# The Conservation of Artifacts Made from Plant Materials

Mary-Lou E. Florian  Dale Paul Kronkright  Ruth E. Norton

# The Conservation of Artifacts Made from Plant Materials

# The Conservation of Artifacts Made from Plant Materials

Mary-Lou E. Florian  Dale Paul Kronkright  Ruth E. Norton

*Cover: Warao basketry tray, Venezuela*
*Fowler Museum of Cultural History, UCLA, X65-7765.*

Course Coordinator: Benita Johnson
Publications Coordinator: Irina Averkieff, GCI
Design: Jacki Gallagher, GCI
Technical Illustration: Janet Spehar Enriquez and Laurie Grove
Printing: Princeton University Press



Library of Congress Cataloging-in-Publication Data

Florian, Mary-Lou E.
The conservation of artifacts made from plant materials / Mary-Lou E. Florian, Dale Paul Kronkright, Ruth E. Norton
Includes bibliographical references and index.
ISBN 0-89236-160-3
1. Plant remains (Archaeology)--Collection and preservation.
I. Kronkright, Dale Paul. II. Norton, Ruth E. III. Title.
CC79.5.P5F58 1990
930.1 ' 028 ' 5--dc20

## The Getty Conservation Institute

The Getty Conservation Institute (GCI), an operating program of the J. Paul Getty Trust, was created in 1982 to enhance the quality of conservation practice in the world today. Based on the belief that the best approach to conservation is interdisciplinary, the Institute brings together the knowledge of conservators, scientists, and art historians. Through a combination of in-house activities and collaborative ventures with other organizations, the Institute plays a catalytic role that contributes to the conservation of our cultural heritage. The Institute aims to further scientific research, to increase conservation training opportunities, and to strengthen communication among specialists.

# Contents

# Preface

Objects made from plant materials comprise a large portion of the ethnographic material in collections around the world. Conservation of such perishable artifacts is especially problematic when they are housed in climates different from those in which they were collected, as is often the case.

A certain amount of research into the conservation of plant material artifacts has been carried out and published. However, to date no substantive volume exists that brings together this scattered information from various disciplines. The present publication, while far from exhaustive in its treatment of the subject, attempts to fill this lacuna.

In July of 1987, the Getty Conservation Institute sponsored and hosted in Los Angeles, California, a six-week course titled *The Conservation of Artifacts Made from Plant Materials*. Recognizing the dearth of easily accessible reference material for use in the course, the GCI invited three of the instructors (Mary-Lou Florian, Dale Kronkright, and Ruth Norton) to prepare class notes synthesizing the topics they were to teach. The present volume is based on the principal texts prepared for that course, which have since been revised and, where necessary, expanded to provide continuity and consistency.

## Contents

*The Conservation of Artifacts Made from Plant Materials* is intended as an informal reference source for practicing conservators rather than as a textbook—that is, it does not provide a complete coverage of the subject of conservation, nor does it present a unified approach. Having been derived from the class notes of three instructors, the five chapters reflect each author's personal perspective and orientation.

Chapter 1, contributed by Mary-Lou Florian, introduces plant anatomy as it relates to the conservator's need to identify plant parts and fibers along with their chemical composition. This information is essential in order to understand when and how deterioration occurs. Morphology is addressed only to the extent that it illuminates identification.

Chapter 2, also prepared by Mary-Lou Florian, is comprised of two separate sections: (1) identification of plant fibers and (2) identification of plant parts or

tissues. For practical purposes, the author has limited the information to the most common plant materials found in artifacts, with an emphasis on materials from western North America. Because fibers of common animal origin at times are used as decorative elements in artifacts, the author has also included identification techniques for these materials. She has selected actual artifact samples to illustrate this chapter, which includes basic laboratory techniques and step-by-step methods for staining fibers and tissues.

Chapter 3, contributed by Ruth Norton, describes the major known methods and techniques used in making artifacts from plant materials, with an emphasis on objects made in Oceania and Southeast Asia—the area of the author's special expertise. The topic of manufacturing technology is important because the methods used in processing plant materials and manufacturing objects have a direct effect on preservation.

The chapter on deterioration, Chapter 4, contributed by Dale Kronkright, builds on the information presented in previous chapters. Kronkright emphasizes that it is the combination of multiple deterioration processes that leads to degradation of artifacts. Because little research has been done in this area, it was necessary to infer some of the information presented from wood deterioration studies.

The fifth and final chapter, like the third, was written by Ruth Norton. Addressing the issue of conservation, it emphasizes the importance of nonintervention whenever possible when dealing with ethnographic artifacts, which serve to document the culture of their manufacturers. The treatments discussed in this chapter are viewed only as last-resort measures in cases where further deterioration is considered imminent or where restoration is required for aesthetic purposes.

For the reader's convenience, bibliographic references are listed at the end of each chapter. An index and a glossary of special terms are also included at the end of the volume.

## The Authors

Mary-Lou E. Florian studied biology and botany at the University of British Columbia and the University of Texas, where she received a Master of Arts degree in botany, with emphasis in plant anatomy. She also studied fine art at the University of Saskatchewan and anthropology at Carleton University, Ottawa. Ms. Florian has worked for the Restoration and Conservation Laboratory of the National Gallery of Canada and was Senior Conservation Scientist at the Canadian Conservation Institute from 1972 to 1978. Since 1978, Ms. Florian has held the post of Conservation Scientist at the British Columbia Provincial Museum in Victoria, B.C., Canada.

Dale P. Kronkright received his Bachelor's degree in American material culture at the University of California, Davis. He also completed a certificate program in wood microtechnique and botanical systematics at the Bailey Wetmore Laboratory, Harvard University, after which he served a two-year internship in interpretive collections conservation with the California Department of Parks and Recreation. Mr. Kronkright has served as Assistant Conservator at the Peabody Museum, Harvard University (1982–1983) and as Museum Conservator at the Redding Museum and Art Center in California (1983–1986). Currently he is Senior Objects

Conservator at the Pacific Regional Conservation Center, Bernice Pauahi Bishop Museum, in Honolulu, Hawaii.

Ruth E. Norton is a graduate of the University of Delaware/Winterthur Museum M.S. program in Art Conservation. She was Objects Conservator at the Pacific Regional Conservation Center, Bernice Pauahi Bishop Museum in Hawaii from 1978 to 1982. During a leave from the Center, Ms. Norton spent eighteen months as Conservator and Trainer at the National Museum of the Philippines. From 1982 to 1987 she was Lecturer in Objects Conservation at the Canberra College of Advanced Education in Canberra, Australia. Ms. Norton is now in private practice.

