have been used for washing clothing in ancient Egypt and in some areas of the ancient Middle East (Barber, 1991, p. 238). However, the inability to obtain samples of Egyptian soapwort leaves and potash, and to import them into Australia for testing (due to Australian quarantine regulations), made this avenue of research difficult. As it was not of direct relevance to the examination of the hypothesis, it was not pursued.

As outlined above, linen fabric samples used for this pilot study consisted of control samples of modern linen, samples of modern linen washed with natron to simulate ancient washing methods, samples of modern linen treated with a magnesium bicarbonate deacidification solution, and samples of ancient Egyptian linen recovered from archaeological sites and currently held in either museum collections or private collections within Australia.

3.4.2.1 Control Samples of Modern Linen

Undyed linen was purchased from Spotlight, Penrith, New South Wales, Australia. It was of a comparable weight and weave to the common or middle grade of ancient Egyptian linen (as described by Vogelsang-Eastwood, 2000). Origin was marked as China. The linen was washed by hand in pure
deionized water. It was then pH tested and found to be pH 5 using a Merck test strip \(\text{colordPH} \text{test strip pH 0-14)}.

The washed linen cloth was then cut into test strips approximately 10 cm x 20 cm. Three test strips were then stored in neutral pH acid free paper folders. These were considered to be control samples of new linen (for photographs and a further description of these samples see Appendix A: 2. Control Samples of Modern Linen).

Six of these test strips were next washed in deionised water, using natron as a cleaning aid, and left un-rinsed. As the amount of natron the ancient Egyptians would have used in washing linen was unknown, modern practice was taken as a guide. Therefore 20mL of un-diluted crystallized natron\(^3\) was rubbed upon the cloth, which was then washed using to 1 L deionized water. The pH of the un-rinsed test strips was measured while still wet and found to be 10 (for photographs and a further description of these samples see Appendix A: 3. New Linen; Washed first in Deionized Water, Dried, Then Washed in Natron). Three of the test strips that had been washed using natron as a cleaning agent were then rinsed in three 1 L changes of pure deionized water. The pH of the rinsed test strips was measured while the sections were

\[^3\] The natron was in its natural state, as collected. It had not been refined or diluted. It was semi-moist, and therefore was measured as a liquid instead of weighed as a dry solid.
still wet and found to be 5 (for photographs and a further description of these samples see Appendix A: 3. New Linen; Washed in Natron and then Rinsed with Deionized Water). These six test strips were then air-dried on glass sheets for 24 hours, before being stored in neutral pH acid free paper folders.

Other test strips of the new linen were treated with magnesium bicarbonate deacidification solution. The magnesium bicarbonate deacidification solution was prepared as per the formula used by the National Library of Australia, Canberra in the 20th century, a one step method based upon the two step method pioneered by Barrow (Morrison 1979, p. 27). A saturated solution of magnesium bicarbonate was created using magnesium bicarbonate and CO$_2$. Three linen test strips were soaked in the deacidification solution for an hour. The pH of the samples was tested while they were still wet and found to be 9 (for photographs and a further description of these samples see Appendix A: 5. Deacidified Linen). The test strips were then air-dried on a glass plate for 24 hours before being stored in neutral pH acid free paper folders.

3.4.2.2 Reference Sample

As a reference sample, a sample of an archaeologically recovered bast rope from a shipwreck was used. This was a bast fibre that was not flax. It was recovered from an ocean environment, so it came from a salt rich environment.
different from the Egyptian textiles.\textsuperscript{4} This sample was obtained from a donor who wished to remain anonymous. (Appendix A: 6. Sample of Rope from the Mary Rose.)

3.4.2.3 *Samples of Natron from the Wadi Natrun Taken for Analysis*

Natron was collected from the water line at a lake in the Natrun Valley. The Natrun Valley contains ten salt lakes, which dry up almost completely during the summer months, leaving deposits of sodium carbonates (natron). The sample was collected from one of the lakes in mid-winter (January 1999). At that time there was a shallow expanse of water, with a sandy beach area of approximately 20 feet surrounding the water covered with a thick crust of natron (see Figs 3.1-3.4, which provide further information on the location and appearance of Wadi Natrun and record the process of sampling, and see also Appendix A: Samples1.Natron).

3.4.2.4 *Samples of ancient Egyptian linen*

Samples of ancient Egyptian textiles were obtained from the collections of the Nicholson Museum of Antiquities, Sydney University, from the Museum of Ancient Cultures, Macquarie University, and from private collections.

Samples of mummy bandages had previously been examined at the Museum

\textsuperscript{4} For a discussion of the nature of seawater, the process of evaporation of seawater, and the chemical composition of ocean sediments see Florian, 1987b, pp. 1-20.
of Victoria as part of the conservation of the mummy of Tby (Tjeby) for exhibition with the British Museum Exhibition, 'Civilisation' (Marsh, 1990a, 1990b). In most cases, samples were restricted to single, loose or recently detached threads, though in some cases larger samples were available for analysis when they were pieces which had become detached from the whole and could not be rejoined.

The samples from the Nicholson Museum consisted of small pieces from a Book of the Dead, threads from a cartonnage mummy cover, and threads from two collections of Late Roman or Byzantine period textiles excavated at Tell-el-Amarna. The Late Roman or Byzantine period textiles held by the Nicholson Museum had been examined and samples taken immediately prior to and immediately after washing with water by the then Nicholson Conservator, Mrs. Patricia Cannon Johnson.

The samples from the Museum of Ancient Cultures consisted of single, already detached threads from a collection of Late Roman or Byzantine period textiles (unprovenanced), pieces of mummy wrappings from known graves at Saqqara, and threads which had fallen off a large textile bundle, possibly clothing, from a known tomb at Saqqara. The Museum of Ancient Culture textiles were all examined in an unwashed, untreated state.
Samples of fabric from Helwan in the Cairo Museum and in the Egyptian Agricultural Museum were observed. Official permission was not received from the Egyptian Agricultural Museum for samples to be taken from their collection for analysis.

Other samples were obtained from private collections whose donors wish to remain anonymous.

3.5 Fibre Identification
A first step in textile analysis is to identify the textile fibre. This is essential both for curatorial reasons, to be able to describe the fabric accurately, and for the conservation of the fabric, so that storage, display and treatment procedures can be correctly formulated. The chemical and physical nature of both natural and man made fibres differ to such an extent that they need different storage conditions and different conservation treatment. An accurate description of the textile fabric is also necessary for textile analysis.

3.5.1 Relevant Previous Studies on the Nature of Linen
Florian (1987a, p. 30) has compiled evidence to show that flax is largely made up of cellulose (56.5% - 64.1%), and also to show that among its other constituents it has significant but variable amounts of lignin (2.0-2.5%), hemicellulose (15.4%-16.7 %), and pectin (1.8%-3.8%). Tímár-Balázsy and
Eastop (1998, p.31) give almost the same percentages of cellulose (64.1%), hemicellulose (16.7%), pectin (1.8%), and lignin (2.0%) for retted flax.

The high range of variability in the consistency of flax can be contrasted with cotton, which Forbes (1964, p.82) gives as between 94% and 96% cellulose and Tímár-Balázsy and Eastop (1998, pp. 31, 33) give as 82.7% before processing and up to 99% after scouring and bleaching. Tímár-Balázsy and Eastop show cotton as completely lacking lignin, hemicellulose and pectin (1998, pp 31).

The wider variability in the cellulose content of flax is most probably a result of several factors; the nature of the plant itself, variability in environmental growing conditions, and variability in the harvesting processes, linen being harvested at varying times to achieve different cropping objectives (see also Section 1.5).

3.5.1 Cellulose

Feller & Wilt (1990, p. 9) provided a summary of the properties of cellulose relevant to conservation science.

Cellulose is the primary constituent of wood, paper, and cotton. It is a carbohydrate made up of glucose units. These have an empirical formula, $C_6H_{12}O_6$. 
and can be given a cyclic structure, sometimes designated as a beta-D-
glucopyranose or anhydroglucose unit (AGU).

In the proceeding diagram the repeated unit is in parenthesis.
The AGU units are linked through a condensation reaction, in which a
molecule of water is lost in forming each link (Feller & Wilt, 1990, p.9).

Native cellulose is known as cellulose I. Properties of cellulose I include high
tensile strength and resistance to hydrolysis (Eveleigh, 1987, p. 435). These
properties are attributable to its structure, which consists of crystalline
regions of cellulose molecules alternating with regions of amorphous
cellulose. Water is able to enter through the regions of amorphous cellulose,
as do dyestuffs. Linen has a higher proportion of crystalline areas than does
cotton, for example, making cotton easier to dye than linen (Cook

Cook (1982, reprinted 1993) reported that the cellulose molecule can be
hydrolysed under acid condition, which produces hydro-celluloses, and by
oxidation, which gives rise to oxycelluloses, an acidic type (a) and a reducing type (b).


Strong alkalis can alter the chemical structure of cellulose I, and produce, upon drying a different crystalline state called cellulose II (Florian, 1987a). With this change of structure from cellulose I to cellulose II the ability of the linen fibre to absorb moisture is greatly reduced, if not stopped. Absorbed moisture allows a fibre to retain its flexibility, so the inability of a fibre to absorb moisture results in rigidity and brittleness (Florian, 1987a, pp. 25-30).

3.5.1.2 Lignin

Lignin is the commonly used term for a number of complex aromatic polymers (see below for a simplified classification of groups of lignins). Lignin is found in the cell walls of all woody plants, where it “combines with hemicellulose material to help bind the cells together and direct water flow” (Dimmel, 1997, p. 78). The monomers that make up lignin structures appear
to vary with the plant species, and the polymers exhibit random cross-linking, making structural studies difficult (Dimmel, 1997). Lignins are generally classified into three major groups based on their structural monomer unit: Gymnosperm lignin, Angiosperm lignin and grass lignin (Higuchi, 1980, p. 2). The presence of lignin in plant fibres, including flax fibres, can be observed through a simple colour reaction, the phloroglucinol - HCl reaction.

A major concern for paper and textile conservators has been the presence or absence of lignin in paper or fabrics, due to the tendency of lignin to increasing yellowing, increasing brittleness, and finally disintegration of paper.

It is believed that these effects are caused by photo-oxidation. A great deal of research has been undertaken, principally by the paper industry, on this question (Morrison, 1979).

In almost fifty years’ research has shown that light-induced yellowing of mechanical and ultra-high yield pulps occurs by photo oxidation of lignin in the fibre wall. ...There is general agreement that the phenoxy1 free radical reacts with oxygen and/or with functional groups in the fibre wall to form quinones, the coloured chromophores. Although there has been much progress both in elucidating the reaction pathways leading to yellowing of bleached mechanical and ultra-high yield pulps, and in identifying the coloured chromophores, more needs to be known about the key oxidation step of phenoxy1 free radicals to quinones (Heitner, 1993, p. 22).
Another concern for the materials scientist is the ability of lignin to break down to compounds with a strong affinity for sulfur dioxide, thus causing paper or textiles containing lignin to take up sulphur dioxide in polluted atmospheres (Thomson, 1986, pp. 143-144). However, much of the lignin present in flax fibre is removed in the manufacturing process, chiefly when the outer layer of the stem is removed manually. Also any remaining lignin may be removed if the finished thread or fabric is bleached. When paper was made by hand from linen and cotton rags there was consequently little or no lignin in the product. Therefore such “rag” papers are called long life or permanent papers, in contrast to newsprint and other modern papers made of wood pulp, where the lignin content of the wood pulp has not been removed prior to paper manufacturing.

3.5.1.3 Hemi-cellulose

Hemi-celluloses are located in all layers of the cell wall, mixed with lignin and/or cellulose. Florian wrote that, “hemicellulose association with cellulose is not completely clear...” However, she inferred that hemi-cellulose, when bonded with cellulose, is more flexible and stronger than cellulose-cellulose bonding (Florian, 1987a, p. 28).
3.5.1.4 Pectin

Pectic substances are linear polymers of polygalacturonic acids. They are located in the outer and middle layers of the plant stem. As they are readily hydrolysed by acids and enzymes, and are attractive to bacteria and fungi, their presence aids the retting process (see also 2.4 Linen production). Thus they can be largely removed from the stem during the manufacturing process.

3.5.1.5 Evidence for Salts in the Flax Plant Prior to Processing

A search of botanical and agricultural references revealed little recent research on the question of salt tolerance in commercially grown flax. Work done at the Department of Soil Science, North Dakota State University, showed that flax was a moderately natrophillic plant, and so would take up sodium during its growth cycle. The uptake of sodium was greatly influenced by the presence or absence of potassium in the soils. Flax plants would take up sodium if the soil was deficient in potassium, but intake of sodium would be greatly reduced if potassium was available. Flax plants took up potassium and sodium differentially; potassium accumulating preferentially in young leaves and sodium accumulating preferentially in old leaf and stem tissues. The study also found that “Commercial flax seed is likely to vary considerably in Na concentration due to edaphic factors, particularly Na and K availability, and genetic factors” (Moraghan & Hammond, 1996, p. 832).
While some idea could be gained of the "normal" levels of salts in flax plants grown commercially today, it might not be comparable to the levels present in flax in ancient Egypt. First, there may be genetic differences between modern cultivars and ancient cultivars. Secondly, even if ancient seed from burial sites could be used, the quality of the Nile Valley soil has been changed through the use of modern chemicals and fertilisers. Thirdly, the soil composition has probably changed because the annual inundation of the Nile (which cleaned the soil of a build-up of ground water salts) no longer takes place.

3.5.2 Fibre Identification

As samples were collected for scientific analysis each textile was examined and described. This was undertaken in order to gain an accurate description of the fabric, and to determine what fibres were representative.

3.5.2.1 Methodology Used for Fibre Identification

A methodology was chosen after consulting two recognised curatorial textile handbooks: *The Primary structures of fabrics; An illustrated classification* (Emery, 1994, 3rd ed), and *A Brief guide to the cataloguing of archaeological textiles* (Walton and Eastwood, 1988). Emery's work has been the standard for textile classification in America for many years (King, ed. 1978, p. 90).
Walton and Eastwood's system was developed specifically for the classification of archaeological textiles, meeting a need for standardization in the specialised field of archaeological textile studies noted earlier by King (1978). Walton and Vogelsang-Eastwood's (nee Eastwood) descriptive system has been followed by many British textile specialists, including Janssen (Hall, 1986), although Janssen has added to it a system of grading derived from the ancient Egyptian system of naming different grades of textiles, based upon the "fineness" [diameter] of the thread and quality of the weaving (Janssen, personal communication 12 April 1999).

There are various national standards for the examination of textiles. These, however, were largely developed for use by the textile industry with new fibres and fabrics. An examination of relevant Australian standards for textile testing showed that they would be inappropriate for use with archaeological textiles as they presumed the existence of a large and uniform sample and subjected the sample to potentially destructive tests. However, for small, irreplaceable and fragile samples the Australian Standards textile tests are inappropriate. For example, Australian Standard AS2001.2.5-1991 Method 2.5: Physical tests-Determination of the number of threads per unit length in woven fabrics involves cutting test pieces of equal size and pressing them
down on a thread counting gauge with metal pins (Standards Australia Committee on Testing of Textiles, 1991).

The system of classification of Walton and Eastwood (1988) takes the nature of archaeological textiles into consideration and therefore limits the analyst to non-destructive examination of the fabric. A further benefit of using this system is that, being widely adopted, it enables comparison between reports.

While taking note of the work of Emery (1994, 3rd ed.), it was the system of Walton and Eastwood that was chosen as the model for this study. The principal reason for this choice was because Emery’s methodology has been developed for curatorial work in museums, in order to describe historic fabrics, while Walton and Eastwood’s simpler system has been developed to describe archaeologically recovered textiles. Specific criteria used for textile analysis in this study are to be found in Appendix A

3.5.2.2 Equipment Used for Textile Analysis: Hand Held Lenses and Optical Microscope

Both examination and description of textiles can be achieved with a minimum of equipment, using just a measuring device marked in centimetres and a low
power-magnifying lens. Thread counts of textiles can be done using a ruler and a hand lens or with a small portable device called a linen tester (a magnifying lens plus a graded scale). A stereomicroscope is very useful in the non-destructive examination of textiles in the laboratory, as it can be used both for thread counting and overall examination of the condition of the textile.

The samples were examined by use of hand lenses and a linen tester; thread count and diameter were measured using devices marked in centimetres (not inches). At the Nicholson Museum a Leitz-Wild binocular microscope was available and samples were examined in both natural and reflected light at low magnification (5x or 10x).

After samples were collected, individual fibres were mounted on glass slides and then both examined and photographed. Samples were examined at the University of Western Sydney, Hawkesbury (using an Olympus BX 60 transmitting light microscope) and the University of Western Sydney, Nepean (using an Olympus binocular microscope, a Nikon transmitted light microscope, and a James Swift polarising light microscope).
While all samples were examined using a transmitted light microscope, only a few textile samples were examined and photographed using the polarising light microscope. Under polarising light some of the surface structure of the flax fibre could be clearly differentiated due to differences in the thickness of the fibres, but no other information of significance for this study was obtained. This was in contrast with the reported use of polarising light microscopy for the analysis of woollen fibres, where it was useful in the examination of scale pattern, pigmentation and dyes (Thurman and Williams, 1979, p. 49).

Photographs of samples were taken on Kodak colour slide film, ASA 100 and ASA 64 by the author using a Pentax Spotmatic SP II and a Pentax SF7. Dr. J. Barron, a Geologist in private practice in Sydney, and the author took photomicrographs on Kodak 35 mm colour slide film, ASA 100 and ASA 64, on Dr. J. Barron’s own equipment. I also took photomicrographs of linen samples using an Olympus BX 60 transmitting light microscope, at the University of Western Sydney, Hawkesbury campus.

3.6 Examination of Samples by SEM

The scanning electron microscope (SEM) is used for a variety of applications in research and industry. The SEM scans the sample with a finely focused
beam of electrons. The bombardment of the sample by electrons emits radiation that then forms an image that can be viewed on a screen by the operator and photographed (Greaves & Saville 1995, p.51). SEM is also used in conjunction with energy dispersive analysis that utilises the radiation generated by the electron beam of the SEM to identify the chemical constituents of the sample.

When using SEM for the examination of threads and fibres the image that is obtained is not of the actual surface of the fabric, but of the conductive coating, which must be used in order to generate an image. Organic materials, such as natural fibres, are “non-conductive” and must be coated with colloidal silver, graphite, or a gold layer before they can be examined. Specimens that are to be examined by EDXA need to be carbon coated. This does not interfere with the X-rays as much as a metal coating would, but does not yield as clear an image for photography as does a gold coating (Greaves & Saville, 1995, p. 63). The sample that is to be examined must be able to fit on a metal stub, which is inserted into a holder within a pressure chamber. Therefore the procedure involves the sacrifice of a small section of fabric or thread, approximately 0.5 cm being a good sample size.
The image generated on a SEM is limited to the surface structure of the sample. Though it has been possible to examine cross sections of fibres on the SEM (Ryder & Gabra-Sanders, 1987, pp. 102-105), what is visible is the outer surface of the cross section. This is in contrast with the effect obtained with a transmitted light microscope or a transmitted electron microscope (TEM), which allows the interior of biological materials to be viewed.

3.6.1 Relevant Previous Studies

Previous analytical work on archaeological textiles was consulted while searching for a method which would show the presence of salts both on and within the linen fibres, and which would also chemically identify these materials. Studies by Needles and Zeronian (1986), Cooke (1990), Ryder and Gabra-Sanders (1987), Stoll and Fengel (1981a, 1981b, 1985, 1988) reported the use of SEM with EDXA. Since SEM became commercially available in the 1960s it has proved useful in studying fibre damage from causes such as mechanical stress or degradation due to light, heat, insects, fungi or chemical reagents (Cooke, 1990, pp.3-14).

Cooke (1990) used SEM to demonstrate different types of fibre damage, and to draw inferences about past use of the fabrics. Ryder and Gabra-Sanders (1987) experimented with the use of SEM to identify fibres, and found SEM
especially useful in the analysis of mineralised fibres. Indeed, Hardman (1994, p. 37) noted, “Until recently, SEM was the principal analytical tool for the study of mineralised materials...[However] EDXA has been increasingly applied [for this purpose].”

Stoll and Fengel (1988) used SEM and a Leitz Microscope with an X-ray spectrometer to obtain EDX analysis of the inorganic materials in Ancient Egyptian linen. Their study is the only previous study to concentrate on an analysis of Ancient Egyptian linen using these methods. Edwards, Ellis, Farwell and Janaway (1996) conducted a study of degraded archaeological linen using Fourier transform Raman spectroscopy. Stoll and Fengel, and also Edwards, Ellis, Farwell and Janaway were primarily interested in measurement of the degree of polymerisation (DP) of the cellulose polymers of the linen fibres in order to investigate possible relations between measurable DP and age.

Two other studies of Ancient Egyptian materials using electron analysis were also relevant, though they were not performed using SEM and EDXA. An analysis of paint samples from the inner surfaces of a Middle Kingdom sarcophagus in the collection of the Museum of Fine Arts (Boston) using an electron beam microanalyser, identified the base of the samples of the paint

3.6.2 SEM Analysis of Linen

Samples were examined at the University of Western Sydney on a JEOL JSM-T330 SEM at various times during 1997 and 1999. However, SEM involved considerable sample preparation, and recording of information was limited to still photography. Various operating problems connected with that particular instrument, the difficulty of sample preparation, and the availability of an Environmental Scanning Electron Microscope (ESEM) at the University of Technology Sydney meant that only a few linen samples were tested using SEM before I switched to using ESEM. None of the SEM results are included in this study as they were superseded by the data from the ESEM. Environmental Scanning Electron Microscopy, described below, was a technique that proved more useful for this study as it was capable of a greater range of analysis, being able to be used both for static analysis and as a dynamic imaging system (Doehne 1997, p. 57).
3.7 Examination by Environmental Scanning Electron Microscopy (ESEM) and Energy Dispersive X-Ray Analysis (EDXA)

3.7.1 Relevant Previous Studies

The ESEM is a relatively new instrument, and the instrumentation is currently undergoing rapid development. ESEM has considerable potential for textile forensic work, including forensic archaeology, as the samples are examined uncoated, with no sample preparation necessary. It also has considerable potential for investigation of the processes of corrosion and biodeterioration (Doehne, 1997), as the processes can be observed under the microscope and also recorded in real time using computer and video equipment. Some of the first applications of ESEM were for the examination of plant and insect material, especially for rare and valuable specimens that were pinned or fixed to cards and which could not be coated (Moore, 1992, pp.31-32).)

A search of the materials conservation literature for evidence of the use of the ESEM for the analysis of organic objects showed that ESEM has been used in one study of wool (Danilatos & Brooks, 1985, pp. 263-272), and also in a study by Wallert (1996, pp. 198-202) of the Dead Sea Scrolls: both the scrolls made of parchment and those made of papyrus. Doehne (1994), Rodriguez-Navarro and Doehne (1999), and Rodriguez-Navarro, Doehne and
Sebastian (1999) extensively employed the technique for their studies of the mechanisms of salt crystallisation within stone.

Doene (1997, pp.55-57) gives a very useful breakdown of the operational differences between the ESEM and SEM. He points out the higher number of variables that need to be considered when using ESEM. Of particular relevance to this study was the ability, using ESEM, to raise the water pressure in order to eliminate visible surface charging, by creating a “thicker, more conductive ionised water coating” (Doene, 1997, p.56).

3.7.2 Examination of Samples

The instrument used for ESEM analysis was a Phillips XL 30 equipped with an EDXA light element EDX detector and a DX4 X-ray analyser. A Peltier cold stage was used for the hydration and dehydration experiments. The computer software used was eDX-ZAF. A video recorder was also attached to the system. This integrated system was used at the Microanalysis Unit of the Department of Science, The University of Technology Sydney (Australia). Analysis was undertaken with the assistance of Miss Katie McBean, under the supervision of Dr. Matthew Phillips.
The ESEM operates at a pressure of 1-20 torr, or near normal atmosphere, in the sample chamber, as compared with a conventional SEM that must operate at considerably higher vacuum. For this study distilled water vapour was used in the chamber, but other low atmosphere gases may be used. These low atmosphere gases prevent charge build-up, the bane of a fibre analyst’s life, when using a conventional SEM. When using a Peltier cold stage and varying the pressure in accordance with the Chart reproduced below, we were able to create high and low humidity conditions at will.

![Relative Humidity Isobars Chart](chart.png)

Table 3.1. Isobar Chart Showing the Relationship Between Vapour Pressure (torr)/Temperature (°C) and Relative Humidity (RH). Source: Wallert (1996, p. 200).

An initial evaluation of the usefulness of the ESEM for this project was done on August 4, 2000 at the Microanalysis Unit, University of Technology
Sydney. Samples examined were: a 1 cm sample of new, untreated, linen yarn (pH 5.0), a 1 cm sample of the same linen which had been soaked in natron from Wadi Natrun, Egypt, un-rinsed (pH 10.0) and a 1 cm sample of yarn from sample MS2 (see Figures 3.5 – 3.13). All samples were examined under low pressure, using water vapour, and then under varying pressures, which caused cycles of wetting and drying to occur in the chamber. Considerable time was expended in working out optimal conditions for examining the fibres. The procedure that appeared to be most effective was to saturate the sample with liquid water by lowering the specimen temperature to 4° C and increasing the water vapour pressure to 8 torr, then desiccated by reducing the chamber pressure to 2 torr. Results were recorded by recording computer images photographically.

A second session working on the XL30 ESEM using the Peltier stage took place at the University of Technology, Sydney, (UTS) on September 8, 2000. Again, control samples of new linen washed with natron were tested, using the procedure that had been found to be the most effective (described above). Samples of new linen washed with natron and then rinsed were also tested, as were samples of MS1 and MS2. Computer images from this session were recorded using videotape, and can be found in Appendix B.
Further work at UTS continued on October 25, 2000 when the ESEM was used with EDXA to examine both control samples and samples of ancient Egyptian linen. Unfortunately, the videotape recording of this session was found upon completion to have been faulty due to equipment failure, and some valuable dynamic imaging was lost. Included in this material were additional images of salt crystals forming within fibre breaks and on the fibres.

Samples from the 16 hour washing test were examined at UTS on November 6th, November 17th and November 29th, 2000 (see 3.9 Examination of Samples from 16-Hour Washing Test Using Ion Chromatography, ESEM and EDXA). Computer images of this work were recorded onto computer disc.
Figure 3.5 ESEM Image of New Linen Washed in Natron. This image was taken before any hydration or dehydration treatment. Computer image taken by Dr. Matthew Phillips and the author at the University of Technology, Sydney.

Figure 3.6 ESEM Image of New Linen Washed in Natron. This image was taken during the first cycle of hydration. Computer image taken by Dr. Matthew Phillips and the author at the University of Technology, Sydney.
Figure 3.7 ESEM Image of New Linen Washed in Natron. This image was taken during the first cycle of dehydration. Computer image taken by Dr. Matthew Phillips and the author at the University of Technology, Sydney.

Figure 3.8 ESEM Image of New Linen Washed in Natron. This image was taken during the second cycle of hydration. Computer image taken by Dr. Matthew Phillips and the author at the University of Technology, Sydney.
Figure 3.9 ESEM Image of New Linen Washed in Natron. This image was taken during the second cycle of dehydration. Computer image taken by Dr. Matthew Phillips and the author at the University of Technology, Sydney.

Figure 3.10 ESEM Image of MS2. This image was taken before any treatment. Computer image taken by Dr. Matthew Phillips and the author at the University of Technology, Sydney.

During ESEM dynamic study there was notable particulate matter visible during scanning of the sample. During hydration this matter was seen to dissolve. This was accompanied by swelling of fibres. During dehydration the fibres were observed to break as crystal formations appeared to grow from the inside of the fibre, as well as on the surface of the fibres (see Figs. 3.11-3.13).
Figure 3.11 ESEM Image of MS2. This image shows the swelling of a fibre during one hydration cycle. Computer image taken by Dr. Matthew Phillips and the author at the University of Technology, Sydney.