## Acknowledgments

Sincere thanks are due to those who contributed much of their time and effort to ensuring that this volume appeared in print: to the authors, mentioned above, who extensively revised the material they prepared for teaching the course in 1987; to Benita Johnson who coordinated that course and the start of the publication process; to Robin Snyder, Assistant Coordinator of the Training Program, who took over the role of coordinating this publication and saw it through to completion; to Liana Beckett for editorial work on the manuscripts; to William Emboden and Charles Selwitz, who reviewed the manuscript from a scientific perspective; and, finally, to Janet Spehar Enriquez and Laurie Grove for the technical illustrations.

# 1 Plant Anatomy: An Illustrated Aid to Identification

*Mary-Lou E. Florian*

This chapter presents the fundamentals of plant anatomy, with emphasis on the identification of tissues and cells in plant parts used in artifacts. Understanding the structure of these materials can assist the conservator in making logical decisions regarding the preservation and conservation of artifacts.

This information is intended for applied use, not as a treatise on plant anatomy. The information presented is restricted to identification of dead materials—often only parts of a plant. Thus an overview of the structure and function of living plants is not presented. Plants chosen for examples either illustrate basic concepts or are commonly used as artifact material. This chapter provides a basic understanding of the arrangement of tissues in plants, and presents a basis for identifying plant parts, tissues, and cells.

This basic description of plant anatomy begins with a discussion of the growth cycle. The morphology of plant parts is illustrated, and the internal arrangement of primary and secondary tissues is outlined, along with the anatomy and chemical makeup of basic cell types in those tissues. The anatomy of a typical dicot and monocot is illustrated and explained, and a brief description of salient characteristics of some lower plants is presented. Higher plants are used to introduce the basic vocabulary and anatomy of cells and tissues. The basic chemicals of cell walls and their structure, reactivity, and location will be reviewed with special reference to conservation of plant parts used in basketry.

## The Classification and Nomenclature of Plants

A basic understanding of plant classification is a prerequisite to the study of plant anatomy. There are several systems of plant classification. For simplicity, an older system will be used as a guide in this text. All classification systems are based on groups of plants with close structural relationships. These groups are subdivided into smaller groups of plants with stronger structural similarities and so on.

The plant kingdom is classified into four divisions: *Thallophyta* (algae, bacteria, and fungi); *Bryophyta* (mosses and liverworts); *Pteridophyta* (ferns and allies); and *Spermatophyta* (seed-bearing higher plants). Materials used in artifacts come from plants in all divisions. Brown kelps (algae) are used for cordage, mosses are

*Figure 1.1. Leaf shapes.*

used as fillers in bedding and textiles, and the colored stems of ferns are used for decoration in basketry. But the majority of materials, from grass leaves to wood splints, come from seed-bearing plants.

The Spermatophyta division contains two distinct groups of plants, the *Gymnospermae* and *Angiospermae*:

Gymnosperms include the rare cycads, gnetales, and ginkoes, and the common coniferous trees and shrubs. The wood and inner bark of coniferous trees are commonly used in artifacts.

Angiosperms—flowering plants—are divided into two classes: Monocotyledonae (monocots) and Dicotyledonae (dicots), based on the presence of one (mono) or two (di) seed leaves (cotyledons) in the seed. Grasses and yuccas are examples of monocots; the hardwood of deciduous trees and the bast fibers of hemp and linen come from dicots. Within each class there are families (Agavaceae, Compositaceae, and so on) which are subdivided into genera that include individual plant species. The nomenclature of a plant—for example, *Quercus alba* (white oak)—gives the genus (*Quercus*) and species (*alba*) names. The species is the basic unit and includes plants from common parents, whereas the genus consists of closely related species, such as *Quercus alba* and *Quercus rubra*.

The classification of plants is based primarily on the floral and reproductive parts and seed structure, which have little application to our need for identification of artifact materials. But there are some basic anatomical differences among the groups that assist in identification:

- Thallophytes (algae and fungi) have a thallus, which is a plant body without roots, stems, or leaves and without vascular tissue.
- Bryophytes (liverworts and mosses) have leaves and stems, but do not have true roots and have limited vascular tissue.
- Pteridophytes (ferns) have stems, leaves, rootlike rhizomes (underground stems), and well-developed vascular tissue.
- Spermatophytes (seed plants) have stems, leaves, and true roots.

The anatomical structure of spermatophytes shows great variation, but there are basic differences among groups—for example, the diffuse arrangement of vascular bundles in monocot stems in contrast to the circular arrangement in dicots. These and other differences that aid identification are discussed in detail later.

# Morphology and Development

## Plant Morphology

Morphology is the form or structure of plant parts. For example, some leaves are thin and long, while others are short and thick (Figure 1.1). The morphology of plant parts often dictates their use in artifacts. However, since morphology can be difficult to distinguish in retrospect when only parts of a leaf or stem have been used, it is not very useful to conservators as a characteristic in the identification of materials.

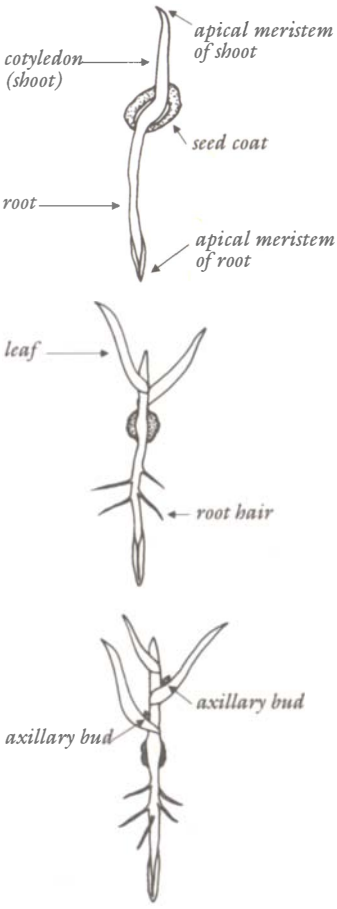



*Figure 1.2. Meristems in three stages of the development of a seed plant.*

## Embryonic Development

On germination of a seed, embryonic cells (meristems) divide and differentiate to form cell clusters that function as a unit called tissue. Meristems are located at the apex of the roots and stem and also in buds (Figure 1.2). Cells in plants may vary in size from 10 μ to 50 μ (one micron is equal to 1/1000 mm) in width and 10 μ to 50 μ (or more) in length. The functions of the tissues are to give the new plant mechanical strength, to adsorb water, and to synthesize and transport food materials needed for further growth and reproduction.

The body of a seed plant is made up of distinct parts or organs: roots, stems, leaves, flowers, fruit, and seeds. These organs are composed of different tissues, such as metabolic, strengthening, protective, reproductive, and so on. In turn, tissues are made up of structural and physiological units called cells.

# Primary Tissues

Embryonic cells present in the meristems of a seed are active throughout the growth of a plant. The tissues that are formed from this embryonic activity are called primary tissue. A tissue is a group of cells that function as a unit. The tissues of a grass plant, for example, are all primary tissues. If the plant is a perennial, new embryonic tissue (cambium) forms each growing season, giving rise to new tissues that increase the girth of the plant; such tissues are called secondary tissues. The wood of a tree, for example, is secondary tissue, but the tissue of the leaves of the same tree is primary tissue. An understanding of the arrangement and function of these tissues in the plant aids in the identification of materials and the understanding of their deterioration.

Primary tissues are found in stems, roots, flowers, and leaves; they are the tissues of the transport (vascular), strengthening, outer protective, reproductive, and metabolic systems. Secondary growth is usually limited to growth in the stem and roots. There the secondary tissues are found in the transport, strengthening, and protective systems.

The tissues within a system (e.g., vascular, strengthening) have specific names related to their position in the plant organ and to their specific function. In each tissue there may be a single type of cell or a variety of cells. The tissue names in the different systems and cell types are listed below as an introduction to the vocabulary (Table 1.1). Descriptions of the tissues and cells in primary and secondary tissue follow.

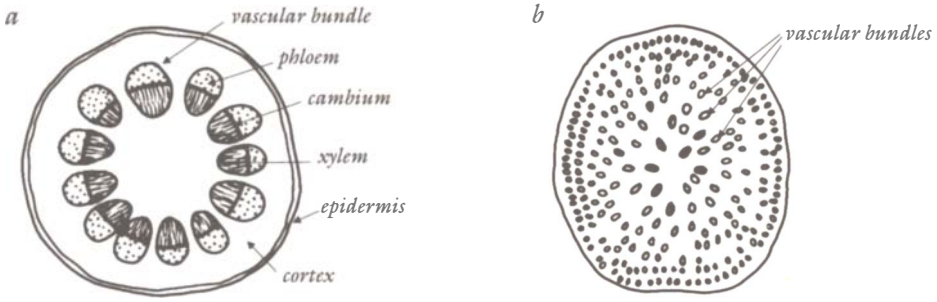



*Figure 1.3. (a) Cross section of a dicot stem. (b) Cross section of a monocot stem.*

*Table 1.1. Primary and secondary plant tissues and their cells.*

| Tissue | Cells in Primary Tissue | Cells in Secondary Tissue |
|---|---|---|
| Transport system | | |
| xylem | vessel member | tracheid |
| | tracheid | vessel member |
| | protoxylem | parenchyma |
| | metaxylem | |
| | parenchyma | |
| phloem | sieve element | sieve element |
| | companion cell | companion cell |
| | parenchyma | |
| Metabolic system | | |
| mesophyll | chlorenchyma | |
| | parenchyma | |
| | aerenchyma | |
| cortex (ground tissue) | parenchyma | |
| | idioblast | |
| | tannin cell | |
| pith | parenchyma | |
| Strengthening | | |
| sclerenchyma | fiber tracheid | tracheid |
| | vascular fiber bundle | fiber tracheid |
| | phloem fiber | phloem fiber |
| | sclereid | sclereid |
| collenchyma | collenchyma | |
| Protective | | |
| epidermis | epidermal | |
| | hypodermal | |
| | stomatal | |
| | trichome | |
| | silica | |
| | glandular | |
| endodermis | endodermal | |
| periderm (bark) | | phellem |
| | | phelloderm |
| Growth | | |
| embryonic | meristematic | vascular cambium |
| | | phellogen |

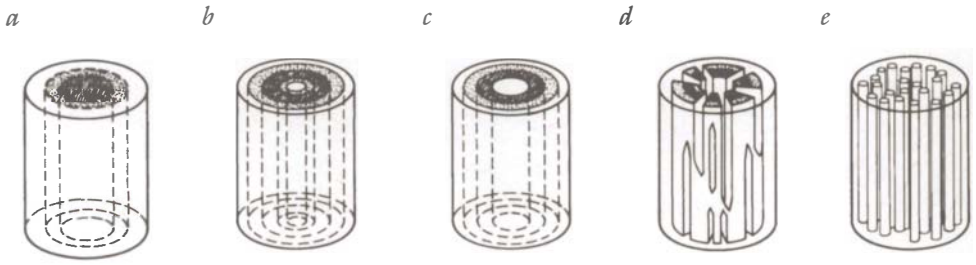



*Figure 1.4. Types of steles: (a) protostele, (b) amphiphloic siphonostele, (c) ectophloic siphonostele, (d, e) dictyostele.*

## Arrangement of Primary Tissues in Plant Parts

The arrangement of these tissues in stems, roots, and leaves, as seen in a cross section of a mature plant part, is described below.

### The Stem

The stem is bounded by a single layer of cells, the epidermis. It is composed of epidermal cells, stomata (complexes of cells that regulate transpiration), glandular cells, and trichome (hair) cells. Inside this outer layer of cells, a layer of hypodermal cells with specific cell characteristics such as pigment or wall thickness may be present in some species.

Inside the epidermis is the cortex (or ground tissue). In some stems, the outer cortex may contain groups of cells or a continuous ring of cells that function as support to strengthen the stem. These are collenchyma or sclerenchyma cells. If the stem is green, there may be specialized cortical cells, chlorenchyma cells, which have a photosynthetic function. Cells of the cortex commonly contain starch, oils, crystals, and so on. The central core of the stem contains the vascular tissue, called the stele. It contains the xylem and phloem tissues and sometimes the central pith (Figure 1.3). Sclerenchyma tissue may also be associated with vascular tissue. The vascular tissue in the stele may take many arrangements, depending upon the plant species.

#### Types of Steles: Arrangement of Xylem, Phloem, and Pith

Four main types of steles are present in vascular plants as shown in Figure 1.4:

- Protostele. The most primitive of the steles, it is composed of a central solid circle of xylem surrounded by phloem (Figure 1.4a). There is no central pith. Protosteles are common in primitive ferns.
- Amphiphloic siphonostele. This has a central pith surrounded by phloem, then xylem, then another outer circle of phloem next to the cortex (Figure 1.4b). This stele is common in ferns, but rare in dicots.
- Ectophloic siphonostele. This has a central pith surrounded by xylem, which in turn is surrounded by phloem (Figure 1.4c). It is common in dicots and gymnosperms.
- Dictyostele. The vascular cylinder consists of a network of separate strands (vascular bundles) which may appear circular in cross section (Figure 1.4d) or scattered throughout the ground tissue (Figure 1.4e). The circular dictyostele is found in dicots and the scattered dictyostele is common in monocots.