Figure 3.12 ESEM Image of MS2. This image shows the same fibre as Figure 3.11 during dehydration, with the resulting formation of crystals. Computer image taken by Dr. Matthew Phillips and the author at the University of Technology, Sydney.
Figure 3.13 ESEM Image of MS2. This image shows the same fibre as Figure 3.11 during dehydration, taken soon after Figure 3.12. The area where crystals were pushing up from the surface of fibre has now cracked. Computer image taken by Dr. Matthew Phillips and the author at the University of Technology, Sydney.

On November 29th samples of new linen and ancient Egyptian linen treated with magnesium bicarbonate deacidification solution were tested using the ESEM, both with and without the Peltier stage. Results were recorded on computer disc.

EDXA measurements were made while the linen samples were visible on the ESEM computer screen. This allowed us to coordinate our EDXA sampling with a computer image of the exact area of a fibre sampled. Measurements were made using 30 KV accelerating voltage and a variable spot beam. Before deciding on a standard atmosphere for taking readings several
different atmospheres were investigated. As the various atmospheres produced no discernible change in EDXA measurements it was determined to proceed using 0.3 torr atmosphere for EDXA and 1 torr for imaging.

Linen samples from all time periods and all geographical areas were examined using ESEM, and EDXA measurements were made. The results of all ESEM and EDXA analyses are reported in full and selected images are reproduced in Appendices A and B.

3.8 Examination by Ion Chromatography (IC)

Chromatography is a family of chemical techniques that are used to separate mixtures of compounds, elements or ions. Liquid chromatography is a form of chromatography that uses a liquid to carry the mixtures past a stationary phase. Ion chromatography (IC) is a form of liquid chromatography that uses ion-exchange resins to separate ions. The technique can be used for separation and detection of anions and cations, as well as biochemical species, such as amino acids and proteins. Walton (1983) writes that ion chromatography has been successfully used to separate alkali-metal cations, an important factor in separating NaCl from other salts in the samples used in this study. The technique is especially useful for distinguishing anions, whereas metallic cations can be analysed in other ways, such as plasma

3.8.1 Relevant Previous Studies
IC has not been widely used for analytical work in archaeological science. The technique, however, has been widely used in environmental science, especially for testing of drinking water quality (Sultan et al., 1996), monitoring of pollution in all sources of water, and the testing of soils and other geological materials (Haddad & Jackson, 1990, pp. 487-716). Some of the few references that were found to its use in the examination and conservation of archaeological objects also involved the monitoring of water quality and the testing of geological materials. For example, Pessoa, Antunes, Figueiredo, and Fortes (1996), Willey (1995) and Kadokura (1985) used ion chromatography to monitor the extraction of salts during the desalination of porous building materials and pottery.

Though commonly used in a wide range of industrial applications involving organic materials, the use of ion chromatography with organic materials has rarely been reported in archaeological science and materials conservation literature. However, Wouters and Verheeken (1989) successfully used it in ancient textile dye studies involving dyes made from five different scale
insects, and the technique is occasionally reported as being useful in the analysis of other ancient dyestuffs.

3.8.2 Ion Chromatography Used to Monitor Salt Extraction

The successful use of IC reported in the conservation literature (cited above), both to identify salts extracted in the desalination process and to monitor their levels during extraction from ceramics and porous building materials, led to the realisation that it might be useful in the monitoring of salt extraction from textiles during a washing process.

It was postulated that if IC could be successfully used to both identify and measure the levels of salts present in “wash water” from ancient textiles, it could thus be determined what salts would be removed by various textile conservation treatments. It would also be possible to chart the relative amount of each salt released from the textile fibres at different times during the conservation treatments. Any particulate materials that had not been removed by conservation treatments from the fibres could be observed by transmitted light microscopy, scanning electron microscopy or environmental scanning electron microscopy, and also identified using environmental scanning electron microscopy coupled with energy dispersive x-ray analysis.
3.8.3 Instrumentation and Methodology

Ion chromatography uses ion-exchange resins to separate atomic or molecular ions and detect these individually at a detector, usually a conductivity detector. In this study IC analysis was carried out using a DIONEX DX 120 with DIONEX Automatic Sampler AS40. For anions the eluent used was 3.5 m M Na₂CO₃/ 1.0 m M NaHCO₃; the flow rate was 1.2 mL/min; and the detection mode was suppressed conductivity at 10 μL (using a 10 μL cell). The storage solution was the eluent. For cations the eluent used was 20 mM methanesulfonic acid. The flow rate was 1.0 mL/min. Auto-suppressed conductivity was used for detection. Calibration was done using commercially prepared reference standards. Concentrations of unknowns were estimated by using computer software that calculated concentration from the area of the peak for an ion.

Because the eluent used when testing for anions was 3.5 m M Na₂CO₃/ 1.0 m M NaHCO₃, the percentage of carbonate and bicarbonate in samples could not be determined. A higher than neutral pH of the solution indicated the presence of the carbonate and bicarbonate in some samples. Magnesium and calcium were also shown in both IC and EDXA elemental analysis. In retrospect it is clear that it would have been advisable to have used both the
above method and another set of IC columns, capable of measuring carbonate and bicarbonate.

It was determined to extract the salts using a constant ratio of water to fabric. As the pH of wash/extraction solution is important in the washing of textiles, due to the chemical and physical effects of varying pH on natural fibres, it was determined to monitor the pH of the wash/extraction water. Therefore it was determined to use the Australian Standard AS 1301.421s-91 Determination of the pH Value of Aqueous Extracts of Paper, Board, and Pulp - Cold Extraction Method, (APPITA Testing Committee, 1991) with some modification. Modification was called for, as the standard requires the sample be cut into small pieces and masticated in the water. As the fabrics were needed for further examination after washing, to determine any changes in thread diameter, colour or texture, it was decided that fabrics would not be cut and masticated during the test process.

There was some uncertainty about the concentration of solution for dilution of the natron sample. At first the natron was dissolved in the proportion of 2.6 g in 60 mL of deionized water. This proved too concentrated a solution. Therefore a 1/100 dilution was made and a meaningful reading was obtained.
All water used was highly purified deionised water normally used for ion chromatography. Polyethylene sample bottles had been cleaned by acid washing using a solution of 50% deionized water, 25% nitric acid and 25% hydrochloric acid, soaked overnight, and then rinsed using six changes deionized water. Finally, each bottle was rinsed using a portion of the test solution, before being filled with the test solution.

Test solutions were prepared using the modified version of *Australian Standard AS 1301.421s-91* detailed above. All sample solutions were vacuum filtered before IC analysis. This was particularly necessary as some solutions contained visible particulate matter.

3.8.4 Initial Examination of Samples by Ion Chromatography

A selection of textile samples was examined to test the usefulness of IC, both for identification and measurement of any salts removed during soaking of textiles in deionised water. These were samples of 1) new linen, 2) new wool, 3) a bast fibre rope recovered from an underwater excavation, 4) natron collected at Wadi Natrun in Egypt and 5) three samples of ancient Egyptian linen. These samples were prepared according to *Australian Standard AS 1301.421s-91 Determination of the pH Value of Aqueous Extracts of Paper, Board, and Pulp - Cold Extraction Method*; the fabric samples were weighed
and then soaked in deionized water in a ration of 20g of textile to 100 mL deionized water. After one hour the textile was removed, and the water was tested using ion chromatography. All textile samples were examined using optical microscopy before and after soaking in water and air-drying. The results of the initial testing are reported in full in Appendix A: Samples.

3.9 Examination of Samples from 16-Hour Washing Test Using Ion Chromatography, ESEM and EDXA

3.9.1 Development of Methodology

I had previously developed some of the methodology for this controlled conservation treatment during my treatment of the mummy of Tjby at the Museum of Victoria in 1990, preparatory to its display with the exhibition on loan from the British Museum, Civilisation. (See also Appendix A 36. Tjby.) The experience gained during the treatment of the mummy of Tjby was of direct relevance to the formation of the 16-hour washing test, even though extraction samples from the mummy of Tjby were not tested using IC.

Bandages which had previously fallen off the mummy Tjby during his exhibition at the museum, and which were retrieved from the floor of the coffin, were examined at the Museum of Victoria. An examination of these
pieces was used to gain knowledge of the nature of the fabric bandages of the mummy as a whole, and to evaluate possible treatments.

Several bandages were selected and grouped into (a) coarse weaves (b) fine weaves, and (c) stiff fabrics, coated with carbonate based material. All were very dirty and brittle.

It was decided to wash the fabrics using only deionised water (pH 6.5 to 7.0) in order to keep chemical additives to the fabric to a minimum. The brittle nature of the fabrics meant they had to be supported at all times. Therefore, they were placed between two layers of nylon net, and the net was loosely sewn around its edges. Then the fabrics were placed upon a plastic-coated metal screen before being placed into a shallow enamel tray for washing.

The pH of the wash water was tested and found to be 6.5. After washing textiles from groups (a) and (b) the wash water tested at pH 7.0. After washing textiles from group (c), those with a gesso/carbonate based coating, the water tested pH 7.5. Samples of the wash water were kept for testing by IC, but suitable arrangements could not be made at that time for IC analysis, and so they were not tested.
During the washing process the water turned a dark yellow. However, the textiles themselves, upon drying, appeared to not have changed colour, or to have lightened to only a small degree. The bandages were washed in five changes of water before the final bath was clear of yellow and any indication of dirt.

The bandages were then removed from the bath, taken from the nylon netting, and placed on glass. As they slowly air-dried the fibres were manually realigned. Upon drying the fabrics were still very brittle. Those with a carbonate coating were found to have no flexibility at all, and no further treatment of these pieces was carried out.

Firstly, the washed pieces were coated with a 2.5%v/v solution of methylcellulose in deionised water and air-dried. Upon drying, sufficient tensile strength had been imparted to the fibres to allow the pieces to be handled. At the time they appeared stable. However, after several weeks they were handled again, and they powdered when slightly abraded or moved.

All the linen bandages that were sized and backed as part of the testing program were clearly identified on their packaging materials, and kept for future reference (Marsh, 1990b).
Following a review of the conservation literature (see both Chapter 1 and literature cited above), a review of previous results obtained by the washing of bandages from the mummy of Tjby as outlined above, and also following consideration of the evidence obtained through the simulated cycles of hydration and dehydration of ancient Egyptian linen during examination using ESEM, it was determined to investigate further the effects of wet cleaning upon ancient Egyptian textiles.

3.9.2 Methodology for the 16 Hour Washing Test

This was a controlled washing test. Linen samples were soaked changes of freshly filtered ultra pure deionised water, at room temperature. The ratio of fabric to deionized water was kept at that recommended in Australian Standard AS 1301.421s – 91 (Determination of the pH value of aqueous extracts of paper, board and pulp-cold extraction method), of 2.0 g of dry material to 100mL of deionized water. As the test samples varied in weight the volume of water was adjusted accordingly. The water was drained off and replaced with fresh changes of deionized water at intervals of 1, 2, 4, and 16 hours. Samples of water from each wash were collected for analysis using IC, and upon collection this water was pH tested using Merck test strips. Then IC was used to identify and quantify the levels of salts present in the wash water from the ancient textiles. Each time samples of water from each
wash were collected, two sub-sections approximately 1 cm square of each textile sample were removed, one to be slow air-dried and the other freeze-dried. After drying, all textile samples were stored in acid free neutral pH paper folders. Any particulate materials that had not been removed by conservation treatments from the fibres in the slow air-dried samples were subsequently examined by transmitted light microscopy, and environmental scanning electron microscopy, and also identified by environmental scanning electron microscopy coupled with energy dispersive X-ray analysis. Therefore at the end of the trials samples were available which could show when certain salts had been released into the wash water, and exactly what salts remained in the fabrics at each stage of the washing trials.

The pH of solutions was kept in the safe zone for linen fibres, (between pH 5.0 and 10.0). The presence of chloride and/or bromide salts in solution may have played a part in the tendency for some samples to swell and to disintegrate during washing, however at the same time those sulfates present would have retarded swelling (Florian 1987a).

Photographs of the test sub-samples are to be found in Figs 3.14 – 3.16. Figures 3.14 and 3.15 show the sub-samples of ancient Egyptian linen at the beginning of the test, as they began soaking. Figure 3.16 shows some of the
sub-samples of ancient linen and the new linen control drying on glass
microscope slides, as well as the pH test strips used for pH testing the wet
samples, and the small vials in which the extraction solutions were kept for
later IC analysis.

ESEM computer images of samples from the test sub-samples are found in
Figs 3.17, 3.19 and 3.21. These show the fibres from the textile sub-samples
collected at various stages of the test. They also show the sample area that
was tested using EDXA. Following each set of ESEM images are EDXA
spectra of the sub-samples pictured (see Figs 3.18, 3.20 and 3.22).

A visual record of 16-hour washing test IC results over time is given in
graphs presented as Figs 3.23 – 3.25. The differences in the relative amounts
of salts extracted are apparent in these graphs, as are the differences between
samples in the rates of extraction.
**Figure 3.14 MS2.** A photograph of MS2 at the beginning of the 16 Hour washing test. The fabric is only beginning to absorb the deionized water (this is apparent in the small patches of darker colour). The photograph was taken by the author.

**Figure 3.15 MS4.** This is a photograph of MS4 at the beginning of the 16 Hour washing test. The photograph was taken by the author.

**Figure 3.16 Sub-samples.** These sub-samples were taken during The 16 Hour Washing for testing. Also shown in the foreground are the pH test strips used to test the pH of each sample. Fabric samples were tested using ESEM with EDXA while samples of the changes of deionized water were tested using Ion Chromatography. The photograph was taken by the author.
Figure 3.17 ESEM Image of New Linen Control. The area shown was tested using EDXA. Computer image taken by K. McBean and the author at the University of Technology, Sydney.

Figure 3.18 EDXA Spectrum of New Linen Control. This EDXA spectrum was taken by K. McBean and author at the University of Technology, Sydney.
Figure 3.19 ESEM Images of MS4.

a) MS4 Sub-sample. This image was taken after the fabric had soaked for 1 hour in deionized water and had then been air-dried. This area was tested with EDXA. Computer image taken by K. McBean and the author at the University of Technology, Sydney.

b) MS4 Sub-sample. This image was taken after 2 hours in deionized water and then air-dried. This area was tested using EDXA. Image taken by K. McBean and the author at the University of Technology, Sydney.

c) MS4 Sub-sample. This image was taken after 4 hours in deionized water and then air-dried. This area was tested using EDXA. Image taken by K. McBean and the author at the University of Technology, Sydney.
d) MS4 Sub-sample. Detail of fibre surfaces. This image was taken after 4 hours in deionized water and then air-dried. Image taken by K. McBean and the author at the University of Technology, Sydney.

e) MS Sub-sample. This image was taken after 16 hours in deionized water and then air-dried. This area was tested using EDX, Image taken by K. McBean and the author at the University of Technology, Sydney.

f) MS4 Sub-sample. Detail of fibre surfaces. This image was taken after the sub-sample was soaked for 16 hours in deionized water and then air-dried. Image taken by K. McBean and the author at the University of Technology, Sydney.
Figure 3.20 EDXA Spectra of Sub-samples of MS4. These sub-samples were from the 16 hour washing test. The EDXA spectra were taken by K. McBean and author at the University of Technology, Sydney.

a) MS4 Sub-sample. Control.

b) MS4 Sub-sample after 1 hour in deionized water.
c) MS4 Sub-sample after 2 hours in deionized water.

d) MS4 Sub-sample after 4 hours in deionized water

e) MS4 Sub-sample after 16 hours in deionized water.
Figure 3.21 ESEM Images of MS2.

a) MS2 Control. This area was tested using EDXA. Image taken by K. McBean and the author at the University of Technology, Sydney.

b) MS2 Sub-sample. Taken after the fabric had soaked for 1 hour in deionized water and had then been air-dried. This area was tested using EDXA Image taken by K. McBean and the author at the University of Technology, Sydney.

c) MS2 Sub-sample. Taken after the fabric had soaked for 4 hours in deionized water and had then been air-dried. This area was tested using EDXA. Image taken by K. McBean and the author at the University of Technology, Sydney.
d) **MS2 Sub-sample.** Taken after the fabric had soaked for 16 hours in deionized water and had then been air-dried. This area was tested using EDXA. Image taken by K. McBean and the author at the University of Technology, Sydney.

**Figure 3.22 EDXA Spectra of Sub-samples of MS2.** These sub-samples were from the 16 hour washing test. The EDXA spectra were taken by K. McBean and author at the University of Technology, Sydney.

![EDXA Spectra of MS2 Sub-samples](image)

**Label A:** ms21hr

a) **MS2 Sub-sample after 1 hour**
b) MS2 Sub-sample after 16 hours.

Figure 3.23 Monitoring Salt Removal. 16 Hour Washing Test.
New Linen Control. Results reported in ppm (mg/L).
Figure 3.24 Monitoring Salt Removal. 16 Hour Washing Test.
MS4. Results reported in ppm (mg/L).

Figure 3.25 Monitoring Salt Removal. 16 Hour Washing Test.
MS2. 16 Hour Washing Test. Results reported in ppm (mg/L).
3.9.3 Results of the 16 Hour Washing Test

The results obtained from the 16-hour washing tests showed that the washing of the ancient linen textiles reduced the levels of some of the salts present in these textiles, and the reduction of the salt contents followed a pattern similar to that known for the solubility of salts (Arnold & Zehnder, 1991). Hence, the level of sodium chloride, which was the most soluble salt present in the samples, was reduced first. In general, as anions and cations appeared in the IC records and the quantity of salts present increased in the IC samples, the quantity of salts present in the corresponding ESEM and EDXA samples decreased, though at no time were these elements completely removed from the ESEM and EDXA ancient linen samples (see Figs. 23 – 25 and Appendix A Samples 9. MS2 and 11. MS4).

The experience gained from the washing tests gives a clear indication that sodium chloride can be released very quickly at the beginning of a washing treatment. The results clearly show that the levels of salt in this linen decreased progressively with further washings. While much of the salt content of an archaeologically recovered textile may be washed out in the first one or two hours of soaking, not all of the salts could be washed out as quickly. Those samples which were removed earliest (at 1, 2 and 4 hours), where the salts content was higher, appeared to be more damaged upon drying than
samples removed last (16 hours), when the total amount of salts present had decreased substantially. Hence, it may be that caution must be taken not to stop the washing process early as the residual salt may still result in considerable damage to the fibres upon drying. ESEM observations indicate that the fibres from linen samples that were washed longest showed the least fibre damage upon drying.

ESEM images of progressive washing (where the fibres were taken through two or more cycles of hydration and dehydration) had no visible effect upon new linen (see Figs 3.5 – 3.9), but was potentially detrimental to ancient fabrics, particularly to those that were previously known to have had a high salt content. This was because the fibers often became very soft and fragile, and could not be safely moved or manipulated while wet. This may be due to the removal of salts that had entered the fibers, leaving gaps in the physical structure. This is in contrast to historic fabrics without a high salt content, which appear to be generally amenable to manipulation while in a damp or wet condition, in order to reshape the textile and realign the warp and weft threads. Therefore fabric samples had to be either carefully handled when wet or not moved at all during the washing and drying procedures. These results, while very interesting, will need to be substantiated by further research. However, ased upon theresults of these pilot 16 hour washing tests,
as well as the pilot ESEM hydration and dehydration studies, a recommendation for the conservation treatment of ancient Egyptian linens which have a high salt content would be to avoid any aqueous treatment of the ancient linens whenever possible. However, if the ancient linen must be washed, then a recommendation would be to wash until IC monitoring indicates that salt levels have been greatly reduced, even if this is for 16 hours or longer.

3.10 Samples of Freeze-Drying

Samples that were freeze-dried were not examined using the ESEM and EDXA since the salt contents would not have been affected by the different drying techniques. The object of freeze-drying samples was to see whether there was any difference in the physical condition of the freeze-dried fibres and the air-dried fibres of samples whose original condition and subsequent treatment were otherwise the same. Therefore the samples were examined using optical microscopy and the results recorded using photography.

3.10.1 Results of Freeze Drying After The Washing Tests

The object of freeze-drying samples was to see whether there was any difference in the physical condition of the freeze-dried fibers and the air-dried fibers of samples whose original condition and subsequent treatment were
otherwise the same. As no previous study has reported the washing and then freeze drying of ancient textiles (only the freeze-drying of archaeological textiles recovered in a wet or wet and already frozen condition) there were no published examples available for comparative purposes.

Normal air-drying was used for samples which had been examined during initial IC testing. Normal air-drying consisted of placing the wet fabrics on either plastic coated drying screens or on plates of glass and allowing the textile samples to dry at room temperature. No attempts were made to control either temperature or relative humidity in the room. Normal drying of samples appeared to have adverse effects on the fabrics. At a normal rate of air-drying the textile disintegrated badly during drying and became like paper pulp. The resemblance of the physical condition of the textile to paper pulp was most marked on a sample that had been dried on a drying screen, as it has visibly retained the imprint of the drying screen after the textile had dried in a manner similar to that of hand made paper (see Fig. 3.26 d).

Test samples of ancient Egyptian linen were then washed in deionized water and vacuum freeze-dried using a Heto FD3 freeze-dryer. Other samples, created during the 16-hour washing test, were either frozen in an domestic refrigerator, then allowed to freeze dry without the use of vacuum (see Fig. 3.
26), or were dried slowly between plates of glass. Samples of slow-drying, 
freeze-drying and vacuum freeze-drying all appeared to be successful to the 
naked eye. However, samples that were vacuum freeze-dried appeared to 
have a greater tendency to powder when moved or flexed. Slow freeze-drying 
or slow air-drying appeared to the naked eye to give the best results.

Freeze drying (either vacuum or slow) did not leave left any crust of dirt or 
debris or crystals of salts on the surface of the fabric. However, these samples 
were dried after washing, not directly after excavation or recovery from an 
underwater environment. Therefore the problems experienced by Jakes and 
Mitchell (1992) with an encrustation of the surface of the textile following 
vacuum freeze-drying, when the textiles were archaeologically recovered and 
freeze-dried without washing, were not encountered.

All of the test samples were examined using optical microscopy and the 
results recorded using photography (see Figs 3. 26). Microscopic examination 
appeared to bear out observations made above.
Figure 3.26 Samples of Freeze Drying.

a) New linen control freeze-dried after 16 hour washing test. Photomicrograph by J. Barron and the author. 2.5 x objective.

b) MS2 freeze-dried, after 16 hour washing test. Photomicrograph by J. Barron and the author. 2.5x objective.

c) MS2 Vacuum freeze-dried. Photograph by the author.
d) MS1 Air Dried. Note how the right half of the textile is matted. Photograph by the author.

3.11 Results of Testing of Deacidification Solution on Linen Samples.

Samples for testing purposes were made by soaking new linen (control) in a deacidification solution. This was left un-rinsed and air-dried at normal room temperature. The dried sample was tested using ESEM and EDXA. For results of the examination see Appendix A 5. Deacidified Linen. A subsample was also taken from the ancient Egyptian linen sample of the Book of the Dead and was treated with deacidification solution, using the same procedure as was used for the control of new linen. The sample from the Book of the Dead was chosen for testing as previous examination by ESEM and EDXA had showed that the textile had most probably not been washed in antiquity.
An examination using ESEM with EDXA of both the new linen (control) treated with deacidification solution and the sub-sample of the Book of the Dead also treated with deacidification solution showed a small amount of residue on the new linen, but a greater residue on the Book of the Dead linen fibres (perhaps indicating that the older fibres had a tendency to absorb more of the deacidification solution during treatment). During further testing in which both the new linen (control) and the sub-sample of the Book of the Dead were observed during a cycle of hydration and dehyrdration both the new linen and the Book of the Dead linen evidenced little physical change.

This line of investigation could be pursued further using more samples and varying solution strengths, as well as using textile samples containing various inks and pigments. Though much work has been done previously to test the effects of deacidification solutions on paper and works of art on paper, much of the work on the effects of deacidification solution on paper and textiles with paints and pigments was done prior to the invention of the ESEM (see Cook & Mansell, 1981).
3.12 Conclusions

Evidence from these studies would indicate that the type and extent of physical fibre damage in linen is dependent on many factors, such as: (a) the physical condition of the textile fibers, (b) the amount and types of salt present in the fibers, (c) the range and frequency of fluctuations of relative humidity, and (d) the rate of hydration and dehydration of the fibers.

A most exciting and productive advance in the analysis of the linen samples was the use of ESEM for the observation and recording of the movement of salts within the fibers, in real time, during cycles of hydration and dehydration. Figures 3.5-3.13 and Appendix B shows this process using the usual sample size, which was either 0.5 cm of one single thread or a small square of representative threads taken from the fabric. In some cases the record showed crystals form and grow, breaking through the surface of the fiber. In other cases crystals formed in fissures in the surface of the fibers that were already present, expanding the fissures and causing damage to the fiber surface.

This evidence appears to demonstrate that salts in solution are carried into the linen fiber, through the porous surface and/or breaks in the surface, and do not simply form on the surface of the fiber. A comparison of the visual record
for the hydration and dehydration of ancient Egyptian fibers and new fibers that were both treated with natron shows that the relatively undamaged and flexible surface of new linen fibers is more resistant to the penetration of salts in solution than is the surface of ancient linen, where fissures allow an easy pathway for the salts in solution. The presence of the fissures in the fibres from ancient linen may have resulted from its use in ancient times, or from extreme desiccation, which may have occurred at any time.

From a single cycle of hydration and dehydration the damage for the new linen appears to be less than for the ancient linen. Damage during cycles of hydration and dehydration for ancient linen with a high salt content appears to be higher than damage for ancient linen with a lower salt content. Damage appears to be progressive with multiple cycles of hydration and dehydration. This is consistent with the behaviour of salts during multiple cycles of hydration and dehydration as observed by Doehne (1994), and Stambolov and van Asperen de Boer (1975 rev. ed.) in studies of salt damage in stone, building materials, and pottery and by Wallert (1996) in papyrus.

Another advance was the monitoring of samples for the removal of soluble salts during washing trials using IC and ESEM with EDXA. The rates of salt removal could be observed and recorded accurately. The information gained
by this pilot study of the removal of salts is directly applicable to the conservation treatment of archaeological textiles.

In particular, the observation that fabrics containing salts underwent more damage when the washing process was shortened was of interest for future conservation treatment of archaeological textiles. The observation that salts were not completely removed from the textiles after 16 hours of washing has a direct bearing on the question of the extent of mineralization of archaeological textiles containing natron and other salts.

Specific achievements of this chapter:

- Formulation of a research design to test the proposition that linen textiles from ancient Egypt had often undergone a form of partial mineralization through washing treatments involving natron and other soluble inorganic salts, as well as through deposit in environments which contained alkaline inorganic salts, and that this partial mineralization has contributed to their survival.

- Identification of suitable ancient Egyptian linen samples which could be tested in order to determine their level of mineralization.
• Testing of control samples of linen, natron, and ancient fibres as well as ancient Egyptian linen in order to determine whether or not they had undergone a process of partial mineralization by natron and other salts.
• Testing of ancient Egyptian linen samples for levels pH.
• Observation of the effects of hydration and dehydration upon linen test samples and the behaviour of natron and other salts that were present in the fabrics.
CHAPTER 4

A Discussion of the Experimental Results and Their Implications for the Conservation and Preservation of Ancient Egyptian Linen

4.1 Introduction
The results from the examination of linen samples in this study need to be discussed in relation to: (1) current textile conservation theory and practice, and (2) the archaeological context of the samples. Only after such a discussion can meaningful conclusions be drawn and recommendations made for the future care of ancient Egyptian linen.

The specific objectives of this chapter are to:

- Outline the current theory and practice of textile conservation with reference to archaeological textiles.
- Discuss the implications of experimental results given in Chapter 3 for the conservation of archaeological textiles from ancient Egyptian sites.

4.2 Textile Conservation Theories and Practice
When objects are removed from an archaeological deposit they are often covered with particulate matter ("dirt", debris, salts, etc.) and may often be stained. The archaeologist usually wants to examine the object as soon as
possible in order to register, draw, and photograph it. In order to gain information from the surface of some objects the archaeologist will often want them to be washed. Sometimes the motive for a request to wash the object is based upon a genuine need for information and sometimes the request is purely for cosmetic reasons, i.e., in order to make the object look good for public relations and publicity purposes.