#### Types of Vascular Bundles: Arrangement of Xylem and Phloem

The individual vascular bundles of the stele are classified on the basis of the arrangement of xylem and phloem. There are four general types of vascular tissue arrangement in the vascular bundle (Figure 1.5):

- Radial Vascular Bundle. The most primitive of the vascular bundles, the xylem and phloem occur in separate strands on alternating radii (Figure 1.5a).

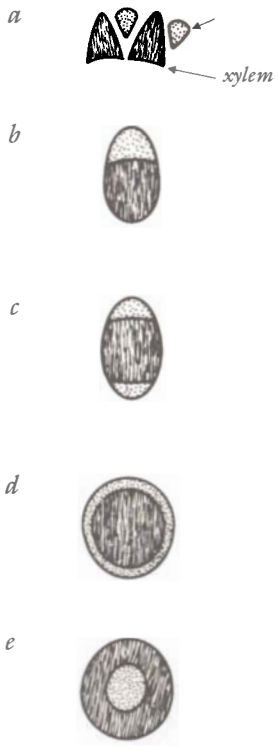



*Figure 1.5. Types of vascular bundles: (a) radial, (b) collateral, (c) bicollateral, (d) concentric amphicribral, (e) concentric amphivasal.*

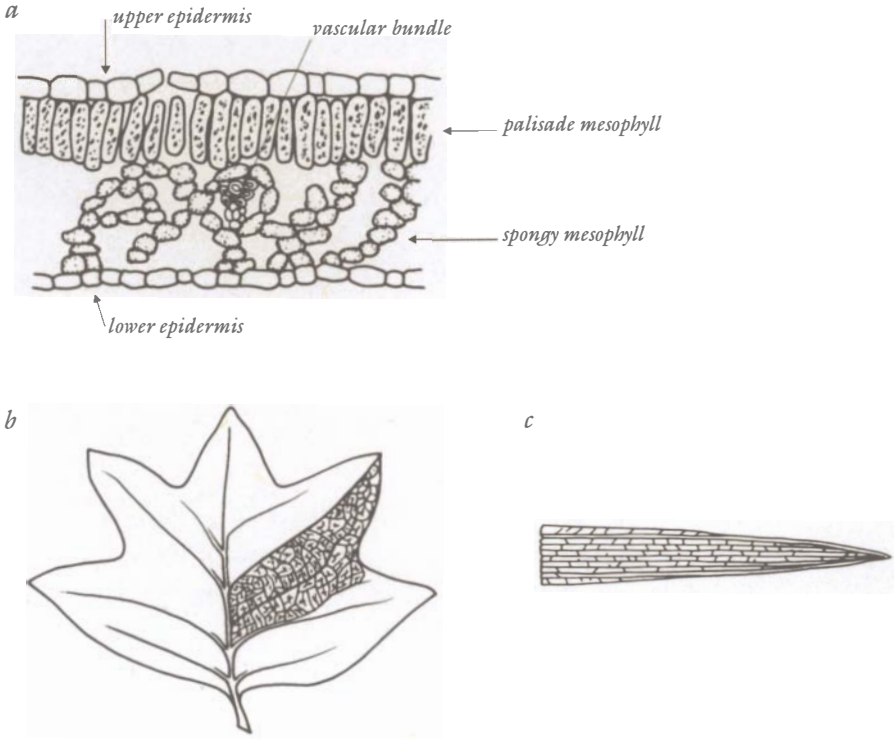
- Collateral Vascular Bundle. This type has separate vascular bundles with the xylem on the inside and the phloem next to the cortex (Figure 1.5b). The bundles are separated by parenchyma cells. Often the protophloem forms phloem fibers for support. Collateral bundles are characteristic of the stems of dicots and gymnosperms, occasionally in some ferns, and rarely in monocots (e.g., corn).
- Bicollateral Vascular Bundle. This type of vascular bundle has both internal and external phloem (Figure 1.5c). It is found in some dicots, for example in Solanaceae (potato family), Cucurbitaceae (gourd family), and Apocynaceae (Indian hemp family).
- Concentric Amphicribral Vascular Bundle. Here the phloem surrounds the xylem (Figure 1.5d). Commonly found in ferns.
- Concentric Amphivasal Vascular Bundle. Here the xylem encircles the phloem (Figure 1.5e). Commonly found in monocots and dicots.

## The Leaf

Structurally, leaves and stems are quite similar. The arrangement of primary tissue in the stele and the arrangement of vascular tissue in the vascular bundles are the same in both. Often, only parts of leaves or stems are used in artifacts and their structural similarity can make identification of the plant part difficult.

Most leaves are dorsoventrally flattened. Between the upper and lower epidermis lie the mesophyll tissue (photosynthetic palisade mesophyll and respiratory and spongy storage mesophyll) and the vascular bundles that form veins. The arrangement of the vascular tissue follows that given for the stem.

*Figure 1.6. (a) Basic tissue arrangement in monocot or dicot leaf shown in cross section. (b) Net venation of a dicot leaf. (c) Parallel venation of a monocot leaf.*



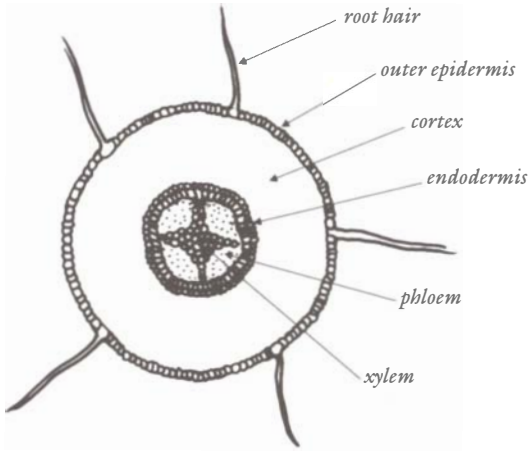



*Figure 1.7. Arrangement of primary tissue in a typical root.*

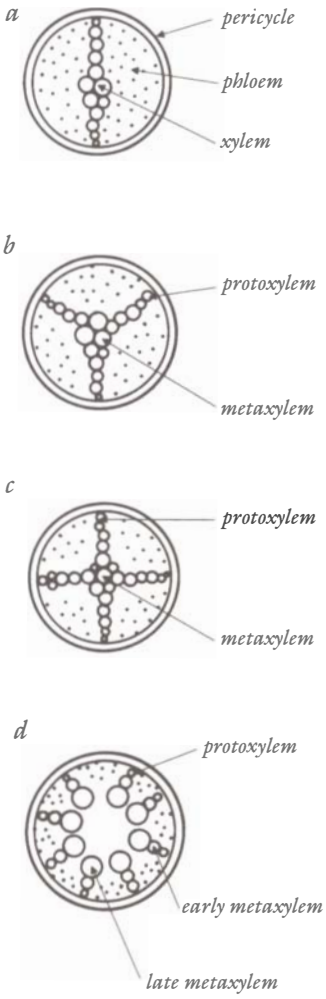



*Figure 1.8. Different mary xylem in the stele of roots: (a) diarch, (b) triarch, (c) tetrarch, (d) polyarch.*

Leaf structure varies depending upon the environment for which it is adapted. Monocot and dicot leaves in cross section may appear similar, but there is a basic difference in the vein structure: In monocots the unbranched veins lie parallel to one another, while dicots contain a reticulate network of branched veins. The parallel arrangement of veins in monocot leaves makes them excellent material for basketry and weaving, because they can easily be split into fine strands while still retaining fibrous strength.