It is often the archaeological field conservator’s task to consider the object’s stability. If the conservator feels that the stability of the object might be threatened by “interventionist treatment”, then the conservator may seek to discourage the archaeologist from the request to “clean” the object. Instead the conservator could argue for a “passive” or “non-interventionist” approach, through appropriate packing and the provision of environmental conditions that would keep the artefact stable.

Later, in a museum or gallery situation, a conservator may assess the condition of the artefact and make a judgement about the advisability of cleaning. Often, however, the field conservator is not the museum or gallery conservator. Although the field conservator may have made some notes available concerning the object, rarely is there time in the field to make complete reports and to compile descriptions of the archaeological deposit.
Therefore, the museum or gallery conservator may make decisions on the treatment of the artefact without a complete record and without an understanding of the environment from which the artefact was recovered.

In order to make a decision on the suitability and safety of any treatment of an archaeological artefact, including the cleaning of archaeological textiles, many factors must be taken into consideration. These are discussed below.

4.3 Evaluation of Conservation Treatments

Materials conservation literature already cited in Chapter 1 described methods for the treatment of archaeological textiles. It is not an objective of this study to discuss and evaluate all conservation treatments for Egyptian linen, but instead to discuss the pros and cons of various conservation treatments for dry Egyptian linen recovered from an archaeological environment, with the discussion framed in relation to the question of the role of salts within Egyptian linen.

4.3.1 To Wash or Not To Wash? That is the Question

Many factors need to be considered regarding washing, drying or other treatment of archaeological textiles from Egypt, and these factors need to be
balanced in order to make appropriate decisions. Below the arguments for and against washing are stated briefly.

4.3.1.1 Arguments in Favour of Water Washing of Ancient Egyptian Linen

1) Dust and dirt particles in fabric are considered abrasives by conservators of historic fabrics. Abrasives are detrimental to fabrics because they can rub against the fibres when fabrics are handled or flexed, causing damage. Therefore, it is beneficial to wash fabrics whenever possible in order to remove abrasives.

2) Particulate matter may constitute food for fungi, insects and bacteria. Material that might attract fungi, insects, and bacteria, should be removed through washing.

3) Particulate matter acts as a coating of the fibres that restricts movement. Fibres move with changes of humidity or through handling. If fibres try to move, and this movement is prevented by a coating, then damage may occur to the fibres. Therefore the coating should be removed.

4) Particulate matter may contain materials that can produce acids. This includes “decomposed remains in grave findings” (Flury-Lemberg, 1988, pp. 23-26). Therefore, particulate matter should be removed before it can produce acids that are detrimental to the fabric.

5) Washing may remove degraded particles of the fibres. Often these degraded fibres contain acids that might attack the textile fibres, causing
damage to them. Therefore, these degraded particles should be removed before they can produce acids that are detrimental to the rest of the fabric.

6) “There is a long tradition of wet cleaning archaeological textiles, sometimes on site” (Brooks, Lister, Eastop & Bennett, 1996, 18).¹

4.3.1.2 Arguments Opposed to the Washing of Ancient Egyptian Linen in Water

1) The “shock” of the water alone (creating stresses on the surfaces of fibres) may damage fragile plant fibres and even cause their disintegration.

2) The capacity of the fibres to swell in water must be considered as a serious problem when treating archaeological textiles. While Flury-Lemberg stated that clean fibres could “breathe” (1988, pp. 23-26) it must be remembered that vegetable fibres cannot actually breathe, as they do not have lungs. Her “breathe” is actually a taking in and giving out of moisture, and that “breathing” means movement along with the changes in humidity. In new fibres there is greater elasticity than in ancient fibres. New fibres can absorb water vapour/water. They retain some of the ability of the original, living, and plant material to take in water. In new fabrics or strong historic fabrics

¹ Though I here quote Brooks, Lister, Eastop & Bennet, I am not inferring that they think this situation is a desirable situation, only that wet cleaning (washing) of archaeological textiles has a “long tradition.”
this ability to absorb moisture and to swell may help to release particulate matter through movement, and so is considered beneficial. While this may be desirable in historic textiles which are still relatively undamaged and flexible (and this is debatable since “breathing” in of polluted atmospheres will probably hasten a breakdown of fibres), it is not generally considered desirable for Ancient Egyptian linen, as ancient Egyptian linen has generally undergone extreme desiccation while within the archaeological deposit and has therefore lost its flexibility. Fissures in the surfaces of fibres of Ancient Egyptian linen are probably at least partially caused by extreme desiccation of the fibres. Rehydration of such fibres will not impart renewed flexibility, for reasons outlined clearly by Florian (1987a). Her argument is quoted here at length, as it is an important one, especially when considering the wet cleaning of previously dry, indeed often extremely desiccated, Ancient Egyptian textiles.

In the living state the above-mentioned polymers [plant tissues] are in a hydrated state. ...Thus conservation of this material must deal with stabilisation and drying of organic colloids.

In artefact material of organic origin, there is an initial drying and shrinkage ... On rewetting and hydration the material swells by diffusion but not back to the original extent because some of the bonding sites for water have been satisfied by intermolecular bonding and are no longer available for water....
Swelling is the first step towards dissolution. When swelling is extreme, the micellar structure is destroyed and the cellulose is no longer crystalline. Extreme swelling of cellulose may occur in strong alkaline solution (10-22% w/v KOH). Under these extreme conditions cellulose may swell enormously but does not dissolve. On drying, cellulose adopts a different crystalline state and is called cellulose II as compared to native cellulose I. Thus conservation treatments designed for native cellulose used for comparable archaeological materials with chemically altered cellulose would be illogical.

Cellulosic materials (paper, plant materials, cellulosic textiles) may have been preserved because of the restriction of swelling due to the presence (high concentration - 3.5% w/v) of sodium chloride normally in seawater. If such materials are placed in deionised or fresh water to remove sodium chloride or for storage excess swelling may occur. Such swelling may cause irreversible bond breakage and deformation of the cellulose fibres giving them weaker mechanical strength and greater chemical solubility (Florian, 1987a, pp. 21-26).

Video footage of the hydration and dehydration of both new linen and ancient Egyptian linen (Appendix B) shows clearly that ancient linen does not respond to hydration and dehydration in the same manner as does new linen. New linen can swell and contract without much damage to the surface of the fibres. Ancient linen, already fractured and brittle due to extreme desiccation in the archaeological environment, breaks even more when subjected to cyclical changes of humidity.

3) Changes of pH are attributable to various factors. They are: (a) the pH of the wash water or the washing solution; (b) the release of salts into solution, changing the pH of the solution to be either more alkaline or acid; (c) the

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release of textile degeneration products; and (d) the release of any additives/stains/deposits that have dried on the textile. Washing may change the pH of the water and thus initiate undesirable changes in the fabric, such as swelling of the fibres.

4) The wet cleaning of excavated textiles can promote previously inhibited biodegradation. This can be an immediate effect of wet cleaning. Dormant fungal spores can be activated, leading to rapid bio-deterioration.

5) Changes may occur to the dimensions of fibre, yarn and weave, due to swelling of fibres and realignment of fibres during drying, the loss of degenerated material, and/or the loss of original coatings.

6) If archaeological textiles are washed, important chemical and physical evidence may be literally washed down the sink with the wash water. Therefore when archaeological textiles are washed, the water samples should be analysed. Analysis should take place as soon as possible, or the sample should be refrigerated until analysis can take place, as components of the wash water may experience chemical change during storage.

7) Conservators who abide by the Code of Ethics and Code of Practice of the Australian Institute for the Conservation of Cultural Material, the Code of Ethics and Guidelines for Practice of the American Institute For Conservation of Historic and Artistic Works, or similar professional codes of practice, have
an ethical responsibility to keep the fabrics in as unadulterated a form as possible.

4.3.2 Arguments for and Against Cleaning Archaeological Textiles in a Dry State by Using Brushes and Instruments

1) Dry cleaning using soft brushes and fine instruments, aided as necessary by the use of a binocular microscope, allows the careful removal of particulate matter without chemical treatment of the fabric. This means that fibres will not swell, pH will not be changed, and evidence of previous usage such as fold lines of clothing and the former contents of fabrics used as containers will not be altered.

2) The process may not be capable of removing all particulate matter.

3) Cleaning with instruments is a potentially time-consuming process.

4) Cleaning the textile in a dry state will not remove acids or deep stains.

4.3.3 Opinions Relating to the Methods of Drying Archaeological Textiles After Conservation

4.3.3.1 Slow or Fast Drying?

1) Slow drying may offer less potential for the disruption of fibres by reducing surface tension during air-drying.
2) Slow drying would increase the possibility of biological degradation of the textile through the colonisation by microorganisms or the multiplication of microorganisms already on or within the textile.

4.3.3.2 Freeze-Drying, Drying from Water, and Solvent Drying

4.3.3.2.1 Arguments for Freeze-Drying

1) Freeze-drying is a controlled process for removing water from the cells of biological material. “Water is removed as ice crystals which sublime into vapour, under vacuum, and re-condense on the coils of the freeze-drier; this ensures that ice in the specimen never enters the aqueous phase” (Moore, 1992, p. 31). Freeze-drying preserves the surface of the biological material, without the distortions that can be caused by air-drying. It also contrasts with air-drying where the surface stress of water removal may cause shrinkage and leave the material brittle.

2) Freeze-drying can be useful when delicate fibres need to be separated from soil matrices. This is often the case for waterlogged deposits, where soil and fabric can be excavated together wet, then frozen, and later cleaned by the conservator under a binocular microscope.

3) Freeze-drying can be done without any pre-treatment in a refrigerator, a domestic freezer or a commercial walk-in freezer, making the process relatively simple and inexpensive (Jakes & Mitchell, 1992).
4.3.3.2.2 Possible Problems with Freeze-Drying of Textiles

1) There has been speculation that there might be some damage to fibres by an expansion of the water volume on freezing, although this has not yet been proven. Peacock (1999, pp. 12-18) seemed to question this speculation. Peacock tested the four major natural fibres through repeated freeze-thaw cycling and found that freeze-drying did not bring about any measurable changes, except for dry linen (i.e. linen frozen when dry and not when wet). “Differences were not significant for the wet samples, but they were for the dry specimens” (for multiple cyclic testing using new yarn).

In a study of the effect of sub-zero temperatures on cellulosic yarn, new and Pharaonic linen yarns were subjected to one freeze-thaw treatment. There was no significant change in either mean percent elongation or mean breaking strength following treatment (Cooke & Peacock 1992). 2

2) There has been some concern about using freeze-drying for textiles as it may desiccate the fibres.

3) In the frozen state, deteriorated artefacts can break if improperly handled (Jensen, 1987, p. 128).

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2 Cooke, W.D. and Peacock, E.S. (1992) Quantitative research in ancient textiles and freeze-drying. In L. Bender Jørgensen and E. Munksgaard (Eds.). Archaeological Textiles in Northern Europe Tidens Tand 5, (pp. 218-228) Copenhagen: School of Conservation, Copenhagen. This reference was cited by Peacock
4) In an often quoted study, Jakes and Mitchell (1992, p. 343) compared vacuum freeze-drying with slow drying while in a frozen state. They found “vacuum freeze drying to be the method most disruptive to fabric and fibre structure. Slow drying while in the frozen state resulted in fibres and fabrics with visible structure and few contaminating deposits on the surface”. However, it must be pointed out that Jakes and Mitchell were comparing waterlogged material which had not been cleaned prior to freezing, and the cited disadvantage of vacuum freeze-drying was that the vacuum pulled particulate matter out of the textile yarn and left it as an obstructing layer upon the surface of the fabric. If the fabrics had been washed prior to freezing there may have been a different result and conclusions.

5.3.3.2.3 Arguments for Drying from Water

1) Drying from water is simple and inexpensive.

2) Drying from water introduces no chemicals or resins which may be unstable.

3) Drying from water leaves no unwanted residues.

4.3.3.2.4 *Arguments Against Drying from Water*

Of considerable concern to conservators and curators is the distortion and disintegration that can be caused by water surface tension when fragile archaeological textiles are dried under normal air-drying conditions.

4.3.3.2.5 *Arguments for Drying from Solvents (Other than Water)*

1) Drying from solvents other than water gives a possible mitigation of the problems that might be caused by drying from water. After water washing the water can be replaced by alcohol, or other solvents, which will evaporate more quickly and which will not create as great a problem as water with surface tension.

2) Solvents, particularly alcohols, can aid in the sterilisation of fabric, thereby minimizing the growth of microorganisms upon or within the fabric.

5.3.3.2.6 *Arguments Against Drying from Solvents (Other than Water)*

1) Drying with solvents is more complicated. Safety equipment and special arrangements for ventilation are needed when using certain solvents.

2) Drying with solvents is generally more expensive.

3) The disposal of solvents needs careful consideration. Safe disposal of hazardous or flammable solvents might be very difficult under field conditions.
4) The use of solvents other than water may introduce chemicals into the fabric that may be unstable.

5) The use of certain solvents may leave unwanted residues.

6) The use of certain solvents might interfere with future analysis.

7) Some solvents might react with particulate matter within fibres.

8) Solvent drying might cause crystals to form more rapidly within the fabric than with slow drying, which might cause crystals to be formed on the surface of the fabric, thereby causing abrasive damage.

4.3.4 Arguments for and Against Deacidification Treatment

Deacidification buffering using magnesium bicarbonate solutions are intended to neutralize acids present in cellulosic materials and to leave an alkaline buffer reserve to prevent acid hydrolysis in the future, resulting in a paper or textile with a minimum pH of 7.5 and a maximum pH of 9.5 (Morrison, 1979, pp. 25-28). Magnesium bicarbonate deacidification solutions were widely used in the mid-to late 20th Century in the conservation treatment of paper by materials conservators, but rarely used on textiles.

There were several different deacidification solutions used in the last century by paper conservators. The simplest was devised by Barrow, and consisted of a supersaturated solution of magnesium carbonate. The solution was prepared
by mixing magnesium carbonate with deionised water, and then the solution was agitated while carbon dioxide gas was bubbled through for at least one hour. Then the suspended solids were allowed to settle, and the clear solution was decanted for use as deacidification solution. The solution was either sprayed onto the paper, or the paper was immersed in the solution. Upon drying the paper was considered neutralised if it had a pH of 7.5 (Werner, 1969, p. 220).

It was recognised that the deacidification left “a deposit of either calcium or magnesium carbonate in the fibres of the paper where it can act as a buffer against extrinsic sources of acidity, such as sulphur dioxide” (Werner, 1969, p. 220). Though it was recognised early that this method of deacidification would not be suitable for paper with inks which were water soluble, it has taken some time for there to be a recognition that the introduction of magnesium and calcium might cause problems, due to physical abrasion of the particles. Cook and Mansell investigated this for watercolours (1981). Using SEM they could demonstrate that the white powder left by deacidification solutions affected the stability of test samples of watercolour on paper. However, they did not identify the white powder through EDXA.³ Of interest is how closely the deacidification solution used for the
deacidification of paper replicates the ground water solution occurring within a natural environment or archaeological deposit within a limestone area.

Natural movement of water in limestone areas may dissolve calcium carbonate, forming calcium bicarbonate. This occurs if the water has a pH below 8.4 (Cornwall 1958, p.193). As pure rainwater is generally more acidic than pH 8.4 this can occur naturally. Also, if the ground water has picked up any carbonic or humic acids, acidification would occur. Of course, the solution may also pick up other soluble minerals in the environment as well. The calcium bicarbonate, now being soluble, can travel in solution until it reaches a surface where evaporation may occur. This may occur on the surface of a rock wall, at the ground surface, or on the surface of an excavated archaeological object.

Historically, carbonates were a major buffering component of the paper making process, through their presence in water and stone vessels used in the hand paper-making process, through the use of limewater in the processing of cotton and linen rags, and through the use of limestone (calcium carbonate) as a filler and whitener (Morrison, 1979, p. 27).

\footnote{ESEM technology was not yet available. Therefore it was not then possible to observe and record salt}
Stoll and Fengel's research into ancient Egyptian linen was a side excursion from their research into paper (personal communication via letter, 1997), and was published in a paper manufacturers' journal (Stoll & Fengel, 1981a, 1981b, 1985). Therefore it comes as no surprise that they were interested in the preservative qualities of salts in the linens they examined during their studies at the University of Munich. When Stoll and Fengel found quantities of mineral components in the ancient linens they tested to be in the order of 1% to 9% by weight, they postulated that the mineral components could be acting as a preservative. Therefore they tested the effectiveness of NaHCO₃ in heat ageing/preservation of new linen. They used samples with a 4% salt content (per weight, after drying) and at a pH of 8.5. Their conclusion was that weakly alkaline salts had a preservative effect upon linen (Stoll & Fengel, 1985, p. 319).

4.3.4.1 Arguments for Deacidification

1) Handmade papers, especially those from traditional paper mills using natural carbonate-rich water in the papermaking process, have remained stable for hundreds of years.
2) Deacidification using carbonate mixtures can restore a neutral or alkaline pH balance to textiles, and thus prevent acid hydrolysis and resulting deterioration of textiles.

3) Egyptian linens washed in ancient times in natron and stored in a carbonate rich environment, have remained stable for thousands of years. It can be argued that Ancient Egyptian linens have themselves constituted a natural ageing test of the effectiveness of deacidification, and their very existence (after upwards of 2,000 years) proves that the presence of natural carbonate buffering materials can aid in the preservation of materials made of plant fibres.

4.3.4.2 Arguments Against Deacidification

1) A deliberate change of pH in the textile induced through the use of a “deacidification” treatment may cause the swelling of fibres.

2) Deacidification solutions deliberately leave a residue of carbonate particulate material as a buffer. Particulate matter may cause abrasion with movement of the fabric.

3) An important study has indicated that deacidification cannot restore strength to already degraded linen (Hackney & Ernst, 1994).

4) The introduction of a residue of carbonates causes a stiffening of the fibres, thus changing the feel or drape of the fabric. While this not an important
consideration for archaeological fabrics it is considered important for historic
textiles by many curators and conservators (Kerr, Jennings & Methe, 1989, p.
144).

5) The introduction of salts through the use of a deacidification solution may
cause the fabric to become damp, as the salts may take in and retain moisture
in a damp environment. If the fabric is allowed to remain damp fungal and
bacterial activity would be encouraged.

6) Salts introduced by deacidification may hydrate and dehydrate, and thus
cause movement within the fibres and on the surface of the fabric. If this
surface is painted, then such movement may cause damage to the paint layer.

4.4 Discussion of Experimental Results

Results of the 16 hour washing tests, air-drying versus freeze-drying
comparisons, and testing of magnesium bicarbonate deacidification solution
on linen samples can be summarised as follows:

1) Washing ancient linen textiles that contained salts dissolved some of the
salts present. The salt burden was, in general, reduced, but not completely
eliminated from any sample. Sodium chloride, the most soluble of the salts
present in samples examined, was reduced first, while other salts were
reduced in a pattern similar to the known pattern of solubility for salts.
Experience gained through this test of the rate of solubility of different salts is valuable as it gives a clear indication that sodium chloride releases very quickly at the beginning of a washing treatment. This could be verified in the future by testing of samples at more frequent intervals (perhaps every 15 or 30 minutes) for the first hour or two hours of any testing of washing procedures. However, the exact rate of early release, while interesting from the scientific analyst’s viewpoint, is not as important to the conservation treatment of the textile as the realisation that while much of the salt content of a textile is washed out in the first hour or two hours of washing, not all of the salts are washed out as quickly. To stop the washing process early because much of the salt is gone is still to risk considerable damage to the fibres upon drying, as optical microscopy and ESEM have demonstrated. The linen fibres that were washed longest showed the least fibre damage upon drying.

2) Progressive washing had no visible effect upon new linen, but was potentially detrimental to ancient fabrics, particularly to those that were previously known to have had a high salt content. The fibres often became very soft and fragile, and could not be safely moved or manipulated while wet. This implies that the salts had become part of the fibre structure. This is in contrast to historic fabrics without a high salt content, which are generally amenable to manipulation while in a damp or wet condition, in order to reshape the textile and realign the threads of the warp and weft. Therefore
ancient fabric samples had to be either carefully handled when wet or not moved at all during the washing and drying procedures.

3) Rapid drying of samples appeared to have adverse effects on the fabrics (see Figure 3.8). Samples of slow drying, freeze-drying and vacuum freeze-drying all appeared to be successful to the naked eye. However, samples that were vacuum freeze-dried appeared to have a greater tendency to powdering when moved or flexed. Slow freeze-drying or slow air-drying appeared to give the best results. Freeze drying (either vacuum or slow) did not leave left any crust of dirt or debris or crystals of salts on the surface of the fabric. However, these samples were dried after washing, not directly after excavation or recovery from an underwater environment. Therefore the problems experienced by Jakes and Mitchell (1992) with an encrustation on the surface of the textile following vacuum freeze-drying were not encountered.

4) The pH of solutions was kept in the safe zone for linen fibres, between 5.0 and 10.0. However, the effects of a change of the pH of fibres during hydration and dehydration may have played a part in the tendency of some samples to swell and to disintegrate during washing. Some fibres may have already undergone temperature and/or pH changes which had converted the cellulose from cellulose I to II, thereby altering their response to hydration and dehydration.
5) Magnesium bicarbonate deacidification solution did not appear to have as pronounced an effect on the linen samples tested as did natural natron, although the magnesium bicarbonate deacidification solution appeared to leave more salts on ancient linen samples than on new linen samples.

6) Under conservation laboratory conditions washing would be done using either filtered tap water, distilled water, or deionised water. In these tests a very pure deionised water was chosen as the solute for all testing, so that we would know exactly what was solubilizing from the fabrics. However, very pure deionized water had the effect of causing ions to be removed from the test samples rapidly. A slower release might have been gained using the same eluent as the IC column, sodium carbonate/bicarbonate. This might have caused a slower release of ions, and made IC testing of the sodium chloride more precise. However, it would not have been a realistic test of conservation washing procedure. As the sodium chloride content of the samples was so high, any future testing of natron samples might consider using IC with special Ion Pac AS9-HC column(s) designed for use with seawater or samples with high chloride content (see Williams, 2000), so that trace elements can be detected at the same time as a high level of sodium chloride can be accurately measured. Future testing also might use distilled or tap water as solute.

7) Both natural natron and modern deacidification solutions may pH buffer fibres, giving some protection against acidity in the environment. This study
adds further support to the findings of Barrow and other paper conservators (Morrison 1979) on the effectiveness of carbonates in buffering organic materials, particularly cellulose, against acid hydrolysis by showing that these materials have aided the preservation of Egyptian linen over thousands of years. It suggests that the preservation of ancient Egyptian linen has been a 4,000+ years natural ageing test, as opposed to the artificial heat ageing tests that 20th Century conservators used to prove the effectiveness of deacidification solutions in the preservation of paper (Morrison 1979).

However, the introduction of salts into fibres may have a long-term destructive aspect, in that salts that may form hard crystals within the fibres can cause harm to the fibres through abrasion during movement of the textile. In addition, unless the environment is kept uniformly dry and stable, the salts will enter into cycles of hydration and dehydration with changes in the relative humidity of the environment. The associated liquid water phase allows dissolved salts to migrate and the growth of large crystals. This can cause damage to the fibres, as demonstrated in the videotape of hydration and dehydration cycles during ESEM examination. This has implications for care of all textiles treated with deacidification solutions and also of linen painting supports that have been sized with carbonate materials. Furthermore, once soluble salts are introduced into linen the evidence cited above shows that it
may be very difficult if not impossible to remove all salts from the fabric in the future without severe disruption of the fibres.

4.4.1 Discussion of the Pattern of Results

Stoll and Fengel (1988) noted that EDXA revealed the presence of extraneous, non-organic materials on fibres (see Figure 4.1). They concluded that the inorganic components in the fibres were evidence that some of the fabrics had been treated with natron, for the purposes of washing and bleaching. The results of this study, indicating that inorganic salts were present in the samples of ancient linen examined, generally correlated with the results obtained by Stoll and Fengel (1988). Important to an interpretation of the results was the distinction between the results obtained by IC and EDXA. Using IC, where the sample was soaked for a limited time in pure deionised water and the resulting solution tested, only the constituents of soluble salts leached from the sample were recorded. EDXA (analysing the untreated, dry, sample itself) was able to identify and record all elements present in the whole sample, not just the soluble materials.
Figure 4.1 X-Ray Energy Spectrum. A spectrum of a linen fabric from the 5th dynasty (approximately 2480-2340 BC) from Stoll and Fengel (1988, p.167).

Analysis of linen samples revealed definite patterns of mineralization by natron and other salts. The samples can be organised into two general groups, here designated as A and B. EDXA spectra of representative samples of these two groups are found as Figure 4.2 a-d. They are also printed as transparencies, to make direct comparison of the spectra easier.
Figure 4.2 EDXA Spectra.

Label A: contnl

![Graph showing EDXA Spectra with elements C, O, Si, and Ca]

a) EDXA spectrum of new linen taken by K. McBean and the author at the University of Technology, Sydney.
b) EDXA spectrum of BD (Book of the Dead) taken by K. McBean and the author at the University of Technology, Sydney.
c) EDXA spectrum of new linen washed with natron and un-rinsed taken by K. McBean and the author at the University of Technology, Sydney.
d) EDXA spectrum of MS3 taken by K. McBean and the author at the University of Technology, Sydney.
A. This group showed only the elements characteristic of the linen fibres themselves, and no mineralization. It included both new control samples and ancient linen known to be used for writing or art (not for clothing) and placed in a container during burial so that it received maximal protection from the surrounding archaeological deposit (see Figure 4.2 a and b). It also includes a textile from the Roman or Byzantine period, which therefore may not have been washed with natron but instead washed with soap during its working life.

B. This group showed, in addition, the presence of elements characteristic of the linen fibres themselves, elements consistent with washing with natron (either in antiquity or as part of controlled experimentation) or soluble salts with the same or very similar chemical composition as natural natron (see Figure 4.2 c and d). In addition, the linen might show additional elements that could have been absorbed through contact with the burial or storage environment.

The possibility of such a record of evidence for use was indicated by the work of Stoll and Fengel (1988), but their work was not able to differentiate their samples into such clear patterns due to the acknowledged lack of clearly
provenanced samples available to them at the time (samples which could be correlated with known archaeological deposits).

This correlation offers the possibility of testing ancient textiles in order to aid the curator and the conservator in the recording, analysis, conservation, storage and display of the textiles, through a greater understanding of their history of usage as well as their chemical and physical nature. The pattern observed above might, with further development, be used to ‘fingerprint’ samples of unknown provenance.

4.4.2 Correlation of Linen Samples with Archaeological Environment

Stoll and Fengel (1988) noted that EDXA revealed the presence of extraneous, non-organic materials on the fibres of the ancient Egyptian linen samples that they had analysed, and they concluded from this that the fabrics had been washed with natron. They also concluded that their studies had confirmed the age of the samples and that there had been no change of processing of fibres during the pre-Islamic period of Egyptian culture.

Results of analysis conducted during this study bear out the findings of previous studies of Egyptian linen (Hall, 1986; Stoll and Fengel, 1988; Tata, 1986), that there was little change in the methods of production of linen yarn
over several thousand years of the Egyptian linen industry, and also that
different grades of quality yarns were produced in all periods. Therefore an
arrangement of results by age showed no important data and thus served no
purpose. However, a correlation of known usage and known burial and
storage environments with the results of chemical and physical examination
and especially with the information gained through EDXA analysis yielded
some important information.

Elements present in the ancient Egyptian linen samples analysed (see
Appendix A: Samples) showed direct correlations with the linen plant fibres,
natron, and elements commonly present in the limestone geological
formations of the Nile Valley. In addition there were some trace elements
present which point to unusual and specific environmental influences.

A division of the elements found in the samples by their probable origin
would yield four categories:

1) Linen plant fibres: Carbon, oxygen, silicon, and calcium.