Leaves have many species-specific characteristics that aid identification. For general purposes, however, Figure 1.6 provides a comparison of basic tissue arrangement in typical, mature monocot and dicot leaves.

## The Root

The cross section of a root in Figure 1.7 shows the arrangement of primary tissues and the clear separation of the external epidermis, cortex, and vascular system.

The epidermis is specialized for water adsorption and usually has root hairs, which are single epidermal cells with hairlike extensions. The cortex consists mainly of parenchyma cells with intercellular spaces. The innermost layer of the cortex is differentiated into an endodermis, the cells of which contain a waxy suberin band called the Casparian strip. Within the endodermis is the vascular cylinder with the outer pericycle and internal xylem and phloem. This stele is a protostele with a central core of xylem surrounded by phloem.

Primary xylem in the stele of roots can assume different patterns. These are called diarch, triarch, tetrarch, and polyarch according to the number of arms of xylem—two, three, four, or many, respectively (Figure 1.8a,b,c,d).

# Basic Cell Types of Primary Tissue

Identification of basic cell types is essential to the identification of materials used in artifacts. Often, only minute fragments that have lost their tissue integrity are available for analysis, and the ability to recognize just one cell may be the key to identification.

## Epidermis

The epidermis constitutes the layer of cells that covers the plant body. The cells take on specific functions, as reflected in their structure. There are protective waxy epidermal cells, guard cells that regulate transpiration or air and water vapor exchange, and glandular and hair cells. The continuity of the epidermis is interrupted by the minute openings of the guard cells, called stomata.

### Structure of the Epidermal Cell

The cell wall of waxy epidermal cells is usually thickened on the surface. The waxy material is called cutin; it often forms a waxy bloom or cuticle on the exposed surface of the cell wall. Pectic substances glue the cuticle to the cell wall. The functions of the wax are waterproofing, ultraviolet and infrared reflectance, and protection from microorganisms.

The epidermal cell may be colored due to the presence of tannins and plant pigments. In Figure 1.9, the structure of the outer epidermis shows a continuous layer of similar epidermal cells.

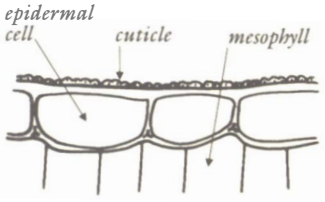



*Figure 1.9. Outer layer of epidermis showing continuous layer of epidermal cells.*

### Stomatal Complex

Stomata are openings in the epidermis. They are surrounded by specialized epidermal cells called guard cells that regulate the size of the opening or stoma. The complex of the stoma and two guard cells is called a stomatal complex (Figure 1.10). Sometimes epidermal cells adjacent to the stomatal complex differ in shape from other epidermal cells; such cells are called subsidiary cells (Figure 1.11). The arrangement of the guard cells and the subsidiary cells is an aid to identification of plant groups.

### Special Types of Epidermal Cells

Other types of cells are found in the epidermis, such as glandular and hair cells. Some epidermal cells may contain silica or cork. A few of these are illustrated in Figure 1.12.

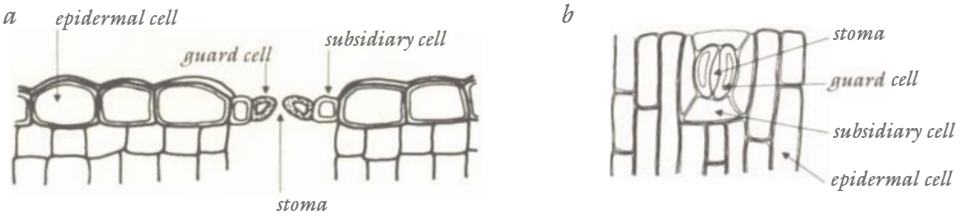



*Figure 1.10. Epidermis of a grass leaf showing stomatal complex and epidermal cells. (a) Cross section of epidermis showing stomatal complex. (b) Surface view of epidermis showing stomatal complex.*

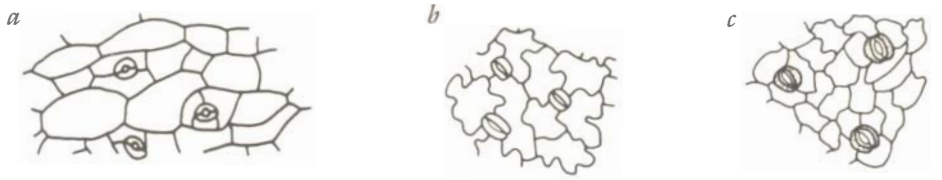



*Figure 1.11. Surface view of epidermis of different plants showing variation in stomatal complex.*


*Figure 1.12. Special types of epidermal cells: (a) uniseriate hair, (b) stellate hair, and (c) stalked glandular hair.*

## Parenchyma Cells

The basic cell type of the metabolic system is the parenchyma cell. It is a thin-walled cell and functions to produce or store starch, pigment, oil, crystals, and tannin. Newly formed parenchyma cells contain a living protoplast (Figure 1.13a).

### Contents of Parenchyma Cells

Cell contents can be an aid to identification. For example, the parenchyma cells of the leaf of the bulrush *Typha latifolia* L. contain crystal-like phytoliths that are readily seen under the microscope (Figure 1.13b).

### Parenchyma Cell Shapes

Parenchyma cells may assume many different shapes reflecting their function. For example, leaf cells seen in cross section may be elongate to draw sunlight into the leaf for efficient photosynthesis. Or parenchyma cells may have a stellate shape to provide large areas for air, adding buoyancy to leaves commonly associated with water environments (Figure 1.13c). Such cells are called aerenchyma cells. Often, the shapes of these cells are also aids to identification.

## Vascular Tissue

The primary tissues of the vascular system are the xylem, which transports water within the plant, and the phloem, which transports metabolic products such as sugar, acids, and protoplasmic contents. The xylem and phloem cells are associated with strengthening fibers and living parenchyma cells to form a vascular bundle. The primary cell types of the xylem are the protoxylem and metaxylem tracheid and vessel member cells. The primary cell types of the phloem are the sieve elements and companion cells.