Samples that showed readings of only these elements were new linen control
samples and ancient Egyptian linen which was either unwashed or which may
have been washed with a soap, instead of natron, during its working life.
These samples of ancient Egyptian linen were Sample 29. BD (Book of the Dead) and Sample 31. N67.36. The Book of the Dead was commonly written on new linen, rolled up and then, after the body of the deceased had been artificially mummified, placed in the wooden coffin with the deceased. Therefore it would be protected from light, soil and debris, and remain dry, being insulated from changes of relative humidity. (See also Appendix A: Samples. 2. New Linen, 29. BD (Book of the Dead), and 31. N67.36.)

2) Natron and a limestone environment:


Samples which showed readings similar to the readings for the elements of linen plant fibres treated with natron were new linen control samples washed with natural natron and those samples from an archaeological environment protected from light and air pollution, i.e. those samples from a tomb burial.

b. Limestone environment: Carbon, oxygen, sodium, magnesium, aluminium, silicon, phosphorus, sulphur, chlorine, potassium, calcium, titanium, and iron. Calcium carbonate (CaCO₃) is the primary constituent of limestone, while magnesium calcium carbonate (CaMg[CO₃]₂) is the major component of dolomitic limestones. In Egypt limestones also commonly contain quatrz
(chief component silica, SiO₂), iron oxides (haematite, Fe₂O₃ or goethite, HFeO₂), besides various clay minerals, all of which are aluminosilicates (Aston, Harrell & Shaw, 2000, pp. 5-77).

It is well known that graveyards commonly have high levels of phosphorus from bones. As well, phosphorus is a natural constituent of soils. Therefore the presence of phosphorus in any of the samples recovered from mummy wrappings in graveyards could be expected.

Samples that contained the elements characteristic of a limestone environment were control samples from simulated archaeological deposits and also ancient Egyptian linen from archaeological deposits. These were samples from the cemeteries on the West Bank of the Nile near present-day Cairo (MS1, MS2, MS3, MS4, MS5, L, and U), from Middle Egypt (MU 2982, TK), from Tell el Amarna (N67.38 and N67.39), and from unknown provenances (N, T, and cartonnage).

The presence of sulfur in some of the samples needs careful consideration. Some of the samples that contained sulfur came from museum collections, where they had lain in non-air-conditioned environments for many years. These museums are located in large urban centres and consequently have
experienced high levels of atmospheric pollution, with \( \text{SO}_2 \) a common air pollutant (Samples N and T). Other samples are known to have been relatively recently excavated, from environments formerly unaffected by air pollution but which may now be beginning to experience air pollution (Samples MS1, MS2, MS3, MS4, and MU2982). In this case the presence of sulphur in the samples may be an indication of the presence of air pollution, as the \( \text{SO}_2 \) in atmospheric pollution could be transferred through rain, dew, or ground water to the archaeological deposits.

c. The cartonnage samples constitute a special sub-group of samples. This is because they were not in direct contact with the soil, but instead were in direct contact with the calcium carbonate, glues and paint that were applied to the linen in order to create cartonnage. It must be noted that these linen fibres and pieces of straw (plant stems and seed heads) were very well preserved, therefore demonstrating that direct contact with these carbonate materials can act to preserve plant fibres.

4.5 The Question of Mineralization

A question for some discussion would be whether the evidence does indeed indicate that these linens, through deliberate washing with Natron by the ancient Egyptians and/or in some cases through their subsequent
archaeological deposit in environmental conditions where alkaline salts are present, have been indeed been partially mineralised?

The Oxford definition would include this process as mineralization, or partial mineralization. If this is so, then we could think of mineralization as a relative scale or continuum of mineralization, as all organic materials, including living organisms, contain inorganic minerals. Indeed, some human beings absorb great quantities of salt, such as certain salt workers in India, who absorb so much salt into their bodies during their lifetimes that their bodies can not be cremated after their deaths, as they will not burn (Kurlansky 2002, p. 354). Can we consider these living people as mineralised?

At what point do we consider fabrics to have been partially mineralised? Is it when elemental analysis shows some inorganic elements to be present (but it also shows that carbon still remains), though the fabric does not appear to be affected by them to the naked eye or the drape of the fabric to human touch? Is it when crystals of salts are visible under the microscope? Is it when the fabric is visually changed, its feel or drape has been stiffened and its colour changed?

Complete mineralization would be both easier to identify and to define. Complete mineralization would occur when all of the organic material (i.e. that containing carbon) in the textile fibres will have been replaced with inorganic minerals.

For this study I have adopted the position that textiles have been partially mineralised when elemental analysis shows a higher than normal level of salts to have combined with and/or replaced the organic matrix of the textile fibre.
As the results of EDXA analysis of a majority of the samples of linen from ancient Egypt showed that the fibres contained a markedly higher level of salts than could have been expected from new, unwashed, linen, I would conclude that ancient Egyptian linen did undergo a process of partial mineralization through either washing with natron or through another form of environmental exposure to high levels of alkaline salts.

4.6 Recommendations

1. The presence of salts within the fibres of textiles needs to be considered in any conservation treatment, or when planning for the display or storage of textiles, as the salts which may have aided in the preservation of the linen while within a stable and dry climate may react to changes in environmental conditions, particularly to moisture and temperature changes, with resulting damaging effects upon fibres. Therefore future conservation examination of ancient Egyptian linen should include testing to determine the presence or absence of salts prior to any conservation treatment. After such an examination the textile conservator will then be able to make an informed decision regarding the advisability of treatment and the provision of suitable storage conditions.

2. Textiles have typically been housed at relative humidities around 50%. However, an understanding of the nature of archaeologically recovered ancient Egyptian linen, as cited above, would lead us to conclude that this is
too high a humidity for the storage of such linen, due to the presence of soluble salts in the linen. Therefore, a lower humidity should be investigated as an alternative for the storage of such linen.

An argument for a higher humidity has been that a low humidity will cause dehydration of organic materials. While this is true for historic textiles kept in historic houses or for materials recovered from wet sites: it is not a consideration when discussing ancient Egyptian linen, which has already been desiccated.

3. As the pH of some ancient Egyptian linen is buffered already by salts within its fibres, additional buffering is not necessary. Indeed, it might raise the pH to a level above 10 and induce a change of cellulose structure, or it may damage the fibres. Therefore ancient Egyptian linen should be kept in storage containers with either a neutral pH or only slightly alkaline linings.

4. As analysis of some of the ancient Egyptian linen samples has shown the presence of small amounts of Cu and other metals within the fibres, and as Cu other metals are known to act as catalysts in the process of photo-oxidation, which is detrimental to the preservation of textiles (Timar-Balazsy & Eastop, 1998, pp. 227-228), it is strongly recommended that this evidence be taken into consideration when determining the level of light used during display
periods and the length of time ancient Egyptian linen is displayed. Ideally, ancient Egyptian linen should be protected from all exposure to light (replicating its archaeological deposit conditions), though practical conditions of museum storage and the necessity for some display of textiles may not allow the ideal to be achieved in practice. However, ancient Egyptian linen should be considered among the most light sensitive of materials, and therefore when in storage they should be boxed or covered and when on display exposed to a light level no greater than 50 lux, with any UV (ultraviolet light) filtered out (Cronyn, 1990, p.78).

5. Wet cleaning of any kind should be avoided unless judged absolutely necessary. Any change of the stable equilibrium reached by the textile with its environment may have detrimental effects. To unnecessarily subject the textile to the shock of environmental change which washing causes is to risk seriously damaging the fibre structure. While washing would reduce salts and particulate matter within the fibres, this study shows that to completely remove these salts would be very difficult, if not impossible, without endangering the stability of the fibres. Instead, storage of the textile at stable low humidity levels is recommended.
6. If washing is necessary, then a small sample of a single representative thread could be tested, using optical microscopy and/or ESEM with EDXA, to gain a better understanding of the nature of the linen, and the presence of salts, and the nature of any salts and particulate material present. Testing would inform the curator and conservator of the nature of the object before any treatment is undertaken. A high salt content might indicate that washing is potentially dangerous to the future stability of the fabric, and the contrary would be the case if the salt content was low. Another way of putting it would be to say that the higher the salt content the more risk washing would pose to the stability of the fabric.

7. Further analysis of linen samples suitable for research purposes could be undertaken. For this analysis a combination of techniques would be recommended: curatorial examination and description followed by optical microscopy, ESEM with EDXA and IC. having been found to yield maximum information in this study of ancient Egyptian linen. However, the use of IC columns designed specifically for the testing of high salt content samples is recommended. This could give a more accurate picture of the rate of release of sodium chloride from the fibres and the total amount of all the salts present than does the more common IC column using sodium carbonate/bicarbonate as eluent. It also might be useful to use TEM with EDXA to analyse cross
sections of fibres, to attempt to determine salt content within the cellular structure of linen fibres.

8. Based upon the research cited in this study, the use of either slow drying or freeze-drying is advocated as a safe method for drying textiles that are known by prior testing to contain salts. If a textile is found to contain a high level of salts, and a decision is made to wash that textile, then freeze-drying might be preferable as a method of drying, as the sublimation of water from the sample during freeze-drying might minimise damage to the fibres. The use of either slow drying or freeze drying appears to minimise the effects of the drying of water upon surface tension as well as to minimise the crystal size of any salts upon drying, but evidence from these studies could be seen as showing that freeze drying might be more effective in certain conditions. Further testing of these methods is highly recommended, both in archaeological field conservation and in laboratory based conservation research.

9. Analysis of textiles and other artefacts recovered from sites in Egypt could be undertaken in order to monitor the effects of environmental pollution on archaeological sites. The results need to be coordinated with ongoing pollution studies conducted by the Egyptian government, and in particular, with work done by the Supreme Council of Antiquities.
One possibility would be to monitor the level of moisture penetration in sandy deposits on sites which are suspected to be affected by air pollution, in order to ascertain just how far such pollution is carried by moisture into a deposit. Another possibility would be to do a comparison of samples of textiles recovered from different environmental zones on one site in order to ascertain whether or not there are differences in the level of pollutants in the textiles. For instance, textiles from a sandy deposit outside a rock cut tomb could be tested and compared with textiles which have been recovered from inside the adjacent tomb.

10. In a flow-on of what has been advocated by many archaeologists in relation to the excavation of archaeological sites, Brooks, et al. (1996, p. 19) advocated that “it may be appropriate to ensure that some archaeological textiles are left untreated to preserve their integrity for future improved techniques of analysis or treatment”.

Firstly there is the stability of the object to be considered. Then there is what is termed by some as the integrity or authenticity of the object, i.e., a state as close to the original as possible. Archaeological analysis for studies of dating, provenance, manufacture, etc. depends for its relevance and accuracy on
objects that have remained unadulterated with modern materials and in as original a condition as possible.

My study has also shown that information may be gained about changes in the environmental conditions of the archaeological site through analysis of the artefacts recovered from the site. This capacity, available since last Century for inorganic materials such as metals and pottery, is now becoming a possibility for organic materials through the use of such sensitive analytical tools as IC and ESEM with EDXA. To risk the destruction of such information through unnecessary conservation treatment might be considered irresponsible.

11. This study has concentrated on linen fabric. Research is necessary to determine whether salts act in a similar matter in fabrics made of other fibres. Research is particularly necessary to determine the role of salts in the preservation of Coptic textiles, where linen was often used in conjunction with wool. This line of research has already been taken up by a Mellon Fellow in the United States of America (Sutcliff, personal communication by e-mail, 2000), and this research will hopefully illuminate the difficult questions surrounding the conservation treatment of fabrics made up of several different fibres.
12. This study opens up the possibility of similar examination of organic archaeological materials other than textiles, such as basketry, and papyrus.

13. The study of natron and other salts in ancient Egyptian linen has relevance not only to archaeological studies, but also to historic studies and to the conservation of cultural materials held in art galleries and libraries. The techniques that were used to detect salt movement in ancient linen could be used in the examination of historic textiles, works of art on linen, and paper based materials. The potential for movement of salts within these materials, and the effects of salts upon paints, pigments and inks has caused concern among cultural heritage managers. Techniques that were successfully used to observe and monitor salt movement in ancient linen could be adapted to the examination of a wide range of organic based cultural materials, to aid curators, conservators, and other managers of the cultural heritage to more informed judgements in questions of treatment, storage and display.

4.5 Conclusions

- This chapter outlined the current theory and practice of textile conservation with reference to the cleaning of archaeological textiles, and discussed arguments for and against their use.
• This chapter discussed the experimental results given in Chapter 3 in relation to the conservation of archaeological textiles from ancient Egypt. Emphasis in the discussion was on the implications of the experimental results for the cleaning of textiles containing salts.

• The use of freeze-drying for samples was discussed.

• The use of deacidification solution for textiles was discussed.

• Recommendations were made concerning the conservation treatment of ancient Egyptian linen.

• Recommendations were made for further research.
Chapter 5

Conclusion

A. M. Pollard and C. Heron, in the preface to the book *Archaeological Chemistry* (1996, p. ix) write of archaeological science that:

Perhaps the most important message it contains is the need to tackle the fundamental issues of chemical change in archaeological materials if scientific analysis is to make major contributions to the study of the past.

This pilot study began an investigation of the fundamental issues of change in ancient Egyptian linen. This study of ancient Egyptian linen led to the hypothesis that:

Textiles from ancient Egypt have often undergone a form of partial mineralization through either (a) treatments involving natron, and possibly other salts, in antiquity and/or (b) environmental conditions where the linen has come into contact with natron, possibly in conjunction with other salts and that this partial mineralization has contributed to their survival.

This study has indicated that linen textiles from ancient Egypt may have often undergone a form of partial mineralization through washing treatments involving natron and other soluble inorganic salts during their usage in antiquity and also through their deposit in archaeological environments containing alkaline inorganic salts. This partial mineralization appears to have
aided in their preservation and contributed to their survival by buffering them against acidity, by protecting them against colonisation by halophobic bacteria and fungi, and through the process of partial mineralization itself. These fabrics appear to have survived because their archaeological environment had helped to preserve their chemical and physical structure. Therefore their present chemical and physical structure should not be disturbed by washing or even high humidification without due care and consideration, as humidification and dehumidification could cause the movement of salts within and out of the fibres, which could result in deterioration of the textile fibres.

As part of this pilot study on the nature of salt movement in ancient Egyptian textiles, linen samples from Egypt were examined using the highly sensitive techniques of Ion Chromatography (IC) and Environmental Scanning Electron Microscopy (ESEM), combined with X-ray analysis. These analytical techniques were successfully used to distinguish between linen fibres, foreign matter present on and within linen fibres, and natron or other salts absorbed into the linen fibres in a form of mineralization.

IC has previously been used to monitor the removal of salts from building materials and ceramics, but its use for the monitoring of salts in organic
artefacts has not previously been reported. ESEM has been successfully used for the study of salts in stone, but not for an observation of the movement of salts in textiles. Its successful use, both for the examination of fibres and for the observation of cycles of hydration and dehydration, was central to the conclusion made in this pilot study. X-ray diffraction and EDXA were used for the identification of crystalline inorganics present in archaeological deposit and linen samples, and this information was correlated with the results of ESEM, IC, and EDXA analysis of ancient Egyptian linen samples. This correlation of archaeological deposits with inorganic elements present in linen recovered from these deposits has demonstrated the possibility of 'fingerprinting' linen using these analytical techniques.

This study has been able to demonstrate for the first time the apparent movement of salts within ancient textile fibres using ESEM with EDXA. Thus the apparent movement of salts in solution into the fibres during hydration and the crystallisation of salts within and upon the surface of textile fibres have been observed and recorded as it happened. It has been demonstrated that inorganic soluble salts such as natron and sodium chloride may mineralise archaeological linen fibres, and that the movement of these salts during cycles of hydration and dehydration may act to damage the textile fibres.
It has been demonstrated that the analytical techniques of IC, optical microscopy, ESEM and EDXA can be used for the examination of linen in order to assess its chemical and physical nature prior to any conservation treatments, or when considering environmental conditions for the storage or display of linen textiles. This method can indicate both the chemical nature of any salts present in the textile and also the relative quantity of such salts. It can also indicate the level of fibre damage already experienced by the specimen fibre, and so give at least a partial indication of the relative strength of the textile fibres. These analytical methods can also be used to monitor aqueous treatments of textiles for salts, enabling the washing process to be carefully monitored for effectiveness. Thus this pilot study has been successful in achieving its specific objectives by:

- Describing the environmental factors that have contributed to the survival of ancient Egyptian linen, so that these factors could be taken into consideration in the treatment, display and storage of these archaeological artefacts;
- Demonstrating an objective method for assessing the state of preservation of archaeological linen through the combined use of the analytical tools of optical microscopy, IC, and ESEM with EDXA;
- Demonstrating that the examination of archaeological linen fibres using ESEM with EDXA can distinguish between the natural fibre of
the linen and any salts or other foreign matter the linen had absorbed from either its usage in antiquity, from its archaeological environment, or from its storage environment;

- Demonstrating that archaeological linen with a high salt content could best be treated through storage within dry environmental conditions in order to stabilize the salts in a crystalline state, thus meeting a specific objective of this study to validate improved methods for the display and storage of archaeological textiles; and

- Demonstrating that if conservation treatment involving washing of the linen is necessary, then ancient Egyptian linen containing salts, which has been examined and evaluated using the above analytical methods, and which is then judged to be suitable for such treatment, can be successfully treated using a combination of water washing and freeze-drying, thus meeting a specific objective of this study, which was to validate improved methods of treatment for archaeological linen textiles; and by

- Adding to our understanding of the chemical and physical nature of ancient Egyptian linen textiles through an examination of the role of natron and other salts play in the preservation and conservation of archaeological textiles.
Ancient Egyptian Linen —

The Role of Natron and Other Salts in the Preservation and Conservation of Archaeological Textiles—

A Pilot Study

Appendix A

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A thesis submitted in fulfilment of the requirement for the degree of Doctor of Philosophy

University of Western Sydney

2002
Appendix A:

Maps

Textile Analysis

Samples
APPENDIX B IS CONTAINED ON CD ROM WHICH ACCOMPANIES PRINT COPY
Map. 1 *Ancient Egypt* (Boulanger, 1965) Shows Upper, Middle and Lower Egypt, as well as ancient city sites.
Map. 2 Helwan. (Detail) Map Scale 1:25,000, Portions of Sheets 79/630 and 79/645, Government of Egypt. 1st edition 1933. 2nd ed. 1950. The map shows the positions of Helwan and Saqqara.
Map 3. Map showing the burial of Tby/Tjeby. Photograph courtesy of the Museum of Victoria, Melbourne.
Map. 4. Around Cairo (Logan, et.al., 1997, 219). A modern map of the Cairo area, showing the Wadi Natrun, the Giza Plateau (West bank of the Nile River and the area from Maadi through Helwan (East bank of the Nile River).
Map. 5 Egypt (Logan, Cole, Simonis, and Wayne, 1997, 12).
A modern map of Egypt. The enlargement shows the locations of Wadi Natrun, Giza and Saqqara in relationship to modern Cairo and modern Alexandria.
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Samples
Textile Samples

The following are a compilation of test results for new linen control samples, for natron used to wash new linen in order to simulate the washing of ancient linen, and for archaeologically recovered samples of ancient Egyptian linen. They are numbered and the order arranged by category: new linen samples are first, then natron, and then all ancient linen samples. Ancient Egyptian linen samples are identified by their museum catalogue number or by a unique set of letters and numbers.

For each sample a short description is given of its provenance\(^1\), together with whatever data was recorded for the sample. Fibres were removed from the larger textiles at different times for different tests. Therefore each textile sample may have several sub-samples listed. A sub-sample number identifies the test samples, when necessary, (e.g., sample 1; sample 2; sample 3).

Whenever possible, samples were photographed before examination using Kodak colour slide film, ASA 64. They were also digitally recorded during ESEM examination and optical microscopy. If samples were soaked or

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\(^1\) Information is given about the linen’s date, area of archaeological recovery, type of archaeological deposit, and any historical information that is known about the linen.
washed then they were also photographed after this treatment. When available, selected colour photographs of the samples, photomicrographs of fibres, and still digital images of fibres taken during ESEM analysis, together with relevant EDXA graphs and IC results are reproduced in Appendix A for each sample. As the photographs have not been reproduced in a one to one format, the photographs, as reproduced on the following pages, cannot be used to calculate specimen sizes.

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Appendix A: Samples. Figure 34.1 N67.40 (a and b together).  
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Appendix A: Samples. Figure 34.3 N67.40b.  
Appendix A: Samples. Figure 34.4 N67.40b.  
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Appendix A: Samples. Table 35.1 N67.42.  

36. Sample X83758 (Mummy of Tby/Tjeby)  
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Appendix A: Samples. Figure 36.2 Tbj/Tjeby (X83758).  
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Appendix A: Samples Table 36.1 The Mummy of Tby/Tjeby (X83758).  
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Numbers 1-36
1. *Linum usitatissimum*

Appendix A: Samples. **Figure 1.1** *Linum usitatissimum*. Photograph by the author February 2002. Sections of this plant are reproduced below.

Appendix A: Samples. **Figure 1.2** *Linum usitatissimum*. Cross-section of the stem. Water mounted and stained to show lignin (blue) and bast fibres (outer layer of purple and light blue). Photograph by the author.

Appendix A: Samples. **Figure 1.3** *Linum usitatissimum*. Longitudinal section of the stem to show bast fibres (stained purple and light blue). Photograph by the author.
Appendix A. Samples. Table 1. *Linum usitatissimum*
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Sample Number</th>
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</tr>
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<td>Method of Analysis</td>
<td>Optical Microscopy</td>
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<tr>
<td>Fibre</td>
<td>Linen</td>
</tr>
<tr>
<td>Spin</td>
<td>NA</td>
</tr>
<tr>
<td>Ply</td>
<td>NA</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td></td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>NA</td>
</tr>
<tr>
<td>Colour</td>
<td></td>
</tr>
<tr>
<td>Environment</td>
<td>NA</td>
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<tr>
<td>Area</td>
<td>Australia</td>
</tr>
<tr>
<td>Period</td>
<td>New</td>
</tr>
<tr>
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</tr>
<tr>
<td>Lignin</td>
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<tr>
<td>Fibrillation</td>
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</tr>
<tr>
<td>Fissures</td>
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</tr>
<tr>
<td>Salt Crystals</td>
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</tr>
<tr>
<td>Particulate Matter</td>
<td>None</td>
</tr>
<tr>
<td>pH</td>
<td></td>
</tr>
<tr>
<td>Photography</td>
<td>C</td>
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</table>

**Key**

*Fibre Analysis*
- L = Linen
- W = Wool
- B = Bast Fibre
- W = White
- N = Natural Linen
- S = Stained (Dark Brown)
- D = Deteriorated
- N/A = Not Applicable
- ? = Uncertain or Not Known

*Environment*
- GB = Burial in Ground
- TB = Tomb Burial
- PB = Presumed Burial in Ground

*Period*
- PD = Pre-Dynastic Period
- D = Dynastic Period
- GR = Greco-Roman/Ptolemaic
- R = Roman/Coptic/Late Antiquity

*Area*
- MC = Memphis Area Cemetery
- ME = Middle Egypt
- UE = Upper Egypt
- U = Unknown
- N/A = Not Applicable
- ? = Uncertain

*Type of Photographic Record*
- P = Colour Photograph
- S = Colour Slide
- B & W = Black and White Photograph
- V = Video Film (B & W)
- C = Computer image, B & W
2. Control Samples of Modern Linen

Undyed pure linen was purchased from Spotlight, Penrith, New South Wales, Australia. It was of a comparable weight and weave to the ordinary grade of ancient Egyptian cloth. However, optical microscopy and ESEM analysis showed it to have a greater tendency to fibrillation than did the ancient Egyptian linen examined in the study. The origin of the new linen was marked as China. The linen was washed by hand in pure deionized water. It was then pH tested and found to be pH 5 using a Merck test strip (colorpHast pH 0-14).

Appendix A: Samples. Figure 2.1 New Linen. Photograph of new linen before any treatment. The colour of the linen in this photograph has become inaccurate when converted to digital format. The actual colour of the linen is a light buff, a natural linen colour. Photograph by the author.

Appendix A: Samples. Figure 2.2 ESEM Image of New Linen. Computer image taken by Dr. Matthew Phillips and the author, taken at the University of Technology, Sydney.
### Appendix A: Samples. Table 2.1 New Linen Washed in Deionized Water

For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
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<th>SEM, ESEM &amp; EDXA</th>
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<tr>
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<td>L</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>15x15</td>
<td>15x15</td>
</tr>
<tr>
<td>Colour</td>
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<td>N</td>
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<td>Environment</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Area</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Period</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Level of Deterioration</td>
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<td>New</td>
</tr>
<tr>
<td>Lignin</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Fibrillation</td>
<td>Small</td>
<td>Small</td>
</tr>
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<td>Fissures</td>
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<td>None</td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Photography</td>
<td>C</td>
<td></td>
</tr>
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</table>

**Key**

**Fibre Analysis**
- L = Linen
- W = Wool
- B = Bast Fibre
- W = White
- N = Natural Linen
- S = Stained (Dark Brown)
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**Environment**
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- R = Roman /Coptic/ Late Antiquity

**Area**
- MC = Memphis Area Cemetery

ME = Middle Egypt
UE = Upper Egypt
U = Unknown
N/A = Not Applicable
? = Uncertain

**Type of Photographic Record**
- P = Colour Photograph
- S = Colour Slide
- B & W = Black and White Photograph
- V = Video Film (B & W)
- C = Computer image, B & W
Appendix A: Samples. Table 2.2 Control New Linen Washed in Deionized Water

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>Linen</td>
<td>Absent</td>
<td>None</td>
<td>Calcium chloride, sodium.</td>
</tr>
<tr>
<td>IC</td>
<td></td>
<td></td>
<td></td>
<td>16 Hour Washing Test:</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Hour 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sodium 95.76 ppm</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>Magnesium 10.40 ppm</td>
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<td></td>
<td></td>
<td></td>
<td>Chloride 11.35 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bromide 0.28 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nitrate 1.97 ppm</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Sulphate 0.76 ppm</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Hour 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sample 1:</td>
</tr>
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<td>Nitrate 0.33 ppm</td>
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<td>Sulphate 0.25 ppm</td>
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<td>Sample 2</td>
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<td></td>
<td></td>
<td></td>
<td>Nitrate 0.46 ppm</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Sulphate 0.38 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hour 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sodium 26.73 ppm</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>Magnesium 2.71 ppm</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Potassium 4.38 ppm</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Calcium 39.83 ppm</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Hour 16</td>
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<td>Chloride 0.08 ppm</td>
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<td>Bromide 0.28 ppm</td>
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<td></td>
<td></td>
<td>Nitrate 0.29 ppm</td>
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<tr>
<td>ESEM</td>
<td>Smooth. Sound. Small amount of</td>
<td>None</td>
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363
<table>
<thead>
<tr>
<th></th>
<th>fibrillation.</th>
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</thead>
<tbody>
<tr>
<td><strong>ESEM Dynamic Study</strong></td>
<td>No changes</td>
<td>None</td>
</tr>
<tr>
<td><strong>EDXA</strong></td>
<td></td>
<td>Carbon, oxygen silicon, Calcium. (See also EDXA spectrum Figure 2.3 on the next page and Figure 2.4, a graph of IC washing test on the following page.)</td>
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<tr>
<td><strong>pH</strong></td>
<td>5.0-6.0</td>
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Appendix A: Samples. Figure 2.3 EDXA Spectrum of New Linen. The spectrum was taken by K. McBean and the author at the University of Technology, Sydney.
Appendix A: Samples. Figure 2.4 New Linen Control. 16 Hour Washing Test. Results reported in ppm (Mg/L).
3. New Linen; Washed first in deionized Water, Dried, Then Washed in Natron.

New linen used as a control has been described in Appendix A 2. Control Samples of Modern Linen. Six pieces of new linen cloth were washed in deionised water, using natron as a cleaning agent. Three of these pieces were then rinsed in deionized water and three were left un-rinsed. The pH of the un-rinsed samples were then measured and found to be pH 10.