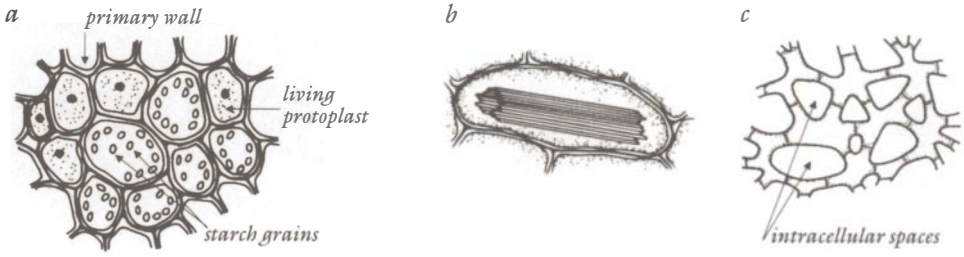



*Figure 1.13. Parenchyma cell characteristics. (a) Parenchyma cell structure. (b) Phytoliths in bulrush parenchyma cell. (c) Parenchyma cell shape specialized for buoyancy.*

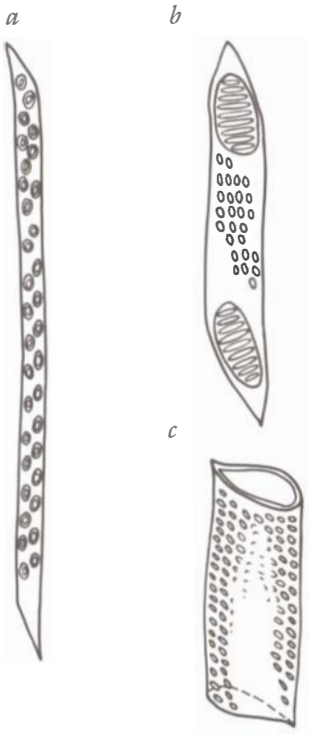



*Figure 1.14. The tracheary elements; tracheids and vessel members. (a) Tracheid with bordered pits. (b) Vessel member with sclariform perforation plate. (c) Vessel member with simple perforation plate.*

## Xylem Tissue Cells

### *Tracheary Elements*

The tracheary elements of the primary xylem are those cells involved in water conduction: the tracheids and vessel members. These cells are present also in secondary xylem. The main differences between secondary and primary xylem are their embryonic origin and organization. Primary xylem is formed by meristematic tissue and secondary xylem from the cambium. Primary xylem and associated primary phloem are organized into strands or vascular bundles, whereas secondary xylem grows in rings and is a radial as well as longitudinal system.

The tracheids are elongate cells with pits on the longitudinal walls and angled, closed end walls. Vessel members are usually short, broad cells. There are pits on the longitudinal walls and the end wall has an opening called a perforation plate, allowing the formation of a long, continuous tube made up of a number of vessel members. This structure is called a vessel. Perforation plates may be simple openings or they may assume a sclariform or ladderlike appearance (Figure 1.14). The characteristics of the perforation plates and pitting are an aid to identification of plant species.

### *Protoxylem and Metaxylem Cells*

Primary xylem cells vary in shape according to the sequence of their formation. The first-formed xylem cells are the protoxylem cells and the next-formed are the metaxylem cells. The differences in the shapes and relative position of these cells in the vascular bundle are an aid to identification. There are no definitive studies of the species commonly found as plant artifact materials, but Figure 1.15 shows the potential use of this characteristic for identification.

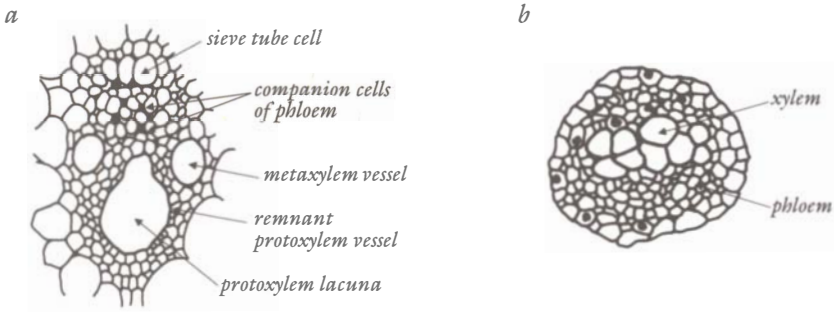



*Figure 1.15. (a) Cross section of vascular bundle of* Zea mays *(corn) showing diagnostic arrangement of protoxylem and metaxylem. The first-formed protoxylem cells disintegrate to form a lacuna. (b) Different xylem and protoxylem cell arrangement in an Agavaceae.*

### *Secondary Wall of Primary Xylem Cells*

In addition to a primary wall, xylem cells also have a secondary wall that appears as annular, helical, sclariform, or reticulate thickenings or pitted elements on the inside of the primary cell wall (Figure 1.16). These thickenings are aids to identifying the presence of primary xylem cells. However, because all shapes and an integration of shapes may be present at a given stage of growth, they do not help with species identification. This is not the case with secondary xylem vessels; their use in identification is discussed in the section on hardwood.

The primary and secondary cell walls are laid down by the living protoplast outside the cell membrane. Once the cell walls are completed, the protoplast dies.

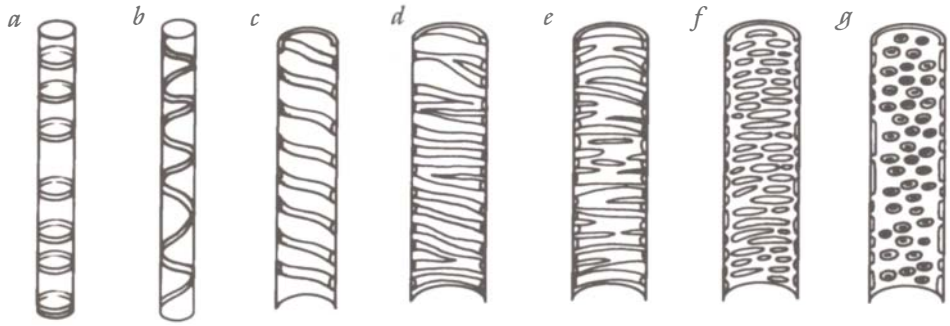



*Figure 1.16. Variety of typical secondary wall thickenings of primary xylem cells: (a) annular, (b,c,d) helical, (e) sclariform, (f) reticulate, and (g) pitted.*

Thus the mature xylem cells are, essentially, extracellular tubes for the transport of water and dissolved minerals.

## Phloem Tissue Cells

The basic cell types of the phloem are the sieve elements, parenchyma cells, sclerenchyma fibers, and sclereids. The primary and secondary phloem contain the same cell types, but transport of food (metabolic products) in the axial system of the primary tissue only occurs longitudinally, whereas the axial and radial systems in the secondary phloem incorporate radial transport as well.