Appendix A: Sample Figures. 3.2 ESEM Image of New Linen with Natron. This is an ESEM image of a sample of new linen that had been washed in natural natron, showing particulate matter and salts. This computer image was taken by Dr. Matthew Phillips and the author at the University of Technology, Sydney.
Appendix A: Samples. Table 3.1 New Linen Washed in Natron.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Test</th>
<th>Optical Microscopy</th>
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<td>Sub-sample Number</td>
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</tr>
<tr>
<td>Fibre</td>
<td>L</td>
<td>L</td>
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<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Weave</td>
<td>1/1</td>
<td>1/1</td>
</tr>
<tr>
<td>Weave Count (sq. cm)</td>
<td>15 x 15</td>
<td>15 x 15</td>
</tr>
<tr>
<td>Colour</td>
<td>W</td>
<td>W</td>
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<tr>
<td>Environment</td>
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<td>N/A</td>
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<td>New</td>
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<td>Generally Sound</td>
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<tr>
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<td>Small Amount</td>
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<td>Fissures</td>
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<td>Absent</td>
</tr>
<tr>
<td>Salts</td>
<td>Present</td>
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<tr>
<td>Particulate Matter</td>
<td>Visible as dark lines inside some cells.</td>
<td>Present</td>
</tr>
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<td>Photography</td>
<td></td>
<td>V, C</td>
</tr>
</tbody>
</table>

Key

N/A = Not Applicable
? = Uncertain or Not Known

Fibre Analysis
L = Linen
W = Wool
B = Bast Fibre
W = White
N = Natural Linen
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P = Colour Photograph
S = Colour Slide
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V = Video Film (B & W)
C = Computer image, B & W
Appendix A: Sample Table 3.2 New Linen; Washed first in Deionized Water, Dried, Then Washed in Natron.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
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</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>Linen</td>
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<td>Present</td>
<td></td>
</tr>
<tr>
<td>IC</td>
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<td></td>
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<td></td>
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<tr>
<td>ESEM Dynamic Study</td>
<td>Small level of damage</td>
<td>Present. Crystallized on the surface.</td>
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<td></td>
</tr>
<tr>
<td>EDXA</td>
<td></td>
<td></td>
<td></td>
<td>Carbon, oxygen, sodium, chlorine, magnesium, aluminium, silicon, sulfur, calcium, iron. (See also EDXA spectrum below.)</td>
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<tr>
<td>pH</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
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</table>
Appendix A: Samples. Figure 3.3 EDXA Spectrum of New Linen Washed with Natron. This spectrum was taken by K. McBean and the author at the University of Technology, Sydney.
4. New Linen Washed in Natron and then Rinsed with Deionized Water.

Three samples of new linen that had been washed using natron as a cleaning agent were then rinsed in deionized water. They were then pH tested while still wet and found to be pH 5. Examination using optical microscopy under low magnification showed less particulate matter on the surface of the fibres than on the than control sample washed with natron and un-rinsed. When examined using ESEM the fibres appeared to have less particulate matter on their surface and between the fibres than did the control that was washed in natron and examined un-rinsed. During the ESEM dynamic study there was less visible crystallisation of salts on the fibres than with the control washed in natron and un-rinsed, but the cycle did occur and it did appear to cause some damage to fibres.

Appendix A: Samples. Figure 4.1 New Linen Washed with Natron and Rinsed with Deionized Water. The colour of the sample is inaccurate, as the sample was a natural linen colour (light buff, not white). Photograph by the author.
Appendix A: Samples. Table 4.1 New Linen Washed in Natron and Rinsed with Deionized Water.

For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
<th>SEM, ESEM &amp; EDXA</th>
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<td>Fibre</td>
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<td>S</td>
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<tr>
<td>Ply</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
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<td>1</td>
</tr>
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<td>Weave Count (cm)</td>
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<td>15x15</td>
</tr>
<tr>
<td>Colour</td>
<td>N</td>
<td>N</td>
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<td>Environment</td>
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<td>N/A</td>
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<td>N/A</td>
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<td>Level of Deterioration</td>
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<td>Absent</td>
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<td>Fibrillation</td>
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<tr>
<td>Fissures</td>
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</tr>
<tr>
<td>Salt Crystals</td>
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<td></td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Photography</td>
<td>C</td>
<td></td>
</tr>
</tbody>
</table>

**Key**

**Fibre Analysis**
L= Linen  
W= Wool  
B= Bast Fibre  
W = White  
N= Natural Linen  
S= Stained (Dark Brown)  
D= Deteriorated  
N/A= Not Applicable  
? = Uncertain or Not Known

**Type of Photographic Record**

P=Colour Photograph  
S= Colour Slide  
B & W = Black and White Photograph  
V = Video Film (B & W)  
C= Computer image, B & W

**Environment**

GB= Burial in Ground  
TB= Tomb Burial  
PB= Presumed Burial in Ground

**Period**

PD= Pre -Dynastic Period  
D= Dynastic Period  
GR= Greco-Roman /Ptolemaic

**Area**

MC= Memphis Area Cemetery  
ME = Middle Egypt

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Appendix A: Samples. Table 4.2 Control New Linen Washed First in Deionized Water, Dried, Then Washed in Natron, and then Rinsed.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>Linen</td>
<td>Absent</td>
<td>Present. Less than un-rinsed sample.</td>
</tr>
<tr>
<td>IC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESEM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESEM Dynamic Study</td>
<td>Small amount of damage. Less than un-rinsed sample.</td>
<td>Crystallization of salts less than un-rinsed sample.</td>
<td></td>
</tr>
<tr>
<td>EDXA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>5.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. Deacidified Linen

Three samples of new linen were first washed in deionized water. Then they were soaked for one hour in a solution of magnesium bicarbonate deacidification solution, pH 9.0. Then they were air-dried. ESEM and EDXA examination of the dried sample show that elements present are carbon, oxygen, sodium, magnesium, silicon, and calcium. There is no peak for chlorine. All peaks except those that represented the linen itself were considerably lower than those recorded for the same elements in the samples treated with natural natron and those ancient Egyptian linens that appeared to have been treated with natron in antiquity.
Appendix A: Sample Figure 5.1 New Line Soaked in Magnesium Bicarbonate Solution. A photograph of a sample of new linen after it has been soaked in a magnesium bicarbonate deacidification solution and air-dried. The colour is inaccurate, as the linen is a natural linen colour (light buff). Photograph by the author.
Appendix A: Sample Figure 5.2. ESEM Image of New Linen Soaked in Magnesium Bicarbonate Solution. This is an ESEM image of new linen soaked in magnesium bicarbonate deacidification solution and air-dried. This computer image was taken by K. McBean and the author at the University of Technology, Sydney.
Appendix A: Sample Figure 5.3 EDXA Spectrum of New Linen Soaked in Deacidification Solution. This new line was washed in deionized water, then soaked in a magnesium bicarbonate deacidification solution and then air-dried.
6. Sample of Rope from the *Mary Rose*

As a reference sample, a sample of an archaeologically recovered bast fibre rope from a 16th Century ocean shipwreck, the Mary Rose, was used. This was a bast fibre that was not flax. It was recovered from an ocean environment and so came from a salt rich environment different from the Egyptian textiles. This sample was obtained from a donor who wished to remain anonymous.

Optical microscopy analysis showed that the fibres were coarse in quality and appeared to be tarred on the outside of the sample. When soaked in deionized water for one hour for I.C analysis the rope itself disintegrated, and considerable damage to the fibres was observed after air-drying.
Appendix A: Samples. Figure 6.1 MR Before Treatment.
A photograph of a sample of MR before soaking in deionised water. Photograph by the author.

Appendix A: Samples. Figure 6.2 MR After Treatment.
A photograph of a sample of MR after soaking in deionised water. Photograph by the author.
<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present Sub-samples 1 and 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>A bast fibre, either hemp or jute. Tarred</td>
<td>Present</td>
<td>Present</td>
<td>Sub-sample 1. (a fresh sample)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lithium 68.87 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Potassium 6.91 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnesium 12.95 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Calcium 11.90 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sub-sample 2. (A sample that had been allowed to stand before examination.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lithium 65.26 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ammonium 14.83 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Potassium 7.98 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnesium 12.34 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Calcium 10.40 ppm</td>
</tr>
<tr>
<td>IC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESEM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washing In Deionized Water</td>
<td>Disintegration of rope with considerable damage to fibres.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDXA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>5.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7. Natron

Natron was collected from the Wadi Natrun (also called the Wadi Natron), a depression in the Libyan Desert approximately northwest of modern Cairo. The Natrun Valley contains ten salt lakes, which dry up almost completely during the summer months, leaving deposits of natron. The sample was collected from one of the lakes in mid-winter (January 1999). At that time there was a shallow expanse of water, with an area of approximately 20 feet surrounding the water covered with a thick crust of natron (see Chapter 3, which provides further information on the location and appearance of Wadi Natrun).
Appendix A: Samples. Figure 7.1 Natron Sample. A photograph of samples of natron being collected at the Wadi Natrun, Egypt by the author in January 1999. Photograph by the author.
Appendix A: Samples. Table 7.1 Natron.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present Sub-samples 1 and 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td></td>
<td></td>
<td></td>
<td>Natron 2.6 g Sub-sample 1. Potassium 26.02 ppm Magnesium 4.47 ppm Calcium 16.77 ppm</td>
</tr>
<tr>
<td>IC</td>
<td></td>
<td></td>
<td></td>
<td>Sub-sample 2. Potassium 26.12 ppm Magnesium 4.50 ppm Calcium 16.75 ppm Natron 1/100 dilution</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sub-sample 1. Fluoride 0.13 ppm Chloride 68.02 ppm Nitrite 3.72 ppm Bromide 1.35 ppm Nitrate 1.32 ppm Phosphate 2.21 ppm Sulphate 222.16 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sub-sample 2. Fluoride 0.23 ppm Chloride 66.80 ppm Nitrite -not present Bromide 1.18 ppm Nitrate- not present Phosphate 2.13 ppm Sulphate 211.58 ppm</td>
</tr>
<tr>
<td>ESEM</td>
<td></td>
<td></td>
<td></td>
<td>(See also Figure 7.2 on the next page.)</td>
</tr>
<tr>
<td>ESEM Dynamic Study</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDXA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix A: Samples. Figure 7.2 Sample of Natron. 1/100 dilution. Results of IC Analysis. All results reported as ppm (Mg/L).
8. MS1

This textile was recovered post-1960 from a ground burial in the Memphis cemetery area. The mummy with which it was associated has been dated as Dynastic. The mummy was found buried directly in a sandy deposit, in association with a mummified body. The quality of the mummification was not high and the grave was judged to be that of a member of the poorer classes. No grave goods are recorded as being in direct association with the burial, but a full range of grave goods is recorded for burials in the immediate area, including fibre materials in basketry, wood, shell, bone ornaments, glass, fiancé (glazed siliceous ceramic), semiprecious stones, and ceramics. The whole archaeological deposit was dry. The linen appeared upon excavation to be quite sound. It was also flexible and could be easily handled. It appeared yellowed and possibly stained, both with dark areas and with a white deposit.

The fibre was identified as linen. Under microscopic analysis the fibres appeared ordinary to coarse in quality. When tested for lignin no lignin was present. The pH of the sample was found to be between 5 and 6.0
Appendix A: Samples. Figure 8.1 MS1. Photograph of MS1 Before Examination. Photograph by the author.

Appendix A: Samples. Figure 8.2. MS1. Photograph of MS1 after washing in deionized water and air-drying. Note how its right half is now matted. Photograph by the author.
Appendix A: Samples. Figure 8.3 MS1. Photomicrograph of MS1 before treatment using Optical Microscopy. 10x.Objective. Photomicrograph by the author.

Appendix A: Samples. Figure 8.4 ESEM Image of MS1. An ESEM image of MS1 before conservation treatment. The computer image was taken by K. McBean and the author at the University of Technology, Sydney.
Appendix A: Samples. Table 8.1 MS1.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
<th>SEM, ESEM &amp; EDXA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-sample Number</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fibre</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>&gt;1</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>5-7x 7</td>
<td>5-7 x 7</td>
</tr>
<tr>
<td>Colour</td>
<td>N, S</td>
<td>N, S</td>
</tr>
<tr>
<td>Environment</td>
<td>GB</td>
<td>GB</td>
</tr>
<tr>
<td>Area</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Period</td>
<td>MC</td>
<td>MC</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Damage</td>
<td>Damage</td>
</tr>
<tr>
<td>Lignin</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Fibrillation</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Fissures</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Photography</td>
<td>S</td>
<td>C</td>
</tr>
</tbody>
</table>

**Key**

**Fibre Analysis**
L= Linen
W= Wool
B= Bast Fibre
W= White
N= Natural Linen
S= Stained (Dark Brown)
D= Deteriorated
N/A = Not Applicable
? = Uncertain or Not Known

**Area**
MC= Memphis Area Cemetery
ME = Middle Egypt
UE = Upper Egypt
U= Unknown
N/A = Not Applicable
? = Uncertain

**Environment**
GB = Burial in Ground
TB= Tomb Burial
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**Type of Photographic Record**
P=Colour Photograph
S= Colour Slide
B & W = Black and White Photograph
V = Video Film (B & W)
C= Computer image, B & W

**Period**
PD= Pre-Dynastic Period
D= Dynastic Period
GR= Greco-Roman /Ptolemaic
R= Roman /Coptic/ Late Antiquity
### Appendix A: Samples. Table 8.2 MS1.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present IC Sub-samples 1 and 2, 3 and 4 (These had been a 1/100 dilution) and EDXRA Sub-sample 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>Linen</td>
<td>Absent</td>
<td>Present</td>
<td>Sub-sample 1. Lithium 59.71 ppm Ammonium¹ 22.52 ppm Potassium 303.16 ppm Magnesium 32.88 ppm Calcium 422.30 ppm</td>
</tr>
<tr>
<td>IC</td>
<td></td>
<td></td>
<td></td>
<td>Sub-sample 2. Lithium 57.05 ppm Ammonium¹ 15.04 ppm Potassium 305.86 ppm Magnesium 33.52 ppm Calcium 429.75 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sub-sample 3. Floride 0.28 x 100= 28.00 ppm Chloride0.91 x 100= 91.00 ppm Nitrite 0.71x100= 71.00 ppm Nitrate 1.25x100= 125.00 ppm Phosphate 1.90x100= 190.00 ppm Sulphate 1.77x100= 177.00 ppm</td>
</tr>
</tbody>
</table>

¹ This sample had been allowed to stand before examination.
<table>
<thead>
<tr>
<th>ESEM Dynamic Study</th>
<th>Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESEM Dynamic Study</td>
<td>Damage to fibre visible during cycle</td>
</tr>
<tr>
<td>Washing in Deionized Water</td>
<td>Extensive Damage</td>
</tr>
<tr>
<td>EDXA</td>
<td>Sub-sample 5. Silicon, chlorine, calcium, oxygen, sodium, magnesium, aluminium, sulphur, iron, carbon, oxygen, phosphorus, potassium, titanium. (See also EDXA spectrum below.)</td>
</tr>
<tr>
<td>pH</td>
<td>Initially 7.5 After storage 5.0 – 6.0</td>
</tr>
</tbody>
</table>

Sub-sample 4.
Floride 0.28 x 100 = 28.00 ppm
Chloride 0.85 x 100 = 85.00 ppm
Nitrite 0.71 x 100 = 71.00 ppm
Nitrate 1.24 x 100 = 124.00 ppm
Phospate 1.90 x 100 = 190.00 ppm
Sulphate 1.51 x 100 = 151.00 ppm

1. This sample had been allowed to stand before examination.
Appendix A: Samples. Figure 8.5 EDXA Spectrum of MS1. An EDXA spectrum of MS1 before conservation treatment taken by K. McBean and the author at the University of Technology, Sydney.
9. MS2

This textile was found buried directly in a sandy deposit, in association with a mummified body, near MS1. The linen appeared upon excavation to be quite sound. It was also flexible and could be easily handled. It appeared only moderately yellowed and slightly stained with few darkened areas.

The fibre was identified as linen using optical microscopy. The fibres were ordinary to coarse in quality. Slight traces of lignin were present. Its pH was found to be between pH 5 and 6.0.

Appendix A: Samples. Figure 9.1. MS2. Photograph of MS2 before examination. Photograph by the author.
Appendix A: Samples. Figure 9.2 MS2. Photomicrograph of MS2 before conservation treatment. 10x objective. Photomicrograph by the author.

Appendix A: Samples. Figure 9.3 MS2. Sample of MS2 after quick drying using Acetone. Photograph by the author.
Appendix A: Samples. Figure 9.4 ESEM Image of MS2. An ESEM image of MS2 before conservation treatment. The computer image was taken by K. McBean and the author at the University of Technology, Sydney.
Appendix A: Samples. Table 9.1 MS2.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
<th>SEM, ESEM &amp; EDXA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-sample Number</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fibre</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>variable</td>
<td>variable</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>8-10x8-10</td>
<td>8-10x8-10</td>
</tr>
<tr>
<td>Colour</td>
<td>N, S</td>
<td>N, S</td>
</tr>
<tr>
<td>Environment</td>
<td>GB</td>
<td>GB</td>
</tr>
<tr>
<td>Area</td>
<td>MC</td>
<td>MC</td>
</tr>
<tr>
<td>Period</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lignin</td>
<td>Slight Traces</td>
<td>Slight Traces</td>
</tr>
<tr>
<td>Fibrillation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fissures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Particulate Matter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photography</td>
<td>S</td>
<td>C</td>
</tr>
</tbody>
</table>

Key

**Fibre Analysis**
L= Linen  
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B= Bast Fibre  
W = White  
N= Natural Linen  
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**Area**
MC= Memphis Area Cemetery  
ME = Middle Egypt  
UE = Upper Egypt  
U= Unknown  
N/A =Not Applicable  
?= Uncertain

**Type of Photographic Record**
P=Colour Photograph  
S= Colour Slide  
B & W = Black and White Photograph  
V = Video Film (B & W)  
C= Computer image, B & W
### Appendix A: Samples. Table 9.2 MS2.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present Sub-samples 1 and 2</th>
</tr>
</thead>
</table>
| Optical Microscopy IC | Linen | Slight traces | | **Sub-sample 1.**  
 Sodium 270.96 ppm  
 Potassium 53.92 ppm  
 Magnesium 377.18 ppm  |
|                       |       |        |               | **Sub-sample 2.**  
 Sodium 256.40 ppm  
 Potassium 49.49 ppm  
 Magnesium 371.29 ppm  |
|                       |       |        |               | **16 Hour Washing Test**  |
|                       |       |        |               | **Hour 1**  
 Chloride 166.28 ppm  
 Bromide 0.30 ppm  
 Nitrate 53.90 ppm  
 Phosphate 0.60 ppm  
 Sulphate 1.61 ppm  |
|                       |       |        |               | **Hour 2**  
 IC Sample 1:  
 Chloride 450.70 ppm  
 Bromide 0.69 ppm  
 Nitrate 171.23 ppm  
 Phosphate 2.05 ppm  
 Sulphate 9.36 ppm  |
|                       |       |        |               | **Hour 4**  
 Potassium 0.10 ppm  
 Magnesium 0.11 ppm  
 Calcium 1.66 ppm  |
|                       |       |        |               | **Hour 16**  
 Sample 1:  
 Potassium 2.98 ppm  
 Magnesium 0.10 ppm  
 Calcium 1.92 ppm  
 Chloride 20.43 ppm  
 Nitrate 7.26 ppm  |
<table>
<thead>
<tr>
<th><strong>ESEM</strong></th>
<th>Fibre smooth before hydration.</th>
<th>Present</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ESEM Dynamic Study</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EDXA</strong></td>
<td></td>
<td>Carbon, oxygen, sodium, magnesium, aluminium, silicon, phosphorus, sulphur, chlorine, potassium, calcium, titanium, iron. (See also Figure 9.3 EDXA spectrum on the next page and Figure 9.4, a chart of IC results for the 16 hr. washing test, on the next page)</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>5.0-6.0</td>
<td></td>
</tr>
</tbody>
</table>

Sample 2:
- Potassium 0.33 ppm
- Magnesium 0.24 ppm
- Calcium 7.23 ppm

Phosphate 5.25 ppm
Sulphate 1.77 ppm
Appendix A: Samples. Figure 9.5 EDXA Spectra of MS2.

Label A: contms2

a) This EDXA spectrum of MS2 was taken before conservation treatment taken by K. McBean and the author at the University of Technology, Sydney.
b) This EDXA spectrum of MS2 was taken after 1 hour washing during the 16 hour washing test. Spectrum taken by K. McBean and the author at the University of Technology, Sydney.
c) This EDXA spectrum of MS2 was taken after 16 hours washing, during the 16 hour washing test. Spectrum taken by K. McBean and the author at the University of Technology, Sydney
Appendix A: Samples. Figure 9.6 MS2. 16 Hour Washing Test. All results reported in ppm (mg/L).
10. MS3

This textile was found buried directly in a sandy deposit, in association with a mummified body, near MS1 and MS2.

The linen appeared upon excavation to be quite sound. It was also flexible and could be easily handled. It appeared yellowed and slightly stained with few darkened areas.

The fibre was identified as linen using optical microscopy. The fibres were ordinary to coarse in quality. Slight traces of lignin were present. When tested it showed a pH of between pH 5 and 6.0.

Appendix A: Samples. Figure 10.1 MS3. MS 3 before conservation treatment. Photograph by the author.
Appendix A: Samples. Figure 10.2 Photomicrograph of MS3.
A photomicrograph of a fibre from MS3 taken before conservation treatment.
10x objective. Note the particulate material visible, particularly to its left.
Photomicrograph by the author.

Appendix A: Samples. Figure 10.3 ESEM Image of MS3.
An ESEM image of MS3 taken before conservation treatment.
The computer image was taken by K. McBean and the author at University of
Technology, Sydney.
Appendix A: Samples. Table 10.1 MS3
For abbreviations see the next page.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
<th>SEM, ESEM &amp; EDXA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-sample Number</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fibre</td>
<td>Linen</td>
<td>Linen</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>2</td>
<td>2 Ply. ESEM showed the fibres to be twisted into thick bundles.</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>Variable, but ordinary to coarse in quality.</td>
<td>Variable, but ordinary to coarse in Quality.</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>12 x 10</td>
<td>12x10</td>
</tr>
<tr>
<td>Colour</td>
<td>N, S</td>
<td>N, S</td>
</tr>
<tr>
<td>Environment</td>
<td>GB</td>
<td>GB</td>
</tr>
<tr>
<td>Area</td>
<td>MC</td>
<td>MC</td>
</tr>
<tr>
<td>Period</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Some damage</td>
<td>The fibres showed more visible damage (breaks) under ESEM than they did under visual assessment or optical microscopy.</td>
</tr>
<tr>
<td>Lignin</td>
<td>Slight traces</td>
<td>Slight traces</td>
</tr>
<tr>
<td>Fibrillation</td>
<td>Not Present</td>
<td>Not present</td>
</tr>
<tr>
<td>Fissures</td>
<td>Not Present</td>
<td>Unclear-may be present</td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
<td>A large quantity of particulate matter was visible.</td>
</tr>
<tr>
<td>Photography</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>
**Key**

*Fibre Analysis*
L = Linen  
W = Wool  
B = Bast Fibre  
W = White  
N = Natural Linen  
S = Stained (Dark Brown)  
D = Deteriorated  
N/A = Not Applicable  
? = Uncertain or Not Known

*Environment*
GB = Burial in Ground  
TB = Tomb Burial  
PB = Presumed Burial in Ground

*Period*
PD = Pre-Dynastic Period  
D = Dynastic Period  
GR = Greco-Roman /Ptolemaic  
R = Roman /Coptic/ Late Antiquity

*Area*
MC = Memphis Area Cemetery  
ME = Middle Egypt  
UE = Upper Egypt  
U = Unknown  
N/A = Not Applicable  
? = Uncertain

*Type of Photographic Record*
P = Colour Photograph  
S = Colour Slide  
B & W = Black and White Photograph  
V = Video Film (B & W)  
C = Computer image, B & W
Appendix A: Samples. Table 10.2 MS3.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>Linen</td>
<td>Slight traces</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>IC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESEM</td>
<td>Thick bundles Some damage.</td>
<td>Present/large quantity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESEM Dynamic Study</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDXA</td>
<td></td>
<td></td>
<td></td>
<td>Carbon, oxygen, silicon, chlorine, calcium sodium, magnesium, sulphur, aluminium, phosphorus, potassium, titanium, iron. (See also EDXA spectrum below.)</td>
</tr>
<tr>
<td>pH</td>
<td>5.0-6.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix A: Samples. Figure 10.4 EDXA Spectrum of MS3. An EDXA spectrum of MS3 taken by K. McBean and the author at the University of Technology, Sydney.
11. MS4

This textile was found buried directly in a sandy deposit, in association with a mummified body, near MS1, MS2 and MS 3.

The linen appeared upon excavation to be quite sound. It was also flexible and could be easily handled. It appeared buff in colour and slightly stained with whitened areas.

The fibre identified as linen using optical microscopy. Under high magnification the fibres appeared highly fibrillated, with many fissures. The fibres were ordinary in quality, but finer than MS1, MS2 or MS3. No lignin was present. The pH was between pH 5 and 6.0.
Appendix A: Samples. Figure 11.1 MS4. A photograph of MS4 before conservation treatment. Photograph by the author.
Appendix A: Samples. Figure 11.2 Photomicrograph of MS4.
Photomicrograph of a sample fibre of MS4 taken before conservation. 10x objective. Photomicrograph by the author.

Appendix A: Samples. Figure 11.3 Photomicrograph of MS4.
A photomicrograph of MS4 taken before conservation treatment, showing the thread and single fibres. 10x objective. Photomicrograph by the author.
Appendix A: Samples. Figure 11.4 ESEM Image of MS4.
Appendix A: Samples Table 11.1 MS4.
For abbreviations see at the end of the table.

<table>
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<th>Method of Analysis</th>
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<th>SEM, ESEM &amp; EDXA</th>
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</thead>
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<td>2</td>
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<td>Fibre</td>
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<td>Linen</td>
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<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>Variable</td>
<td>Variable</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>12 x 10</td>
<td>12 x 10</td>
</tr>
<tr>
<td>Colour</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Environment</td>
<td>GB</td>
<td>GB</td>
</tr>
<tr>
<td>Area</td>
<td>MC</td>
<td>MC</td>
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<tr>
<td>Period</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Damage</td>
<td>Damage</td>
</tr>
<tr>
<td>Lignin</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Fibrillation</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Fissures</td>
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<td>Present</td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>?</td>
<td>Present</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Photography</td>
<td>S, C</td>
<td>C</td>
</tr>
</tbody>
</table>

**Key**

**Fibre Analysis**
- L = Linen
- W = Wool
- B = Bast Fibre
- W = White
- N = Natural Linen
- S = Stained (Dark Brown)
- D = Deteriorated
- N/A = Not Applicable
- ? = Uncertain or Not Known

**Environment**
- GB = Burial in Ground
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- PB = Presumed Burial in Ground

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- R = Roman /Coptic/ Late Antiquity

**Area**
- MC = Memphis Area Cemetery

ME = Middle Egypt
UE = Upper Egypt
U = Unknown
N/A = Not Applicable
? = Uncertain

**Type of Photographic Record**
- P = Colour Photograph
- S = Colour Slide
- B & W = Black and White
- Photograph
- V = Video Film (B & W)
- C = Computer image, B & W

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Appendix A: Samples. Table 11.2 MS4.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>Linen damage (fissures and fibrillation)</td>
<td>Absent</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>IC</td>
<td></td>
<td></td>
<td></td>
<td>16 Hour Washing Test</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hour 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IC Sample 1:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Potassium 0.34 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnesium 1.06 ppm</td>
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<td></td>
<td></td>
<td></td>
<td>Calcium 33.05 ppm</td>
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<td></td>
<td></td>
<td></td>
<td>Chloride 99.85 ppm</td>
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<td></td>
<td></td>
<td></td>
<td>Bromide 0.29 ppm</td>
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<td></td>
<td></td>
<td>Nitrate 30.28 ppm</td>
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<td></td>
<td></td>
<td></td>
<td>Phosphate 0.58 ppm</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>Sulphate 1.03 ppm</td>
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<td></td>
<td></td>
<td></td>
<td>Hour 2</td>
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<td>Chloride 1.57 ppm</td>
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<td></td>
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<td>Phosphate 2.21 ppm</td>
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<td>Sulphate 0.48 ppm</td>
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<td>Potassium 0.14 ppm</td>
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<td>Calcium 2.84 ppm</td>
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<td></td>
<td></td>
<td>Chloride 5.78 ppm</td>
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<td></td>
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<td>Phosphate 1.28 ppm</td>
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<td>Sulphate 0.82 ppm</td>
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<td></td>
<td></td>
<td></td>
<td>Hour 16</td>
</tr>
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<td></td>
<td>Chloride 0.28 ppm</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Bromide 0.28 ppm</td>
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<td></td>
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<td></td>
<td></td>
<td>Nitrate 0.30 ppm</td>
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<td>Phosphate 2.04 ppm</td>
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<td></td>
<td></td>
<td></td>
<td>Sulphate 0.43 ppm</td>
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<tr>
<td>ESEM</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>---------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESEM Dynamic Study</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>EDXA</td>
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<td>Carbon, oxygen, sodium, magnesium, aluminium, silicon, phosphorus, sulphur, chlorine, potassium, calcium, titanium, iron. (See also EDXA spectrum on the next page.)</td>
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<tr>
<td>pH</td>
<td>5.0-6.0</td>
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<td></td>
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</table>
Appendix A: Samples. Figure 11.5 ESEM Spectrum of MS4. An ESEM spectrum of MS4 before conservation treatment taken by K. McBean and the author at the University of Technology, Sydney.

Appendix A: Samples. Figure 11.6 MS4. 16 Hour Washing Test. Results reported in ppm (Mg/L).
The textile was found buried directly in a sandy deposit, in association with a mummified body, near MS1, MS2, MS3 and MS4.

The linen appeared upon excavation to be quite sound. It was also flexible and could be easily handled. It appeared yellowed and stained, and also showed a few whitened areas.

The fibre was identified as linen using optical microscopy. The fibres were ordinary to coarse in quality. The threads showed considerable variation; there being 1, 2 and 3 plied fibres. The threads appear to be strong but were actually quite fragile and weak under any movement.

No lignin was present. The pH was between pH 5 and 6.0.
Appendix A: Samples. Figure 12.1 MS5. MS5 before examination. Photograph by the author.

Appendix A: Samples. Figure 12.2 MS5. Photomicrograph of MS5 before conservation treatment. 10x objective. Photomicrograph by the author.
Appendix A: Samples. Figure 12.3 MS5. Photomicrograph of MS5 before conservation treatment. 10x objective. This photomicrograph of a single fibre shows particulate matter on the fibre. Photomicrograph by the author.

Appendix A: Samples. Figure 12.4 ESEM Image of MS5. An ESEM image showing particulate matter on the fibres, fissures, breaks and fibrillation of the fibres. This computer image was taken by K. McBean and the author at the University of Technology, Sydney.
Appendix A: Samples Table 12.1 MS5.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
<th>SEM, ESEM &amp; EDXA</th>
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<tr>
<td>Sub-sample Number</td>
<td>I</td>
<td>2</td>
</tr>
<tr>
<td>Fibre</td>
<td>Linen</td>
<td>Linen</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>1, 2 &amp; 3</td>
<td>1, 2 &amp; 3</td>
</tr>
<tr>
<td>Diameter (mm)</td>
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<td>Variable</td>
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<td>Weave Count (cm)</td>
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<td>12 x 12</td>
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<td>N</td>
</tr>
<tr>
<td>Environment</td>
<td>GB</td>
<td>GB</td>
</tr>
<tr>
<td>Area</td>
<td>MC</td>
<td>MC</td>
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<tr>
<td>Period</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Damage</td>
<td>Damage</td>
</tr>
<tr>
<td>Lignin</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Fibrillation</td>
<td>Not visible</td>
<td>Present</td>
</tr>
<tr>
<td>Fissures</td>
<td>Not visible</td>
<td>Present</td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>Not visible</td>
<td>Present</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Visible</td>
<td>Present</td>
</tr>
<tr>
<td>Photography</td>
<td>S, C</td>
<td>C</td>
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</table>

**Key**

*Fibre Analysis*
- L = Linen
- W = Wool
- B = Bast Fibre
- W = White
- N = Natural Linen
- S = Stained (Dark Brown)
- D = Deteriorated
- N/A = Not Applicable
  - ? = Uncertain or Not Known

*Type of Photographic Record*
- P = Colour Photograph
- S = Colour Slide
- B & W = Black and White Photograph
- V = Video Film (B & W)
- C = Computer image, B & W

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- TB = Tomb Burial
- PB = Presumed Burial in Ground

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- D = Dynastic Period
- GR = Greco-Roman / Ptolemaic
- R = Roman / Coptic / Late Antiquity

*Area*
- MC = Memphis Area Cemetery
- ME = Middle Egypt
- UE = Upper Egypt

U= Unknown
N/A = Not Applicable
? = Uncertain

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Appendix A: Samples. Table 12.2 MS5.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>Linen</td>
<td>Absent</td>
<td>Not visible</td>
<td></td>
</tr>
<tr>
<td>ESEM</td>
<td>Damage</td>
<td></td>
<td>Present</td>
<td>Chlorine, carbon, oxygen, silicon, sulphur, calcium sodium, magnesium, aluminium, phosphorus, potassium, titanium, iron. (See also EDXA spectrum on the next page.)</td>
</tr>
<tr>
<td>EDXA</td>
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<td></td>
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</tr>
<tr>
<td>pH</td>
<td>5.0-6.0</td>
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<td></td>
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</table>
Appendix A; Samples. Figure 12.5 EDXA Spectrum of MS5. An EDXA spectrum taken by K. McBean and the author at University of Technology, Sydney.
MU 546 is a large textile from the New Kingdom or Late Period. There was no information available on its acquisition or exact provenance, though it was recorded as being from a tomb burial from one of the cemeteries of Memphis. Therefore it was not examined extensively.

A small fibre that had already detached itself from the body of the fabric was examined using Optical Microscopy.

Appendix A: Samples. Figure 13.1 MU546. Photograph by the author.
Appendix A: Samples. Figure 13.2 MU 546.
A photomicrograph of MU 546 thread, showing the twist.
10x objective. Photomicrograph taken by the author.

Appendix A: Samples. Figure 13.3 MU 546.
A photomicrograph showing the twist of the threads.
4x objective. Photograph by the author.
Appendix A: Samples. Table 13.1 MU 546.
For abbreviations see the end of the table.

<table>
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<th>Method of Analysis</th>
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<td>Spin</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
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</tr>
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<td>Colour</td>
<td>N</td>
</tr>
<tr>
<td>Environment</td>
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<tr>
<td>Area</td>
<td>MC</td>
</tr>
<tr>
<td>Period</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Excellent condition.</td>
</tr>
<tr>
<td>Fibrillation</td>
<td>Absent</td>
</tr>
<tr>
<td>Fissures</td>
<td>Absent</td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>Absent</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Low or absent</td>
</tr>
<tr>
<td>Photography</td>
<td>P, S</td>
</tr>
</tbody>
</table>

**Key**

**Fibre Analysis**
- L = Linen
- W = Wool
- B = Bast Fibre
- W = White
- N = Natural Linen
- S = Stained (Dark Brown)
- D = Deteriorated
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- ? = Uncertain or Not Known

**Environment**
- GB = Burial in Ground
- TB = Tomb Burial
- PB = Presumed Burial in Ground

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- D = Dynastic Period
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**Area**
- MC = Memphis Area Cemetery
- ME = Middle Egypt
- UE = Upper Egypt
- U = Unknown

N/A = Not Applicable
? = Uncertain
MU 1546 is a pleated linen textile fragment. There was no information available on its acquisition or exact provenance, and therefore it was not examined extensively.

Appendix A: Samples. Figure 14.1 MU1545. Photograph by the author.
Appendix A: Samples. Table 14.1 MU 1545.
For abbreviations see at the end of the table.

<table>
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<th>Method of Analysis</th>
<th>Optical Microscopy</th>
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<td>Spin</td>
<td>S</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
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<td>N</td>
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<tr>
<td>Environment</td>
<td>U</td>
</tr>
<tr>
<td>Area</td>
<td>U</td>
</tr>
<tr>
<td>Period</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Fabric in excellent condition.</td>
</tr>
</tbody>
</table>

Key

Fibre Analysis
L = Linen
W = Wool
B = Bast Fibre
W = White
N = Natural Linen
S = Stained (Dark Brown)
D = Deteriorated
N/A = Not Applicable
? = Uncertain or Not Known

Environment
GB = Burial in Ground
TB = Tomb Burial
PB = Presumed Burial in Ground

Period
PD = Pre-Dynastic Period
D = Dynastic Period
GR = Greco-Roman/Ptolemaic
R = Roman/Coptic/Late Antiquity

Area
MC = Memphis Area Cemetery
ME = Middle Egypt
UE = Upper Egypt
U = Unknown
N/A = Not Applicable
? = Uncertain

Type of Photographic Record
P = Colour Photograph
15. MU 1547

MU 1547 is a linen textile. There was no information available on its acquisition or exact provenance, and therefore it was not examined extensively.

Appendix A: Samples. Table 15.1 MU 1547.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre</td>
<td>Linen</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>1</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>10 x16</td>
</tr>
<tr>
<td>Colour</td>
<td>W/N</td>
</tr>
<tr>
<td>Environment</td>
<td>U</td>
</tr>
<tr>
<td>Area</td>
<td>U</td>
</tr>
<tr>
<td>Period</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Good condition.</td>
</tr>
</tbody>
</table>

Key

**Fibre Analysis**
- L= Linen
- W= Wool
- B= Bast Fibre
- W = White
- N= Natural Linen
- S= Stained (Dark Brown)
- D= Deteriorated
- N/A = Not Applicable
- ? = Uncertain or Not Known

**Environment**
- GB= Burial in Ground
- TB= Tomb Burial
- PB= Presumed Burial in Ground

**Period**
- PD= Pre -Dynastic Period
- D= Dynastic Period
- GR= Greco-Roman /Ptolemaic
- R= Roman /Coptic/ Late Antiquity

**Area**
- MC= Memphis Area Cemetery
- ME = Middle Egypt

UE = Upper Egypt
U= Unknown
N/A =Not Applicable
? = Uncertain
16. MU 1550

MU 1550 is a fragmentary linen textile. There was no information available on its acquisition or exact provenance, and therefore it was not examined extensively. A thread that had already detached itself from the undyed area of the textile was examined using optical microscopy.

Appendix A: Samples. Figure 16.1 MU 1550. Photograph by the author.
Appendix A: Samples. Figure 16.2 MU 1550.
Photomicrograph of a thread. 10x objective.
Photomicrograph by the author.

Appendix A: Samples. Figure 16.3 MU 1550.
Photomicrograph of a thread. 10x objective.
Photomicrograph by the author.
Appendix A: Samples. Table 16.1 MU 1550.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre</td>
<td>L</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>2</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>10 x 15</td>
</tr>
<tr>
<td>Colour</td>
<td>N/Blue</td>
</tr>
<tr>
<td>Environment</td>
<td>U</td>
</tr>
<tr>
<td>Area</td>
<td>U</td>
</tr>
<tr>
<td>Period</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Fragmentary</td>
</tr>
<tr>
<td>Photography</td>
<td>P, C</td>
</tr>
</tbody>
</table>

**Key**

*Fibre Analysis*
- L = Linen
- W = Wool
- B = Bast Fibre
- W = White
- N = Natural Linen
- S = Stained (Dark Brown)
- D = Deteriorated
- N/A = Not Applicable
- ? = Uncertain or Not Known

*Environment*
- GB = Burial in Ground
- TB = Tomb Burial
- PB = Presumed Burial in Ground

*Period*
- PD = Pre-Dynastic Period
- D = Dynastic Period
- GR = Greco-Roman / Ptolemaic
- R = Roman / Coptic / Late Antiquity

*Area*
- MC = Memphis Area Cemetery
- ME = Middle Egypt
- UE = Upper Egypt
- U = Unknown

N/A = Not Applicable
? = Uncertain

*Type of Photographic Record*
- P = Colour Photograph
- S = Colour Slide
- B & W = Black and White Photograph
- V = Video Film (B & W)
- C = Computer image, B & W
17. MU 1551

MU 1551 is a linen textile. There was no information available on its acquisition or exact provenance, and therefore it was not examined extensively.

Appendix A: Samples. Table 17. 1 MU 1551.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre</td>
<td>L</td>
</tr>
<tr>
<td>Spin</td>
<td>U</td>
</tr>
<tr>
<td>Ply</td>
<td>1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>1</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>14 x 22-24</td>
</tr>
<tr>
<td>Colour</td>
<td>N</td>
</tr>
<tr>
<td>Environment</td>
<td>U</td>
</tr>
<tr>
<td>Area</td>
<td>U</td>
</tr>
<tr>
<td>Period</td>
<td>D ?</td>
</tr>
</tbody>
</table>

Key

Fibre Analysis
L= Linen
W= Wool
B= Bast Fibre
W = White
N= Natural Linen
S= Stained (Dark Brown)
D= Deteriorated
N/A= Not Applicable
? = Uncertain or Not Known

Environment
GB= Burial in Ground
TB= Tomb Burial
PB= Presumed Burial in Ground

Period
PD= Pre-Dynastic Period
D= Dynastic Period
GR= Greco-Roman /Ptolemaic
R= Roman /Coptic/ Late Antiquity

Area
MC= Memphis Area Cemetery
ME = Middle Egypt
UE = Upper Egypt
U= Unknown
N/A =Not Applicable
? = Uncertain

Type of Photographic Record
P= Colour Photograph
S= Colour Slide
B & W = Black and White Photograph
V = Video Film (B & W)
C= Computer image, B & W

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18. MU 1552

MU 1552 is a fragmentary linen textile. There was no information available on its acquisition or exact provenance, and therefore it was not examined extensively.

Appendix A: Samples. Figure 18.1 MU1552. Photograph by the author.

Appendix A: Samples. Figure 18.2. Photomicrograph of MU 1552. 10x objective. Photomicrograph by the author.
Appendix A: Samples. Table 18.1 MU 1552.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre</td>
<td>L</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>15 x 30</td>
</tr>
<tr>
<td>Colour</td>
<td>N</td>
</tr>
<tr>
<td>Environment</td>
<td>U</td>
</tr>
<tr>
<td>Area</td>
<td>U</td>
</tr>
<tr>
<td>Period</td>
<td>D ?</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Fragmentary, but in good condition.</td>
</tr>
<tr>
<td>Photography</td>
<td>C</td>
</tr>
</tbody>
</table>

**Key**

*Fibre Analysis*
- L = Linen
- W = Wool
- B = Bast Fibre
- W = White
- N = Natural Linen
- S = Stained (Dark Brown)
- D = Deteriorated
- N/A = Not Applicable
- ? = Uncertain or Not Known

*S = Colour Slide
B & W = Black and White Photograph
V = Video Film (B & W)
C = Computer image, B & W

*Environment*
- GB = Burial in Ground
- TB = Tomb Burial
- PB = Presumed Burial in Ground

*Period*
- PD = Pre-Dynastic Period
- D = Dynastic Period
- GR = Greco-Roman /Ptolemaic
- R = Roman /Coptic/ Late Antiquity

*Area*
- MC = Memphis Area Cemetery
- ME = Middle Egypt
- UE = Upper Egypt
- U = Unknown

N/A = Not Applicable
? = Uncertain

*Type of Photographic Record*
- P = Colour Photograph
MU2469 is a fragmentary linen textile of Roman-Coptic date. There was no information available on its acquisition or exact provenance, and therefore it was not examined extensively.

**Appendix A: Samples. Table 19.1 MU 2469.**
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre</td>
<td>L, W</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>1) White area 8 x8</td>
</tr>
<tr>
<td></td>
<td>2) Black, White, Yellow &amp; Red areas</td>
</tr>
<tr>
<td></td>
<td>15 x 15 and</td>
</tr>
<tr>
<td></td>
<td>11 x 30</td>
</tr>
<tr>
<td>Colour</td>
<td>White, Black, Yellow, Red, Natural</td>
</tr>
<tr>
<td>Environment</td>
<td>PB</td>
</tr>
<tr>
<td>Area</td>
<td>U</td>
</tr>
<tr>
<td>Period</td>
<td>R</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Fragmentary</td>
</tr>
</tbody>
</table>

**Key**

*Fibre Analysis*
- L = Linen
- W = Wool
- B = Bast Fibre
- W = White
- N = Natural Linen
- S = Stained (Dark Brown)
- D = Deteriorated
- N/A = Not Applicable
- ? = Uncertain or Not Known

*Period*
- PD = Pre-Dynastic Period
- D = Dynastic Period
- GR = Greco-Roman /Ptolemaic
- R = Roman /Coptic/ Late Antiquity

*Area*
- MC = Memphis Area Cemetery
- ME = Middle Egypt
- UE = Upper Egypt
- U = Unknown

*Environment*
- GB = Burial in Ground
- TB = Tomb Burial
- PB = Presumed Burial in Ground

*Type of Photographic Record*
- P = Colour Photograph
- S = Colour Slide
- B & W = Black and White Photograph
- V = Video Film (B & W)
- C = Computer image, B & W
MU2479 is a fragmentary linen textile of Roman-Coptic date. There was no information available on its acquisition or exact provenance, and therefore it was not examined extensively.

Appendix A: Samples. Figure 20.1 MU 2479. 10x objective. Photomicrograph by the author.
Appendix A: Samples. Table 20.1 MU2479.
For abbreviations see at the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre</td>
<td>L (?) &amp; W</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>2</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>7 x 9-11</td>
</tr>
<tr>
<td>Colour</td>
<td>N</td>
</tr>
<tr>
<td>Environment</td>
<td>PB</td>
</tr>
<tr>
<td>Area</td>
<td>U</td>
</tr>
<tr>
<td>Period</td>
<td>R</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
</tr>
<tr>
<td>Photography</td>
<td>C</td>
</tr>
</tbody>
</table>

**Key**

*Fibre Analysis*
- L = Linen
- W = Wool
- B = Bast Fibre
- W = White
- N = Natural Linen
- S = Stained (Dark Brown)
- D = Deteriorated
- N/A = Not Applicable
- ? = Uncertain or Not Known

*Environment*
- GB = Burial in Ground
- TB = Tomb Burial
- PB = Presumed Burial in Ground

*Period*
- PD = Pre-Dynastic Period
- D = Dynastic Period
- GR = Greco-Roman/Ptolemaic
- R = Roman/Coptic/Late Antiquity

*Area*
- MC = Memphis Area Cemetery
- ME = Middle Egypt
- UE = Upper Egypt
- U = Unknown
- N/A = Not Applicable
- ? = Uncertain

*Type of Photographic Record*
- P = Colour Photograph
- S = Colour Slide
21. MU2485

MU2485 is a fragmentary linen textile of Roman-Coptic date. There was no information available on its acquisition or exact provenance, and therefore it was not examined extensively.

Appendix A: Samples. Table 21.1 MU2485.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre</td>
<td>L &amp; W</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>13 x 25-30</td>
</tr>
<tr>
<td>Colour</td>
<td>N &amp; Red</td>
</tr>
<tr>
<td>Environment</td>
<td>PB</td>
</tr>
<tr>
<td>Area</td>
<td>U</td>
</tr>
<tr>
<td>Period</td>
<td>R</td>
</tr>
</tbody>
</table>

Key

Fibre Analysis
L= Linen
W= Wool
B= Bast Fibre
W = White
N= Natural Linen
S= Stained (Dark Brown)
D= Deteriorated
N/A= Not Applicable
? = Uncertain or Not Known

Environment
GB= Burial in Ground
TB= Tomb Burial
PB= Presumed Burial in Ground

Period
PD= Pre -Dynastic Period
D= Dynastic Period
GR= Greco-Roman /Ptolemaic
R= Roman /Coptic/ Late Antiquity

Area
MC= Memphis Area Cemetery
ME = Middle Egypt
UE = Upper Egypt
U= Unknown
N/A = Not Applicable
? = Uncertain

Type of Photographic Record
P= Colour Photograph
S= Colour Slide
B & W= Black and White Photograph
V= Video Film (B & W)
C= Computer image, B & W
MU2488 is a fragmentary linen textile of Roman-Coptic date. There was no information available on its acquisition or exact provenance, and therefore it was not examined extensively.

Appendix A: Samples. Table 22.1 MU2488.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre</td>
<td>L &amp; W</td>
</tr>
<tr>
<td>Spin/Ply</td>
<td>Z</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>Variable</td>
</tr>
<tr>
<td></td>
<td>12-16 x</td>
</tr>
<tr>
<td></td>
<td>20-23</td>
</tr>
<tr>
<td>Colour</td>
<td>N &amp; Red</td>
</tr>
<tr>
<td>Environment</td>
<td>PB</td>
</tr>
<tr>
<td>Area</td>
<td>U</td>
</tr>
<tr>
<td>Period</td>
<td>R</td>
</tr>
</tbody>
</table>

**Key**

*Fibre Analysis*
- L = Linen
- W = Wool
- B = Bast Fibre
- W = White
- N = Natural Linen
- S = Stained (Dark Brown)
- D = Deteriorated
- N/A = Not Applicable
- ? = Uncertain or Not Known

*Environment*
- GB = Burial in Ground
- TB = Tomb Burial
- PB = Presumed Burial in Ground

*Period*
- PD = Pre-Dynastic Period
- D = Dynastic Period
- GR = Greco-Roman /Ptolemaic
- R = Roman /Coptic/ Late Antiquity

*Area*
- MC = Memphis Area Cemetery
- ME = Middle Egypt
- UE = Upper Egypt
- U = Unknown

*N/A = Not Applicable
? = Uncertain

*Type of Photographic Record*
- P = Colour Photograph
- S = Colour Slide
- B & W = Black and White Photograph
- V = Video Film (B & W)
- C = Computer image, B & W

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23. **MU 2982**

This sample was taken from a large bundle of plain linen fabric. It may have been clothing or a sheet. It was recovered, post-1960, from a tomb burial, from a named funerary temple of the Dynastic period, in the Memphis cemetery area.

Using optical microscopy the fibres were identified as linen. Under optical microscopy, fibre within woven areas that appeared to be sound showed small breaks where the warp and weft crossed each other. Fibres were of good quality, though not of exceptional quality.

*Appendix A: Samples. Figure 23.1. MU 2982.* A photograph of the textile bundle by the author.
Appendix A: Samples. Figure 23.2 MU2982. Photomicrograph of fibres. 10x objective. Photomicrograph by the author.

Appendix A: Samples. Figure 23.3 MU2982. A photomicrograph of a single fibre 10x objective. Photomicrograph by the author.

Appendix A: Samples. Figure 23.4 ESEM Image of MU2982. ESEM Image of fibres. Computer image taken by K. McBean and the author at the University of Technology, Sydney.

Appendix A: Samples. Figure 23.5 ESEM Image of MU2982. ESEM Image of fibres. Computer image taken by K. McBean and the author at the University of Technology, Sydney.
Appendix A: Samples. Table 23.1 MU2982.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
<th>SEM, ESEM &amp; EDXA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-sample Number</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fibre</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>10-12x 14</td>
<td>10-12 x 14</td>
</tr>
<tr>
<td>Colour</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Environment</td>
<td>TB</td>
<td>TB</td>
</tr>
<tr>
<td>Area</td>
<td>MC</td>
<td>MC</td>
</tr>
<tr>
<td>Period</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Appears to be in excellent condition, but examination showed breaks in fibres.</td>
<td>Breaks in fibres.</td>
</tr>
<tr>
<td>Fibrillation</td>
<td></td>
<td>Absent</td>
</tr>
<tr>
<td>Fissures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Photography</td>
<td>S</td>
<td>C</td>
</tr>
</tbody>
</table>

Key

*Fibre Analysis*
L = Linen
W = Wool
B = Bast Fibre
W = White
N = Natural Linen
S = Stained (Dark Brown)
D = Deteriorated
N/A = Not Applicable
? = Uncertain or Not Known

*Environment*
GB = Burial in Ground
TB = Tomb Burial
PB = Presumed Burial in Ground

*Period*
PD = Pre-Dynastic Period
D = Dynastic Period
GR = Greco-Roman /Ptolemaic
R = Roman /Coptic/ Late Antiquity

*Area*
MC = Memphis Area Cemetery
ME = Middle Egypt
UE = Upper Egypt
U = Unknown
N/A = Not Applicable
? = Uncertain

*Type of Photographic Record*
P = Colour Photograph
S = Colour Slide
B & W = Black and White Photograph
V = Video Film (B & W)
C = Computer image, B & W
### Appendix A: Samples. Table 23.2 MU 2982.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>Linen. Breaks at crossover of warp and weft</td>
<td>Present</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESEM</td>
<td></td>
<td>Large amount present</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDXA</td>
<td></td>
<td></td>
<td></td>
<td><strong>Sample 2.</strong> Carbon, nitrogen, oxygen, sodium, magnesium, aluminium, silicon, phosphorus, sulphur, chlorine, potassium, calcium.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(See also EDXA spectrum on the next page.)</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix A: Samples. Figure 23.6 EDXA spectrum of MU2982. This spectrum was taken by K. McBean and the author at the University of Technology, Sydney.
This fibre was from fabric recovered from a tomb burial, identified as Early Dynastic in the Memphis cemetery area. It was recovered prior to 1960. The tomb deposit was reported as dry. In proximity to the burial were a variety of grave goods. The artefacts recovered included some basketry, wood, ivory, pottery, bone objects, and copper objects.

Using optical microscopy, the fibre was identified as linen. No lignin was present. The fibres were very fine and beautifully spun, very white in colour and transparent. Under high magnification the fibres were very fine (see fig. 24.5). In what appeared to the naked eye to be a single fibre there was a single twist, indicating two fibres spun together (see fig. 24.4).

The fibres were fragile, and although they could be handled once or twice I became concerned that with any more handling they might disintegrate. There was also a large amount of visible particulate matter (dirt and/or salts). This was collected and analysed using X-Ray Diffraction Analysis (see Chapter 2, sections 2.3.1.4.2 – 2.3.1.4.4 and Table 2.1).
This fabric may have been prepared from young plants, due to the small diameter of the fibres. It was certainly carefully retted and otherwise prepared. The exceptional whiteness of the fibre raises the question of whether or not the fabric was bleached. It may have been sun bleached, after washing with natron. If washed with natron the trace elements would have acted as a catalyst to photo-oxidation. Therefore the presence in the fibres of copper (see EDXA results cited below) is very interesting, as copper is a metal trace element which could act as a catalyst to photo-oxidation (Timar-Balazsy & Eastop, 1998). This sample came from a tomb context where the linen may have been in proximity to copper grave goods. (See also sample 25. U, from the same type of burial.)

Also notable in the sample is the absence of sodium and chlorine.
Appendix A: Samples. Figure 24.1 L. Photograph by the author.

Appendix A: Samples. Figure 24.2 ESEM Image of L. ESEM image of the sample showing breaks and fibrillation, taken by K. Mc Bean and the author at the University of Technology, Sydney.
Appendix A: Samples. Figure 24.3 ESEM Image of L. ESEM image of the sample showing breaks and fibrillation, taken by K. Mc Bean and the author at the University of Technology, Sydney.