### *The Sieve Elements*

The sieve elements, or sieve-tube members, are long cells with thin primary cell walls and without a protoplast (Figure 1.17). Protoplasm flows into adjacent cells through sieve areas on the walls of the sieve cells. The distinctive shapes of the sieve areas are rarely seen in dried artifactual material, because the cells are thin-walled and collapse during dehydration of the proteinaceous cell contents. Comparative anatomy studies show that gymnosperms and lower plants have sieve cells with sieve areas along the length of the cell walls, whereas angiosperms have sieve areas only at the end walls of the cells. The sieve cells do not have a protoplast; adjacent living companion cells in angiosperms contribute the necessary materials for functioning.

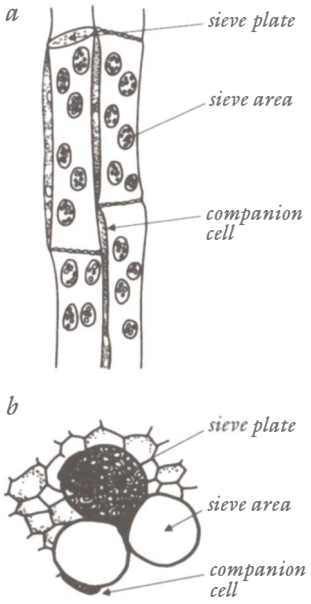



*Figure 1.17. (a) Longitudinal view of sieve tube showing sieve elements with adjacent companion cell, surface sieve areas, and sieve end plate. (b) Cross section of primary phloem showing sieve elements, sieve plate, and adjacent companion cells.*

### *Sclerenchyma Phloem Fiber Cells*

Fibers are commonly located on the outside of primary phloem. These cells are long, with thick walls, and are used as commercial fibers (for example, *Linum*, *Cannabis*, *Apocynum*). Sclereids may also be associated with phloem, and are an aid in identification (Figure 1.18). Details of sclerenchyma fibers and sclereids are discussed in the section on primary supporting tissue.

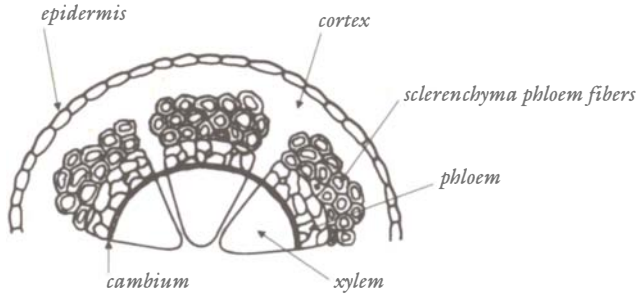



*Figure 1.18. Diagram of location of phloem fibers in commercial linen plant stem.*

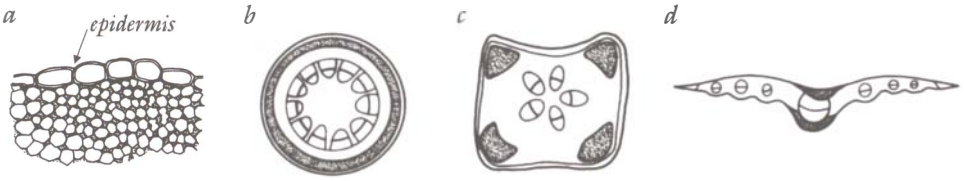



*Figure 1.19. Collenchyma cell shape and distribution: (a) cross section of collenchyma tissue showing unevenly thickened walls of cells, (b,c) cross section of stems showing typical distribution of collenchyma (dark area) in stems, and (d) in a leaf.*


*Figure 1.20. Sclerenchyma cell (a) fibers and (b) sclereid.*

## Primary Supporting Tissue

### Collenchyma

The collenchyma cell has relatively soft, pliable primary walls and an active protoplast. The cell walls are rich in pectic substances and hemicellulose, which allow them to swell to a turgid state for strength. The wall is not lignified. To make a drooping celery stalk crisp, for instance, placing it in water will allow the collenchyma cells to adsorb water and become turgid. The cell walls are unevenly thickened; the thickest region is at the corners between cells (Figure 1.19a).

Collenchyma is located either directly beneath the epidermis or one or two cells below it. In stems it may form strands, ribs, or a continuous ring of tissue (Figure 1.19b,c). In the leaf blade it is associated with the midrib on the ventral and dorsal regions (Figure 1.19d).

### Sclerenchyma

Sclerenchyma tissue is composed of cells with thick secondary walls. Sclerenchyma cells generally take two forms—long, slender cells called fibers and isodiametric cells called sclereids—but there is a wide range of transitional forms (Figure 1.20a,b). The walls of these two sclerenchyma cells show strong birefringence (the ability to refract light) under crossed nicols using polarized light.

*Sclereids*

Sclereids (Figure 1.21) are usually found as isolated cells in a tissue and, because they differ so much in form and size from other cells, are called idioblasts. They may occur in the ground tissue, epidermis, and vascular system and vary greatly in shape.

*Sclerenchyma Fibers*

Like the sclereids, sclerenchyma fibers are found in many plant parts. The fibers are long, with strong secondary walls. Usually they occur in bundles and are widely used commercially. The ends of the long fibers in a bundle overlap, adding strength (Figure 1.20). In commercial applications, individual fibers or fiber bundles may be used, depending on the degree of fabrication. In dicots, sclerenchyma fibers are commonly associated with stem vascular bundles such as phloem (bast) fibers (Figure 1.18).

The individual fiber cells in longitudinal view show the thick secondary wall, the central lumen of the cell, and characteristic nodular markings along the length of the fiber. These markings are often species specific and aid in identification of fibers. Common sclerenchyma phloem fibers used in artifacts include the hemps, linen, milkweed, stinging nettle, ramie, and jute (Figure 1.22).