Appendix A: Samples. Figure 24.4 ESEM Image of L. ESEM image of the sample showing the two plyed fibres, taken by K. Mc Bean and the author at the University of Technology, Sydney.
Appendix A: Samples. Figure 24.5 ESEM Image of L. ESEM image of the sample showing the extremely fine, white, fibres, taken by K. Mc Bean and the author at the University of Technology, Sydney.
Appendix A: Samples. Table 24.1 L.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Replicate Number</th>
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<td>L</td>
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<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
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<td>1 or &lt;1</td>
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<td>NA</td>
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<td>W</td>
<td>W</td>
</tr>
<tr>
<td>Environment</td>
<td>TB</td>
<td>TB</td>
</tr>
<tr>
<td>Area</td>
<td>MC</td>
<td>MC</td>
</tr>
<tr>
<td>Period</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>In excellent condition, but fragile.</td>
<td>Breaks.</td>
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<tr>
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<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Fibrillation</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>Fissures</td>
<td>Absent</td>
<td>?</td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Photography</td>
<td>S</td>
<td>C</td>
</tr>
</tbody>
</table>

Key

**Fibre Analysis**

L = Linen
W = Wool
B = Bast Fibre
W = White
N = Natural Linen
S = Stained (Dark Brown)
D = Deteriorated
N/A = Not Applicable
? = Uncertain or Not Known

**Area**

MC = Memphis Area
Cemetery
ME = Middle Egypt
UE = Upper Egypt
U = Unknown

**Environment**

GB = Burial in Ground
TB = Tomb Burial
PB = Presumed Burial in Ground

**Period**

PD = Pre-Dynastic Period
D = Dynastic Period
GR = Greco-Roman /Ptolemaic

**Type of Photographic Record**

P = Colour Photograph
S = Colour Slide
B & W = Black and White Photograph
V = Video Film (B & W)
C = Computer image, B & W

R = Roman /Coptic/ Late Antiquity

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### Appendix A: Samples. Table 24.2 L.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignn</th>
<th>Visible Salts</th>
<th>Elements Present</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Optical Microscopy</strong></td>
<td>Linen Apparently sound but fragile when handled</td>
<td>Absent</td>
<td>Large amount of particulate material</td>
<td>Sample 2. Carbon, Oxygen, Iron, Magnesium, Aluminium, Silicon, Phosphorus, Sulphur, Potassium, Calcium, Iron, and Copper. (See also EDXA chart on the next page.)</td>
</tr>
<tr>
<td><strong>IC ESEM</strong></td>
<td>Sample 2. Very fine, and very white. What appeared to be a single thread was shown to be two fibres spun together.</td>
<td></td>
<td>Present, but not a large amount Visible.</td>
<td>Sample 2.</td>
</tr>
<tr>
<td><strong>EDXA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Appendix A: Samples. Figure 24.6 EDXA Spectrum of L. This EDXA spectrum was taken by K. McBean and the author at the University of Technology, Sydney.
This sample was from a textile recovered from a tomb burial identified as Pre-Dynastic from the Memphis cemetery area. It was recovered prior to 1960. Using Optical Microscopy the sample was identified as linen. The fibre was of very good quality. It was a light blonde to white in colour. The surface appeared "polished", i.e. lustrous. There were no fissures and few transverse breaks visible. The diameter of the fibres was small. The cell walls long and smooth. A lignin test was negative, i.e. there were no areas of colour change. The polished or lustrous effect is a sign that the fibre has been carefully retted and all wax and extraneous materials removed. This would indicate that the fibre was probably from a young plant, it had been well retted/processed and had undergone little wear/use.

The presence of Cu in the sample is interesting (see EDXA spectrum below), as both the textiles U and L came from tomb contexts where the linen may have been in proximity to copper grave goods, although the fibres of the textiles are not visibly mineralised with copper.
Appendix A: Samples. Figure 25.1 U. A photograph of a single thread and a sample of the archaeological deposit U was found in, as received. Photograph by the author.

Appendix A: Samples. Figure 25.2 U. A single thread. Photograph by the author.
Appendix A: Samples. Figure 25.3 ESEM Image of U. An ESEM image of the sample showing broken surfaces of the threads and particulate matter. The image was taken by K. McBean and the author at the University of Technology, Sydney.

Appendix A: Samples. Figure 25.4 ESEM Image of U. An ESEM image of the sample showing breaks in the threads and particulate matter. The image was taken by K. McBean and the author at the University of Technology, Sydney.
Appendix A: Samples Table 25.1 U.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
<th>SEM, ESEM &amp; EDXA</th>
</tr>
</thead>
<tbody>
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<td>Fibre</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>1</td>
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</tr>
<tr>
<td>Weave Count (cm)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Colour</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>Environment</td>
<td>TB</td>
<td>TB</td>
</tr>
<tr>
<td>Area</td>
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<td>MC</td>
</tr>
<tr>
<td>Period</td>
<td>PD</td>
<td>PD</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Good</td>
<td>Some damage to surfaces.</td>
</tr>
<tr>
<td>Lignin</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Fibrillation</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Fissures</td>
<td>Absent</td>
<td>Some</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
<td>High Levels</td>
</tr>
<tr>
<td>pH</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Photography</td>
<td>C</td>
<td></td>
</tr>
</tbody>
</table>

Key

**Fibre Analysis**
L= Linen
W= Wool
B= Bast Fibre
W = White
N= Natural Linen
S= Stained (Dark Brown)
D= Deteriorated
N/A= Not Applicable
?= Uncertain or Not Known

**Environment**
GB= Burial in Ground
TB= Tomb Burial
PB= Presumed Burial in Ground

**Period**
PD= Pre-Dynastic Period
D= Dynastic Period
GR= Greco-Roman /Ptolemaic
R= Roman /Coptic/ Late Antiquity

**Area**
MC= Memphis Area Cemetery
ME = Middle Egypt
UE = Upper Egypt
U= Unknown
N/A =Not Applicable
?= Uncertain

**Type of Photographic Record**
P=Colour Photograph
S= Colour Slide
B & W = Black and White Photograph
V = Video Film (B & W)
C= Computer image, B & W
## Appendix A: Samples. Table 25.2 U.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Optical Microscopy</strong></td>
<td>Linen Light to White.(^{10}) Very fine Surface “polished” Excellent condition</td>
<td>Absent</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ESEM</strong></td>
<td></td>
<td></td>
<td>High levels of particulate material</td>
<td></td>
</tr>
<tr>
<td><strong>ESEM Dynamic Study</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EDXA</strong></td>
<td></td>
<td></td>
<td>Carbon, oxygen, iron, copper, sodium, magnesium, aluminium, silicon, phosphorus, sulphur, chlorine, potassium, calcium(^{11}). (See also EDXA spectrum on the next page.)</td>
<td></td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

10. This fabric may have been sun bleached after washing with natron. Chlorine is well-known oxidative bleach. If washed with natron the metal elements could have acted as a catalyst to photo oxidation (Timar-Balazsy & Eastop, 1998, pp. 226-228).

11. The presence of copper is interesting, as both the textiles U and L came from tomb contexts where the linen may have been in proximity to copper grave goods, although the fibres of the textiles are not visibly mineralised with copper.
Appendix A: Samples. Figure 25.5 EDXA Spectrum of U. An EDXA spectrum of the sample taken by K. McBean and the author at the University of Technology, Sydney.
26. T

This sample was from a Graeco-Roman mummy recovered from, an unknown cemetery. It was probably a tomb burial. The date of recovery was unknown. It had long been held in a museum collection. The fibre was identified as linen, of ordinary quality. Lignin was found to be present. A photograph taken using the ESEM shows an area identified as one of possible use wear (there was evidence of erosion on the surface while rest of fibres appeared sound).
Appendix A: Samples. Figure 26.1 T. A photograph of the threads as received. Photograph by the author.

Appendix A: Samples. Figure 26.2 T. A photograph of a thread. Photograph by the author.
Appendix A: Samples. Figure 26.3 ESEM Image of T. An ESEM image showing damage to the surfaces of fibres, taken by K. McBean and the author at the University of Technology, Sydney.

Appendix A: Samples. Figure 26.4 ESEM Image of T. An ESEM image showing relatively undamaged surfaces of fibres, taken by K. McBean and the author at the University of Technology, Sydney.
**Appendix A: Samples. Table 26.1 T.**  
For abbreviations see the end of the table.

<table>
<thead>
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<th>Method of Analysis</th>
<th>Optical Microscopy</th>
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<td>L</td>
</tr>
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<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
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<tr>
<td>Diameter (mm)</td>
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<td>Colour</td>
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<td>N</td>
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<td>Environment</td>
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<td>Probable TB</td>
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<tr>
<td>Period</td>
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<td>GR</td>
</tr>
<tr>
<td>Level of Deterioration</td>
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<td>Some damage</td>
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<tr>
<td>Lignin</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
<td>Small amount Present</td>
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<td>Photography</td>
<td>C</td>
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</tr>
</tbody>
</table>

Key

**Fibre Analysis**

L= Linen  
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B= Bast Fibre  
W = White  
N= Natural Linen  
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**Area**

MC= Memphis Area Cemetery  
ME = Middle Egypt  
UE = Upper Egypt  
U= Unknown

N/A = Not Applicable

Type of Photographic Record

P= Colour Photograph  
S= Colour Slide  
B & W = Black and White Photograph  
V = Video Film (B & W)  
C= Computer image, B & W
## Appendix A: Samples. Table 26.2 T.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
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</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>Linen</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>IC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESEM</td>
<td>Area of probable use wear</td>
<td>Present</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDXA</td>
<td></td>
<td></td>
<td></td>
<td>Carbon, oxygen, iron, sodium, magnesium, aluminium, silicon, phosphorus, sulphur, chlorine, potassium, calcium. (See also EDXA spectrum on the next page.)</td>
</tr>
</tbody>
</table>
Appendix A: Samples. Figure 26.5 EDXA Spectrum of T. This EDXA spectrum was taken by K. McBean and the author at the University of Technology, Sydney.
This sample was from a fragment of textile recovered from a ground burial in Middle Egypt. It was originally part of grave clothing or wrapping for a burial. The period was not definitely identified, but was probably late. Under optical microscopy the fibres were identified as linen. The fibre was ordinary in quality, the threads were quite strong and flexible, but the processing of the fibres may not have been of the highest standard as some areas of the fibres tested positive when tested for lignin. The pH was tested and found to be 6.0. The fabric was recovered post-1960.
Appendix A: Samples. Figure 27.1 TK. Photograph of TK before examination. Photograph by the author.

Appendix A: Samples. Figure 27.2 TK. Detail of TK before examination. Photograph by the author.
Appendix A: Samples. Figure 27.3 ESEM Image of TK.
ESEM Image taken by K. McBean and the author at University of Technology, Sydney.

Appendix A: Samples. Figure 27.4 ESEM Image of TK.
ESEM image taken by K. McBean and the author at University of Technology, Sydney.
Appendix A: Samples. Table 27. 1 TK.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
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<td>L</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
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<tr>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
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<td>1</td>
<td>1</td>
</tr>
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<td>Weave Count (cm)</td>
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<td>10 x 12</td>
<td>10 x 12</td>
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<td>W</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
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<td>GB</td>
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<td>ME</td>
<td>ME</td>
</tr>
<tr>
<td>Period</td>
<td>U</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Level of Deterioration</td>
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<td>Strong</td>
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<td>Lignin</td>
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<td>Present</td>
<td></td>
</tr>
<tr>
<td>Fibrillation</td>
<td>Absent</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Fissures</td>
<td>Absent</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
<td>Present</td>
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<tr>
<td>pH</td>
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<tr>
<td>Photography</td>
<td>C</td>
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</tr>
</tbody>
</table>

**Key**

Fibre Analysis  
L = Linen  
W = Wool  
B = Bast Fibre  
W = White  
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ME = Middle Egypt  
UE = Upper Egypt  
U = Unknown

N/A = Not Applicable  
? = Uncertain

Type of Photographic Record  
P = Colour Photograph  
S = Colour Slide  
B & W = Black and White Photograph  
V = Video Film (B & W)  
C = Computer image, B & W

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## Appendix A: Samples. Table 27.2 TK.

<table>
<thead>
<tr>
<th>TK</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>Linen Fibres are strong and very white ¹</td>
<td>Present</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC</td>
<td></td>
<td></td>
<td></td>
<td>Fluoride –0.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Chloride 11.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bromide</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Phosphate 0.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sulphate 0.43</td>
</tr>
<tr>
<td>ESEM</td>
<td>Good, but with some breaks in the fibres.</td>
<td>Present</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDXA</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>nitrogen, iron, sodium, magnesium, aluminium,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>phosphorus, sulphur, calcium.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(See also EDXA spectrum on the next page.)</td>
</tr>
<tr>
<td>pH</td>
<td>6.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹. This white colour is not from a dye, but indicates the fibre was bleached, probably through photo-oxidation.
Appendix A: Samples Figure 27.5 EDXA Spectrum of TK. This spectrum was taken by K. McBean and the author at the University of Technology, Sydney.
28. N (Linen from Cartonnage Mask)

Cartonnage samples were taken from the backing of a cartonnage mask recovered from a tomb burial. The tomb was excavated prior to 1960. It appeared to be of Dynastic date. The exact area of its excavation was not known. It has been part of a museum collection for approximately a century.

Appendix A: Samples. Figure 28.1 N (Cartonnage Mask). Photograph by the author.
Appendix A: Samples. Figure 28.2 N (Cartonnage Mask). Optical Microscopy showing linen fibres. 10x objective. Photomicrograph by J. Barron and the author.

Appendix A: Samples. Figure 28.3 N (Cartonnage Mask). Optical Microscopy with crossed polars. 10x objective. Photomicrograph by J. Barron and the author.
Appendix A: Samples. Figure 28.4 ESEM Image of N (Cartonnage Mask).
An ESEM image of a thread, showing the bundles of fibres twisted together. Computer image taken by K. McBean and the author at the University of Technology, Sydney.

Appendix A: Samples. Figure 28.5 ESEM Image of N (Cartonnage Mask).
An ESEM image of fibres showing salts on the fibres. Computer image taken by K. McBean and the author at the University of Technology, Sydney.
Appendix A: Samples. Table 28.1 N (Cartonnage Mask).
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
<th>SEM, ESEM &amp; EDXA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicate Number</td>
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<td>2</td>
</tr>
<tr>
<td>Fibre</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>&gt;1</td>
<td>&gt;</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>Variable 9-10 x 13-14</td>
<td>Variable 9-10 x 13-14</td>
</tr>
<tr>
<td>Colour</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Environment</td>
<td>TB</td>
<td>TB</td>
</tr>
<tr>
<td>Area</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Period</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Good Condition</td>
<td>Good Condition</td>
</tr>
<tr>
<td>Lignin</td>
<td>Uncertain. Difficult to test.</td>
<td>Uncertain. Difficult to test.</td>
</tr>
<tr>
<td>Fibrillation</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Fissures</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Photography</td>
<td>S</td>
<td>C</td>
</tr>
</tbody>
</table>

**Key**

**Fibre Analysis**
L= Linen  
W= Wool  
B= Bast Fibre  
W= White  
N= Natural Linen  
S= Stained (Dark Brown)  
D= Deteriorated  
N/A= Not Applicable  
? = Uncertain or Not Known

**Environment**
GB= Burial in Ground  
TB= Tomb Burial  
PB= Presumed Burial in Ground

**Period**
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**Area**
MC= Memphis Area Cemetery  
ME = Middle Egypt  
UE = Upper Egypt  
U= Unknown  
N/A =Not Applicable  
? = Uncertain

**Type of Photographic Record**
P= Colour Photograph  
S= Colour Slide  
B & W = Black and White Photograph  
V = Video Film (B & W)  
C= Computer image, B & W


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### Appendix A: Samples. Table 28.2 N (Linen from Cartonnage Mask)

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>Linen</td>
<td>Dark colour of thread made test results difficult to read. May be absent.</td>
<td>Small amount of particulate material</td>
<td></td>
</tr>
<tr>
<td>IC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESEM</td>
<td></td>
<td></td>
<td>May be present, but very small amount</td>
<td></td>
</tr>
<tr>
<td>ESEM Dynamic Study</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDXA</td>
<td></td>
<td></td>
<td>Carbon, oxygen, sodium, magnesium, aluminium, silicon, phosphorus, sulphur, chlorine, potassium, calcium, iron. (See also EDXA spectrum on the next page.)</td>
<td></td>
</tr>
</tbody>
</table>
Appendix A: Samples. Figure 28.6 EDXA Spectrum of N (Cartonnage Mask). An EDXA spectrum of the sample recorded by K. McBean and the author at the University of Technology, Sydney.
29. BD (Book of the Dead)

Samples were taken from a Book of the Dead (linen with writing in ink) recovered from a tomb burial. The tomb was excavated prior to 1960. It appeared to be of Dynastic date. The exact area of its excavation was not known. It has been part of a museum collection for approximately a century.

Three differing fabrics were taken and examined by optical microscopy.

a) The fibre was identified as linen. It was white in colour. The fibre was of good quality. No lignin was found to be present.

b) The fibre was identified as linen. It was darkened in colour. Lignin may be present, but the dark colour of the fibres made this determination difficult.

c) A sample with writing on it in an ink.
Appendix A: Samples. Figure 29.1 BD (Book of the Dead). This is a photograph of samples from the Book of the Dead prior to examination. Photograph by the author.

Appendix A: Samples. Figure 29.2 BD (Book of the Dead) Sample with Writing. Photograph by the author.
Appendix A: Samples. Figure 29.3 BD (Book of the Dead). A photomicrograph of the sample showing the fabric photographed using optical microscopy with a 2.5 objective by J. Barron and the author.

Appendix A: Samples. Figure 29.4 BD (Book of the Dead). A photomicrograph of the fibres using optical microscopy. 10x objective. Photomicrograph by J. Barron and the author.
Appendix A: Samples. Figure 29.5 ESEM Image of BD (Book of the Dead). An ESEM image of the fibres, showing fibbrilation and eroded surfaces. A computer image taken by K. McBean and the author at the University of Technology, Sydney.

Appendix A: Samples. Figure 29.6 ESEM Image of BD (Book of the Dead). An ESEM image of the fibres. Possible glue on fibres is evident from previous paper backing. There is almost no evidence of particulate matter. Computer image taken by K. McBean and the author at the University of Technology, Sydney.
### Appendix A: Samples. Table 29. 1 BD (Book of the Dead).
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Replicate Number</th>
<th>Method of Analysis</th>
<th>Fibre</th>
<th>Spin</th>
<th>Ply</th>
<th>Diameter (mm)</th>
<th>Weave Count (cm)</th>
<th>Colour</th>
<th>Environment</th>
<th>Area</th>
<th>Period</th>
<th>Level of Deterioration</th>
<th>Lignin</th>
<th>Fibrillation</th>
<th>Fissures</th>
<th>Salt Crystals</th>
<th>Particulate Matter</th>
<th>Photography</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L</td>
<td>S</td>
<td>1</td>
<td>.5</td>
<td>19x20/25+</td>
<td>N</td>
<td>TB</td>
<td>?</td>
<td>D</td>
<td>Good</td>
<td>Absent</td>
<td>Present</td>
<td>Absent</td>
<td>Absent</td>
<td>Absent</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L</td>
<td>S</td>
<td>1</td>
<td>.5</td>
<td>19x20/25+</td>
<td>S</td>
<td>TB</td>
<td>?</td>
<td>D</td>
<td>Good</td>
<td>Indeterminate</td>
<td>Absent</td>
<td>Absent</td>
<td>Absent</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>S</td>
<td></td>
<td>.5</td>
<td>19x20/25+</td>
<td>N,S, Inked</td>
<td>TB</td>
<td></td>
<td></td>
<td>Good</td>
<td>Indeterminate</td>
<td>Absent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Key**

**Fibre Analysis**
- L= Linen
- W= Wool
- B= Bast Fibre
- W = White
- N= Natural Linen
- S= Stained (Dark Brown)
- D= Deteriorated
- N/A= Not Applicable
- ? = Uncertain or Not Known

**Environment**
- GB= Burial in Ground
- TB= Tomb Burial
- PB= Presumed Burial in Ground

**Period**
- PD= Pre-Dynastic Period

**Type of Photographic Record**
- P= Colour Photograph
- S= Colour Slide
- B & W = Black and White Photograph
- V = Video Film (B & W)
- C = Computer image, B & W

D= Dynastic Period
GR= Greco-Roman /Ptolemaic
R= Roman /Coptic/ Late Antiquity
Area
- MC= Memphis Area Cemetery
- ME = Middle Egypt
- UE = Upper Egypt
- U= Unknown

N/A =Not Applicable
? = Uncertain
### Appendix A: Samples. Table 29.2 BD (Book of the Dead).

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Optical Microscopy</strong></td>
<td>Linen</td>
<td>Sample1. Absent Sample 2. Dark colour of fibre made testing difficult. May be absent</td>
<td>Almost no evidence of particulate matter</td>
<td></td>
</tr>
<tr>
<td><strong>ESEM, ESEM Dynamic Study</strong></td>
<td></td>
<td></td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td><strong>EDXA</strong></td>
<td></td>
<td></td>
<td>Carbon, oxygen, calcium aluminium, silicon, sulphur.</td>
<td>(See also EDXA spectrum on the next page.)</td>
</tr>
</tbody>
</table>
Appendix A: Samples. Figure 29.6 EDXA Spectrum BD (Book of the Dead). An EDXA spectrum taken by K. McBean and the author at the University of Technology, Sydney.
30. Cartonnage

Cartonnage samples were taken from a cartonnage recovered from a tomb burial. The tomb was excavated prior to 1960. The cartonnage appears to be of Dynastic date. The exact area of its excavation was not known.

Cartonnage is generally made up of either a linen or papyrus backing, to which a calcium carbonate layer is added, often and with straw and glue also added to the layers. It was used for funeral masks and for mummy covers in ancient Egypt. Both textile fibres and plant fibres that had become detached from the cartonnage backing during conservation examination were sampled.

The textile fibres were identified as linen. They varied in quality and colour. There were probably several different sources for the fabric and fibres used as the cartonnage backing. No lignin was found to be present.

The pH was tested and found to be between 5.0 and 6.0.
Appendix A: Samples. Figure 30.1 Cartonnage. Photographs taken of the cartonnage fragments during conservation treatment by the author. Courtesy of the Nicholson Museum of Antiquities, The University of Sydney.
Appendix A: Samples. Figure 30.2 Cartonnage. Photograph of samples of loose fibres and straw. Photograph by the author.
Appendix A: Samples. Figure 30.3 ESEM Image of Cartonnage Sample 1. 
ESEM image taken by K. McBean and the author at University of Technology, Sydney.

Appendix A: Samples. Figure 30.4 ESEM Image of Cartonnage Sample 2. 
ESEM image taken by K. McBean and the author at the University of Technology, Sydney.
Appendix A: Sample. Figure 30.5 ESEM Image of Cartonnage Sample 3. ESEM image taken by K. McBeam and the author at University of Technology, Sydney. The sample appears to be straw.
Appendix A: Samples. Table 30.1. Cartonnage Sample 1.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
<th>SEM, ESEM &amp; EDXA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicate Number</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fibre</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>Ply</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>Variable</td>
<td></td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Colour</td>
<td>N,S</td>
<td></td>
</tr>
<tr>
<td>Environment</td>
<td>TB</td>
<td>TB</td>
</tr>
<tr>
<td>Area</td>
<td>MC?</td>
<td>MC?</td>
</tr>
<tr>
<td>Period</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Lignin</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Fibrillation</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Fissures</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Photography</td>
<td>C</td>
<td></td>
</tr>
</tbody>
</table>

**Key**

**Fibre Analysis**

L = Linen  
W = Wool  
B = Bast Fibre  
W = White  
N = Natural Linen  
S = Stained (Dark Brown)  
D = Deteriorated  
N/A = Not Applicable  
? = Uncertain or Not Known

**Environment**

GB = Burial in Ground  
TB = Tomb Burial  
PB = Presumed Burial in Ground

**Period**

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**Area**

MC = Memphis Area Cemetery  
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UE = Upper Egypt

U = Unknown  
N/A = Not Applicable  
? = Uncertain

**Type of Photographic Record**

P = Colour Photograph  
S = Colour Slide  
B & W = Black and White Photograph  
V = Video Film (B & W)  
C = Computer image, B & W
Appendix A: Samples. Table 30.2 Cartonnage Sample 2.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
<th>SEM, ESEM &amp; EDXA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicate Number</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fibre</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>Variable</td>
<td>Variable</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>N/A</td>
<td>NA</td>
</tr>
<tr>
<td>Colour</td>
<td>N, S</td>
<td>N, S</td>
</tr>
<tr>
<td>Environment</td>
<td>TB</td>
<td>TB</td>
</tr>
<tr>
<td>Area</td>
<td>MC?</td>
<td>MC?</td>
</tr>
<tr>
<td>Period</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Lignin</td>
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<td></td>
</tr>
<tr>
<td>Fibrillation</td>
<td></td>
<td>Present</td>
</tr>
<tr>
<td>Fissures</td>
<td></td>
<td>?</td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Photography</td>
<td>C</td>
<td></td>
</tr>
</tbody>
</table>

**Key**

**Fibre Analysis**
- L = Linen
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**Type of Photographic Record**
- P = Colour Photograph
- S = Colour Slide
- B & W = Black and White Photograph
- V = Video Film (B & W)
- C = Computer image, B & W

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Appendix A: Samples. Table 30. 3 Cartonnage Sample 3.
For abbreviations see the end of the table.

<table>
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<th>Method of Analysis</th>
<th>Optical Microscopy</th>
<th>SEM, ESEM &amp; EDXA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicate Number</td>
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<td>2</td>
</tr>
<tr>
<td>Fibre</td>
<td>Straw</td>
<td>Straw</td>
</tr>
<tr>
<td>Spin</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Ply</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Colour</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Environment</td>
<td>TB</td>
<td>TB</td>
</tr>
<tr>
<td>Area</td>
<td>MC?</td>
<td>MC?</td>
</tr>
<tr>
<td>Period</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Photography</td>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>

**Key**

**Fibre Analysis**
L= Linen  
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**Area**
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N/A =Not Applicable  
?= Uncertain

**Type of Photographic Record**
P= Colour Photograph  
S= Colour Slide  
B & W = Black and White Photograph  
V = Video Film (B & W)  
C= Computer image, B & W
Appendix A: Samples. Table 30.4 Cartonnage Sample 4.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
<th>SEM, ESEM Dynamic Study &amp; EDXA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicate Number</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fibre</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>Variable</td>
<td>Variable</td>
</tr>
<tr>
<td>Weave Count (cm)</td>
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<td>N/A</td>
</tr>
<tr>
<td>Colour</td>
<td>N,S</td>
<td>N,S</td>
</tr>
<tr>
<td>Environment</td>
<td>TB</td>
<td>TB</td>
</tr>
<tr>
<td>Area</td>
<td>MC?</td>
<td>MC?</td>
</tr>
<tr>
<td>Period</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Degraded</td>
<td></td>
</tr>
<tr>
<td>Lignin</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Fibrillation</td>
<td>Present</td>
<td>Fibres fractured.</td>
</tr>
<tr>
<td>Fissures</td>
<td></td>
<td>Present</td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td></td>
<td>Present</td>
</tr>
<tr>
<td>Photography</td>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>

Key

**Fibre Analysis**
L= Linen  
W= Wool  
B= Bast Fibre  
N= Natural Linen  
S= Stained (Dark Brown)  
D= Deteriorated  
N/A= Not Applicable  
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**Type of Photographic Record**
P= Colour Photograph  
S= Colour Slide  
B & W = Black and White Photograph  
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**Environment**
GB= Burial in Ground  
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**Period**
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**Area**
MC= Memphis Area Cemetery  
ME = Middle Egypt  
UE = Upper Egypt  
U= Unknown
Appendix A: Samples Table 30.5 Cartonnage.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>There were several different samples, both threads and plant stems. Samples 1, 2, and 4 were linen. Sample 3 was straw.</td>
<td>Absent</td>
<td>Sample 2. Cartonnage/Linen. Focused on crystal. Appears to be a sodium chloride crystal, both from the EDXA reading and from the cubic crystal shape.</td>
<td></td>
</tr>
<tr>
<td>ESEM</td>
<td></td>
<td></td>
<td></td>
<td>Sample 1. Carbon, Oxygen, Sodium, Silicon, Chlorine, Calcium.</td>
</tr>
<tr>
<td>ESEM Dynamic Study</td>
<td>Sample 4. Cartonnage/Linen. During dynamic study using ESEM the surface shows particulate matter. Sample took a long time to hydrate, but a short time to dehydrate. After ESEM hydration/dehydration cycle fibres fractured into small bundles. Fibrillation. Severely degraded</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDXA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>pH</th>
<th>Sample 4: 5.0-6.0</th>
</tr>
</thead>
</table>

Iron, Magnesium, Aluminium, Phosphorus, Sulphur, Potassium

**Sample 2.**
Carbon, Oxygen, Iron, Sodium, Magnesium, Aluminium, Silicon, Phosphorus, Sulphur, Chlorine, Potassium, Calcium.

**Sample 3.**
*Cartonnage / Straw.*
Carbon, Oxygen, Sodium, Magnesium, Aluminium, Silicon, Phosphorus, Sulphur, Chlorine, Potassium, Calcium.

(See also EDXA Spectra on the next three pages.)
Appendix A: Sample. Figure 30.6 EDXA Spectrum of Cartonnage Sample 1. EDXA spectrum taken by K. McBeam and the author at University of Technology, Sydney.
Appendix A: Sample. Figure 30.7 EDXA Spectrum of Cartonnage Sample 2.
EDXA spectrum taken by K. McBeam and the author at University of Technology, Sydney
Appendix A: Sample. Figure 30.8 EDXA Spectrum of Cartonnage Sample 3.
EDXA spectrum taken by K. McBeam and the author at University of Technology, Sydney
31. N67.36

The sample came from a fragment of a textile identified as from the Roman-Coptic period and from Tell el Amarna. It was probably recovered in the period 1920-1940 (pre-1960).
Appendix A: Samples. Figure 31.1 N67.36. A photograph taken prior to conservation treatment. Photograph by P. C. Johnson. Courtesy of the Nicholson Museum of Antiquities, The University of Sydney.

Appendix A: Samples. Figure 31.2 N67.36. A photograph taken post conservation treatment. Photograph by the author.
Appendix A: Samples. Figure 31.3 N67.36.
A photomicrograph taken of fibres prior to conservation treatment. 10x objective. Photomicrograph by the author.

Appendix A: Samples. Figure 31.4 ESEM Image of N67.36. An ESEM image of the sample prior to conservation treatment taken by K. McBean and the author at the University of Technology, Sydney.
Appendix A: Samples. Table 31.1 N37.36.
For abbreviations see the end of the table.

<table>
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<td>Spin</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Ply</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Diameter (mm)</td>
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<td>&gt;1</td>
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<td>11 x 11-13</td>
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<td>ME</td>
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<tr>
<td>Period</td>
<td>R</td>
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</tr>
<tr>
<td>Level of Deterioration Before Treatment</td>
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<td>Excellent condition</td>
</tr>
<tr>
<td>Lignin</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Fibrillation Before treatment</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Fissures Before Treatment</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Salt Crystals Before Treatment</td>
<td>Virtually absent</td>
<td>Virtually absent</td>
</tr>
<tr>
<td>Particulate Matter Before Treatment</td>
<td>Virtually absent</td>
<td>Virtually absent</td>
</tr>
<tr>
<td>Photography</td>
<td>S</td>
<td>C</td>
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**Key**

**Fibre Analysis**
- L = Linen
- W = Wool
- B = Bast Fibre
- W = White
- N = Natural Linen
- S = Stained (Dark Brown)
- D = Deteriorated
- N/A = Not Applicable
- ? = Uncertain or Not Known

**Environment**
- GB = Burial in Ground
- TB = Tomb Burial
- PB = Presumed Burial in Ground

**Period**
- PD = Pre-Dynastic Period
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- GR = Greco-Roman /Ptolemaic
- R = Roman /Coptic/ Late Antiquity

**Area**
- MC = Memphis Area Cemetery
- ME = Middle Egypt
- UE = Upper Egypt
- U = Unknown

**Type of Photographic Record**
- P = Colour Photograph
- S = Colour Slide
- B & W = Black and White Photograph
- V = Video Film (B & W)
- C = Computer image, B & W

500
### Appendix A: Samples. Table 31.2 N67.36.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
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</tr>
<tr>
<td>ESEM</td>
<td>Good condition</td>
<td>Very small amount</td>
<td>Carbon, oxygen, calcium.</td>
<td>Possibly sodium, magnesium, aluminium, chlorine, potassium,</td>
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<td>EDXA</td>
<td></td>
<td></td>
<td></td>
<td>(See EDXA spectrum on the next page.)</td>
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</table>
Appendix A: Samples. Figure 31.5 EDXA Spectrum of N67.36. An EDXA spectrum of a sample prior to conservation treatment taken by K. McBean and the author at the University of Technology, Sydney.
The sample came from a fragment of a textile identified as from the Roman-Coptic period and from Tell el Amarna. It was recovered prior to 1960, probably in the period 1920-1940.

The fibres were identified as linen. The sample taken before conservation treatment was too small for a lignin test. ESEM analysis showed the fibres to be badly broken. A large amount of particulate matter was visible.
Appendix A: Samples. Figure 32.1 N67.38. Photograph taken prior to conservation treatment. Photograph by P.C. Johnson. Courtesy of the Nicholson Museum of Antiquities, the University of Sydney.

Appendix A: Samples. Figure 32.2 N67.38. Photograph taken after conservation treatment. Photograph by the author.
Appendix A: Samples. Figure 32.3 N67.38. A photograph showing the different weaves. It was taken after conservation treatment. Photograph by the author.

Appendix A: Samples. Figure 32.4 ESEM Image of N67.38. An ESEM image of the sample taken before conservation treatment showing fibres to be broken and a large amount of particulate matter to be visible. Computer image taken by K. McBean and the author at the University of Technology, Sydney.
Appendix A: Samples. Table 32.1 N67.38.
For abbreviations see the end of the table.

<table>
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<td>Spin</td>
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<td>S</td>
</tr>
<tr>
<td>Ply</td>
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<td>1</td>
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<td>Diameter (mm)</td>
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<td>&gt;1</td>
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<td>1.19 x ?</td>
<td>1.19 x ?</td>
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<td>2. 10-12 x 10-12</td>
<td>2. 10-12 x 10-12</td>
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<td>N</td>
<td>N</td>
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<tr>
<td>Environment</td>
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<td>GB</td>
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<tr>
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<tr>
<td>Period</td>
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<td>R</td>
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<tr>
<td>Level of Deterioration</td>
<td>Fibres broken</td>
<td></td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Photography</td>
<td>C</td>
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**Key**

_Fibre Analysis_
L= Linen  
W= Wool  
B= Bast Fibre  
W = White  
N= Natural Linen  
S= Stained (Dark Brown)  
D= Deteriorated  
N/A= Not Applicable  
? = Uncertain or Not Known

_Environment_
GB= Burial in Ground  
TB= Tomb Burial  
PB= Presumed Burial in Ground

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PD= Pre-Dynastic Period

D= Dynastic Period  
GR= Greco-Roman /Ptolemaic  
R= Roman /Coptic/ Late Antiquity

_Area_
MC= Memphis Area Cemetery  
ME = Middle Egypt  
UE = Upper Egypt  
U= Unknown

N/A = Not Applicable  
? = Uncertain

_Type of Photographic Record_
P= Colour Photograph  
S= Colour Slide  
B & W = Black and White Photograph  
V = Video Film (B & W)  
C= Computer image, B & W

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### Appendix A: Samples. Table 32.2 N67.38

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
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<td>IC</td>
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<td></td>
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<tr>
<td>ESEM</td>
<td>Badly broken</td>
<td>Large amount</td>
<td></td>
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<tr>
<td>ESEM Dynamic Study</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>EDXA</td>
<td></td>
<td></td>
<td></td>
<td>Carbon, oxygen, sodium, silicon, chlorine magnesium, aluminium, phosphorus, sulphur, potassium, calcium, iron.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(See also EDXA spectrum on the next page)</td>
</tr>
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Appendix A: Samples. Figure 32.5 EDXA Spectrum of N67.38. The spectrum of a sample taken before conservation treatment. The EDXA spectrum was taken by K. McBean and the author at the University of Technology, Sydney.
33. N67.39

The sample came from a fragment of a textile identified as from the Roman-Coptic period and from Tell el Amarna. It was recovered prior to 1960, probably in the period 1920-1940.

The fibre was identified as linen using optical microscopy. The fibres were small and of good quality, though some were broken. The sample taken before conservation treatment was too small for a lignin test, but the sample taken after conservation treatment was tested for lignin. No lignin was found to be present.

Appendix A: Samples. Figure 33.1 N67.39. A photograph of the sample taken prior to conservation treatment. Photograph taken by P.C. Johnson. Courtesy of the Nicholson Museum of Antiquities, the University of Sydney.
Appendix A: Samples. Figure 33.2 N67.39. A photograph taken after conservation treatment of the sample. Photograph taken by the author.

Appendix A: Samples. Figure 33.3 N67.39. A photomicrograph taken of fibres from the sample taken before conservation treatment. 10x objective. Photomicrograph by the author.
Appendix A: Samples. Figure 33.4 ESEM Image of N67.39. An ESEM image of the sample before conservation treatment taken by K. McBean and the author at the University of Technology, Sydney.
Appendix A: Samples. Figure 33.6 ESEM Image of N67.39. An ESEM image of the sample after conservation treatment taken by K. McBean and the author at the University of Technology, Sydney.

Appendix A: Samples. Figure 33.7 ESEM Image of N67.39. An ESEM image of the sample after conservation treatment taken by K. McBean and the author at the University of Technology, Sydney.
Appendix A: Samples. Table 33.1 N67.39.
For abbreviations see the end of the table.
Sample 1 is the sample taken from the main textile before conservation treatment.
Sample 2 is the sample taken from the main textile after conservation treatment.

<table>
<thead>
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<th>Method of Analysis</th>
<th>Optical Microscopy</th>
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<td>S</td>
</tr>
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<td>Spin</td>
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<td>4</td>
</tr>
<tr>
<td>Ply</td>
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<td>1</td>
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<tr>
<td>Diameter (mm)</td>
<td>13 x 15</td>
<td>13 x 15</td>
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<tr>
<td>Weave Count (cm)</td>
<td>ME</td>
<td>ME</td>
</tr>
<tr>
<td>Colour</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Environment</td>
<td>GB</td>
<td>GB</td>
</tr>
<tr>
<td>Area</td>
<td>R</td>
<td>R</td>
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<tr>
<td>Level of Deterioration</td>
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<td>Excellent Condition</td>
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<td>N/A</td>
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<td>Fibrillation</td>
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<td>Absent</td>
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<td>Fissures</td>
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<td>Reduced</td>
</tr>
<tr>
<td>Salt Crystals</td>
<td>Present</td>
<td>Reduced</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>

Key

**Fibre Analysis**
L = Linen
W = Wool
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W = White
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N/A = Not Applicable
? = Uncertain or Not Known

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PB = Presumed Burial in Ground

**Period**
PD = Pre-Dynastic Period

**Area**
MC = Memphis Area Cemetery
ME = Middle Egypt
UE = Upper Egypt
U = Unknown

N/A = Not Applicable
? = Uncertain

**Type of Photographic Record**
P = Colour Photograph
S = Colour Slide
B & W = Black and White Photograph
V = Video Film (B & W)
C = Computer image, B & W
Appendix A: Samples. Table 33.2 N67.39.

Sample 1 is the sample taken from the main textile before conservation treatment. Sample 2 is the sample taken from the main textile after conservation treatment.

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Lignin</th>
<th>Visible Salts</th>
<th>Elements Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>Linen</td>
<td>Sample 1: too small for lignin test Sample 2: absent</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Excellent condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESEM</td>
<td>Sample 2: Some damage.</td>
<td>Sample 2: large amount present, including crystals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDXA</td>
<td></td>
<td></td>
<td></td>
<td>Sample 1 (Before Treatment): Carbon, Oxygen, Sodium, Silicon, Chlorine, Potassium, Calcium Significant Peaks: Magnesium, Aluminium, Phosphorus, Sulphur, Iron Sample 2 (After Treatment): Calcium Significant Peaks: Carbon, Oxygen, Sodium, Magnesium, Aluminium, Silicon, Phosphorus, Sulphur, Chlorine, Potassium, Iron, Copper 7 (See also EDXA spectra on the following pages.)</td>
</tr>
</tbody>
</table>

7. ESEM showed some particulate matter is still present, including crystals. The peak sizes and definition had changed considerably. The largest peak was now calcium. Sodium and chlorine had shrunk significantly, indicating that the highly soluble compound of sodium chloride had been reduced by washing. The addition of copper may have come from the wash water used, which was distilled water where the piping employed in the water system and distillation system may have contained copper.
Appendix A: Samples. Figure 33.8 EDXA Spectra N67.39.

Label A:

a) An EDXA spectrum of the sample before conservation treatment taken by K. McBean and the author at the University of Technology, Sydney.

Label A:

b) An EDXA spectrum of the sample after conservation treatment taken by K. McBean and the author at the University of Technology, Sydney.
The sample N67.40b came from a fragment of a textile identified as from the Roman-Coptic period and from Tell el Amarna. It was probably recovered in the period 1920-1940 (pre-1960).

The sample was originally catalogued and recorded as N7.40 and was photographed as such prior to conservation treatment. During conservation treatment it became apparent that two different textiles had been catalogued together, and the two fabrics were then given the numbers N.67.40a and N.67 40b.

It became apparent after the conservation treatment that the linen warp was in relatively good condition, but the woollen weft had frayed and matted (see Appendix A: Samples. Figs. 34. 3-5).
Appendix A: Samples. Figure 34.1 N67.40 (a and b together). Photograph taken before conservation treatment. Photograph by P. C. Johnson. Courtesy the Nicholson Museum of Antiquities, the University of Sydney.

Appendix A: Samples. Figure 34.2 N67 a and N67.40b. Photograph taken after conservation treatment. Photograph by the author.
Appendix A: Samples. Figure 34.3 N67.40b. Photograph of a section of the fabric, after conservation treatment. Photograph by the author.

Appendix A: Samples. Figure 34.4 N67.40b. A photograph of a section of the fabric taken after conservation treatment. Photograph by the author.
Appendix A: Samples. Table 34.1 N67.40b.
For abbreviations see the end of the table.

<table>
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<td>S</td>
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<tr>
<td>Ply</td>
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<td>Environment</td>
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<tr>
<td>Area</td>
<td>ME</td>
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<tr>
<td>Period</td>
<td>R</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Linen in relatively good condition.</td>
</tr>
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</table>

**Key**

**Fibre Analysis**
L= Linen  
W= Wool 
B= Bast Fibre  
W = White 
N= Natural Linen  
S= Stained (Dark Brown) 
D= Deteriorated 
N/A = Not Applicable 
? = Uncertain or Not Known

**Environment**
GB = Burial in Ground  
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**Period**
P = Pre-Dynastic Period  
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**Area**
MC = Memphis Area Cemetery  
ME = Middle Egypt  
UE = Upper Egypt  
U = Unknown 

N/A = Not Applicable

? = Uncertain

**Type of Photographic Record**
P = Colour Photograph  
S = Colour Slide  
B & W = Black and White Photograph  
V = Video Film (B & W)  
C = Computer image, B & W
The sample came from a fragment of a textile identified as from the Roman-Coptic period and from Tell el Amarna. It was probably recovered in the period 1920-1940 (pre-1960). It was severely damaged by insects. Though it was photographed, the photograph is of loose threads in a plastic bag and gives no information about weave or pattern.

Appendix A: Samples. Table 35.1 N67.42.
For abbreviations see the end of the table.

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Optical Microscopy</th>
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<tr>
<td>Diameter (mm)</td>
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</tr>
<tr>
<td>Weave Count (cm)</td>
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</tr>
<tr>
<td>Colour</td>
<td>N &amp; S</td>
</tr>
<tr>
<td>Environment</td>
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</tr>
<tr>
<td>Area</td>
<td>ME</td>
</tr>
<tr>
<td>Period</td>
<td>R</td>
</tr>
<tr>
<td>Level of Deterioration</td>
<td>Severe insect damage.</td>
</tr>
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<td>Photography</td>
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**Key**

**Fibre Analysis**
L = Linen
W = Wool
B = Bast Fibre
W = White
N = Natural Linen
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**Environment**
GB = Burial in Ground
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**Area**
MC = Memphis Area Cemetery
ME = Middle Egypt
UE = Upper Egypt
U = Unknown

N/A = Not Applicable
? = Uncertain
Type of Photographic Record
P = Colour Photograph
S = Colour Slide
B & W = Black and White Photograph
V = Video Film (B & W)
C = Computer image, B & W
36. Mummy of Tbj/Tjeby (X83758)

The Mummy of Tby or Tjeby the Elder (Museum of Victoria Number (X83758) was excavated in November 1923 from a tomb burial at Naga ed-Deir, and dated to some time in the 19th Century BC, during the Middle Kingdom (Stevens, Thomas, Bartlett & McDougall, 1978; Hope, 1983-1984).

Examinations of the Mummy of Tby/Tjeby have taken place at various times at the Museum of Victoria (Marsh, 1990a, 1990b). The fibres were all identified as linen. A variety of fabrics were used for the mummy bandages. These ranged from ordinary to good quality. None was of exceptional fineness. Calcium carbonate and other particulate matter appeared to be present on some of the fibres.
Appendix A: Samples. Figure 36.1 Tby/Tjeb (X83758). A photograph of the Mummy of Tby/Tjeb the Elder taken upon excavation. Courtesy of the Museum of Victoria, Melbourne.
Appendix A: Samples. Figure 36.2 Tby/Tjebý (X83758). A photograph of textile bandages before conservation treatment. Photograph courtesy of the Museum of Victoria, Melbourne.

Appendix A: Samples. Figure 36.3 Tby/Tjebý (X83758). A photograph of textile bandages after conservation treatment, the mummy of Tby/Tjebý (X83758). Photograph courtesy of the Museum of Victoria, Melbourne.
Appendix A: Samples Table 36.1 The Mummy of Tby/Tjeby (X83758).
For abbreviations see at the end of the table.

<table>
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<td>Period</td>
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<td>Level of Deterioration</td>
<td>Fragile</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>Present</td>
</tr>
</tbody>
</table>

Key

**Fibre Analysis**
- L= Linen
- W= Wool
- B= Bast Fibre
- W = White
- N= Natural Linen
- S= Stained (Dark Brown)
- D= Deteriorated
- N/A= Not Applicable
- ? = Uncertain or Not Known

**Type of Photographic Record**
- P= Colour Photograph
- S= Colour Slide
- B & W = Black and White Photograph
- V = Video Film (B & W)
- C= Computer image, B & W

**Environment**
- GB= Burial in Ground
- TB= Tomb Burial
- PB= Presumed Burial in Ground

**Period**
- PD= Pre-Dynastic Period
- D= Dynastic Period
- GR= Greco-Roman / Ptolemaic
- R= Roman / Coptic/ Late Antiquity

**Area**
- MC= Memphis Area Cemetery
- ME = Middle Egypt
- UE = Upper Egypt
- U= Unknown

N/A = Not Applicable
? = Uncertain
Appendix A: Samples Table 36.2 The Mummy of Tby/Tjeby (X83758).

<table>
<thead>
<tr>
<th>Analytical Techniques</th>
<th>Fibre</th>
<th>Visible Salts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Microscopy</td>
<td>Linen</td>
<td>Present</td>
</tr>
<tr>
<td></td>
<td>Several different textiles</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>Neutral to alkaline- 6.5-7.0+</td>
<td></td>
</tr>
</tbody>
</table>
Textile Analysis
Textile Analysis

1.1 Examination Format

In order to identify the textile and in order to gain information towards an understanding of the techniques used in manufacture, information was gathered and entered onto a Textile Examination Form. This incorporated, as preliminary cataloguing, categories that were suggested by Walton and Eastwood (1988) and demonstrated in Eastwood (1992).

The following is an example of the textile examination form used for recording information about linen textiles examined in this study.
TEXTILE EXAMINATION FORM
THESIS: NATURE AND CONSERVATION OF ARCHAEOLOGICAL TEXTILES

GLENNDÁ SUSAN MARSH-LETTS

Date:
Institution/Collection:
Identification Number:
Provenance:

Description:
1. Condition:

2. Dimensions:
3. Colour(s):
4. Fibre:
5. Preparation of Fibres:
6. Thread Count:
7. Spin (S, I or Z) / Ply (S or Z):
8. Weave:
9. Faults:
10. Other Weaving Techniques:
11. Non-woven Techniques
12. Finishes:
13. Applied Decorations and Fastenings:
14. Evidence for Use:

Conservation Treatment(s):

Microscopy
Sample(s)
Methods Used:

Observations:

Results/Conclusions:

Photographs:

Photo microscopy:

Drawings:
At a later stage information gathered from chemical and physical analysis was added to these forms. The information was then grouped by various criteria for discussion.

1.2 Examination Methods

Textiles were examined in order to describe and record their physical condition. Weave, spin, ply, thread diameter, thread count, fibre type, and thread colour were all noted. The fibres were tested for lignin content.

1.2.1 Determination of the Weave

Firstly, an attempt was made to determine the warp (the threads originally used to set up the loom) and the weft (the threads drawn through the warp). The determination of warp and weft allows the description of weave and the taking of a thread count.

Appendix A: Textile Analysis Figure 1. Weave. This drawing illustrates a method of recording the warp and weft. In this case it is a recording of tabby weave (Eastwood, 1992, p. 260).
This task is relatively easy if the textile is whole or if one edge (selvage) is preserved to show direction. However, many archaeological textiles are fragmentary and therefore it is not possible to distinguish warp from weft with certainty, for “warp can never be positively distinguished from weft without selvedges...” (King, 1978, p. 90).

With Coptic textiles, if a set of linen threads crossed at right angles with a set of woollen threads it is possible to infer that the linen is the warp and the wool the weft, as this was the usual procedure (though it must always be remembered that this is only an inference and not a certainty).

1.2.2 Spin and Twist

To determine spin and twist, diagrams in the handbooks mentioned above were consulted.

SPIN: The direction that the thread was originally spun can be recorded as S (anti-clockwise) or Z (clockwise) or I (for no spin). Also it can be recorded as tight, medium, or loose.

PLY: When two or more threads are plied together it was recorded as S or Z ply and number of threads was noted.
Appendix A: Textile Analysis Figure 2. Spin. This is an illustration of an S-twist and a Z-twist from Emery (1994 3rd ed., p. 11).

Appendix A: Textile Analysis. Figure 3. Ply. This is an illustration of S-spin and Z-ply from Walton (1989, p.317).

While this procedure has been deemed of importance for textile identification, for the purposes of this study it transpired that it was of relatively small importance.
1.2.3 Diameter of Thread

The diameter of threads was recorded in millimetres. This was done manually, along with the thread count. The diameter was also recorded in the visual records during environmental scanning electron microscopy, as a scale was incorporated in the photographic record. Unfortunately, the transmitted light microscope available for use at the University of Western Sydney, Nepean, was not equipped with a special ocular lens for measurement. The lack of this equipment made accurate measurement of changes in fibre diameter difficult.

Diameter was useful both for a determination of the relative fineness of linen thread and for noting any dimensional change to the threads during treatment(s) and testing.

Diameter has been found useful in other studies for identifying woollen fibres, where it has been used to determine fleece types, but evidence from this study was consistent with the observations of Ryder and Gabra-Sanders (1987), who found that a measurement of the diameter of flax fibres was not as useful in distinguishing various bast fibres or in dating flax fibres. Flax fibres showed “similarity regardless of age or source. No evolutionary trends like those found with wool were evident” (Ryder & Gabra-Sanders, 1987, pp. 91, 106-107).
1.2.4 Thread Count

For a thread count the number of threads per cm is used in Australia. (In the USA a count per inch is sometimes taken, and sometimes the count is taken in cm.) A standard scale is placed over a section of the fabric and the threads counted using a hand-held magnifying glass or binocular microscope. Warp and weft are counted and reported individually. Several sections are done, if the textile is large enough, and an average is given for an area. If an area is highly irregular this is also recorded. If warp and weft cannot be determined then notes are made referring to one direction as System 1 and the other as System 2, or it is indicated that warp and weft cannot be distinguished.

Example: Warp 10 per cm. x Weft 15 per cm.

System 1 / 10 per cm. x System 2/ 15 per cm.

The importance of thread count is similar to that of diameter. It is useful both for a determination of the relative fineness of the fibre and textile and for noting any dimensional change to the fibre during treatment(s) and testing.
1.2.5 Fibre Analysis

Though less than “scientific”, most initial identification of fibres by textile conservators has generally been determined by “how it looks” and “how it feels.” This suggests to the analyst the parameters of microscopy. It also may indicate the direction of further testing through such methods as chemical spot testing or through chemical staining followed by examination using transmitted light microscopy.

Examination under low power using a binocular microscope is useful, especially when examining whole fabric samples. Using a binocular microscope it is often possible to determine which fibres are typical and which fibres are extraneous. It also allows the identification of extraneous material which might be culturally significant and which therefore should not be removed.¹

Any loose threads present can be sampled for optical light microscopy. The normal procedure used is to recover a small section of a single thread (.5 cm to 1 cm is generally adequate). A section is then placed on a glass microscope slide with a couple of drops of liquid paraffin or water. It can be teased apart if necessary with a dissecting needle, to determine ply and to separate a section into the original fibres. Then a cover slip can be

¹ For example, extraneous material might prove to be residue from a filling of malachite in a linen bag once used by a trader in Egyptian eye cosmetics.
placed over the fibres and the slide labelled. Examination is generally confined to low magnification (10x to 40x).

1.2.5.1 Criteria for Fibre Identification


The following criteria taken from The Textile Institute (1975, p. 16) were used for the identification of fibres from the samples analysed in this study using transmitted light optical microscopy.

Linen (*Linum usitatissimum* L.) The ultimate fibres consist of pointed cells with very thick walls and very small lumina. A peculiarity of the flax fibre, in common with the majority of bast fibres, is the presence of transverse dislocations, often in the form of an X, which show up very clearly when the fibres are mounted in liquid paraffin. 1. When the fibres are wetted they twist rapidly to the left (clockwise) many times, then a few to the right.

Wools. Wools are hair fibres of sheep and other animals. Their chief characteristic is the presence of scales on the outside of the fibres (visible under the microscope). The pattern of scales varies between different breeds/species.
Silks. \textit{(Bombyx mori)} Filament threads. When degummed they are fine, uniform and without visible internal structure. However, wild silks can look quite different from the cultivated/carefully-processed silks.

Cottons. Staple length and fineness variable. Fibres show convolutions (twists) in both directions.

\textit{1.2.6 Colour}

A search of the literature for methods of recording the colour of fibres and threads found much more inconsistency of method in this area than in fibre identification. Several analysts have indicated that they had considered whether to record with a standard system, such as the Munsell Colour system, but had abandoned it as they realised that the colours as seen would not be true indications of the original colours, due to deterioration of the fibres and/or dyes, and also possible staining (Thurman & Williams, 1979, p. 37).

Ideally each colour could be tested and the dye correctly identified, using spectrographic or chromatographic methods, though the exact identification of natural dyes from archaeological textiles can be more difficult than with modern samples using synthetic dyes, due to the effects of the archaeological deposit upon the textile fibres and the dyes.
(Hardman, 1994, p. 119) This option was considered, but not undertaken during this study. Most of the samples obtained for this study (and all of the flax samples) are not dyed fabrics, and therefore dye testing was not necessary.

Colour in the undyed flax samples used in this study was noted as 1) "White", indicating a very light colour and possibly indicating photo oxidation of the fibre; 2) "Natural Linen" where the fibre was either the blonde of new, natural, undyed linen or was slightly darkened; 3) "Stained" where the fibre appeared to be darkly stained with some extraneous material; or 4) "Degraded" where the fabric was severely degraded.

1.2.7 Spot Testing/Staining

For those samples identified as linen, a further test was done to determine the presence or absence of lignin. This was done in order to gain an idea of the relative “quality” of the fibre and to determine whether it might have undergone photo oxidation (bleaching).

The standard test for lignin, to be found in Garner, 1949 (pp. 138-139) is as follows. A small section of the sample is prepared on a glass slide and
is tested with a phloroglucinol solution. This consists of a 2% solution of phloroglucinol in ethanol mixed with an equal volume of concentrated HCl. A drop of the test solution is placed on the sample, which is then examined under a transmitted light microscope, any red colour present observed, and the relative percentage and location of red staining noted. Red colour indicates the presence of lignin.