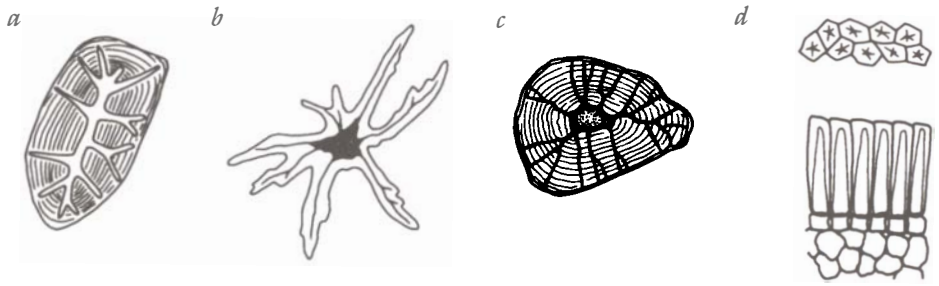



*Figure 1.21. Examples of sclereid shapes: (a) stem, (b) leaf, (c) fruit, (d) seed coat in surface (upper) and longitudinal (lower) view.*

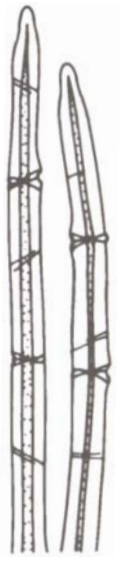


*Figure 1.22. Longitudinal view of individual fibers from* Linum usitatissimum *(linen) showing characteristic nodular markings and central lumen.*

In monocots, leaf fibers may enclose a vascular bundle like a sheath or form caps on one or both sides of the bundle. This is detailed in the section on monocot leaves. The sclerenchyma leaf fibers of monocots are commonly used as fibers in artifacts and commercial goods (manila, agave, pineapple fibers, sisal, and so on). The sclerenchyma vascular bundle sheaths or caps are retted out or pulled mechanically from the leaf tissue.

## Secondary Tissues

Secondary tissue is found in trees, both dicotyledons (hardwoods) and gymnosperms (softwoods), as well as in bushes and shrubs. Occasionally secondary tissue is produced in some large biennial plants.

The secondary tissues are formed during the second phase of plant growth, which increases the girth of the primary plant body. Primary tissues are formed from embryonic cells called apical meristems, which are located at the tips of the shoots, roots, and buds, while secondary tissues are formed from new embryonic cells in stems and roots called cork cambium and vascular cambium.

The vascular cambium is located between the xylem and phloem, within the vascular stele, and produces new secondary xylem and phloem. Cork cambium is located in the outer cortex and produces a periderm of mainly bark or cork cells, which take the place of the epidermis.

Secondary xylem is what we call wood. Secondary phloem is often called the inner bark, and periderm is the true bark. Both primary xylem and phloem, as previously described, consist of cells running longitudinally. The secondary xylem and phloem have these longitudinal cells but also have cells that radiate outward from the central axis of the plant body. These cells make up the xylem or phloem rays.

Primary and secondary cells are similar in function, and the same basic cells are present, but the tissue organization is different. Because the secondary tissue has a three-dimensional structure, it is necessary to view all three sides in order to understand the complete organization of the tissue and structure of the cells. To do this, wood is sectioned on three surfaces:

- cross (or transverse) section, taken across the long axis of the stem;
- radial section, a longitudinal section taken on the radius of the circular stem or root;
- tangential section, a longitudinal cut on the tangent of the circumference of the circular stem or root.

## Organization of Secondary Tissues in a Woody Stem

The three-dimensional diagram of a woody stem in Figure 1.23 shows the arrangement of the outer bark, secondary phloem, cambium, and secondary xylem on the transverse surface.

The secondary xylem (wood) has two distinctive features: (1) annular growth rings that represent the amount of tissue formed in one growing season, and (2) different cell wall thicknesses at the edges of these rings. The thin-walled cells of early wood tissue are formed in the spring, during the rapid growing season, and the thicker-walled cells of late wood at the end of the growing season. The central region of the wood may appear darker in color than external wood. The dark central region is wood in which colored resins, tannins, phenolic materials, and other substances, have been deposited to waterproof the wood and make it resistant to decay. This central wood is called heartwood. The outer region of wood adjacent to the cambium is lighter in color; in life it has a higher water content and stores carbohydrates such as starch. This is called sapwood.

Secondary phloem forms on the outer side of the cambium. In some older tree trunks, such as western red cedar, yellow cedar, and some *Eucalyptus* species, this is the most external tissue and is incorrectly called bark. The secondary phloem also shows annular growth rings, but not as distinctly as in the wood. The thickness of this tissue varies with the species.

The periderm, when present, is the outside tissue of the stem. This tissue is composed of the circular bands of outer phellem or bark cells, the middle cork cambium or embryonic tissue, and inner phelloderm cells or secondary cortex. On the transverse and radial surface, the parenchyma cells of the wood and phloem rays are seen as continuous lines of cells running out on radii of the circular stem. The wood and phloem rays run continuously through the xylem and phloem. On the tangential surface the rays are seen as individual cells in cross section. The shape of these rays varies with species. All the cells of the secondary tissue have secondary walls with the exception of the parenchyma ray cells.

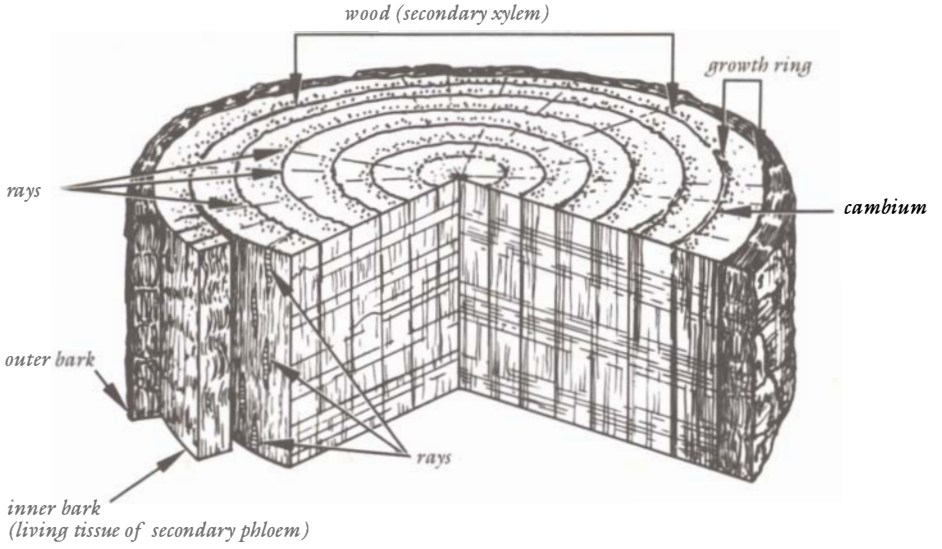



*Figure 1.23. Three-dimensional aspect of tree Ctrunk or woody stem.*

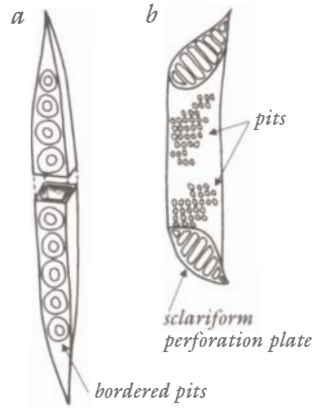



*Figure 1.24. Comparison of (a) a tracheid and (b) a vessel member.*

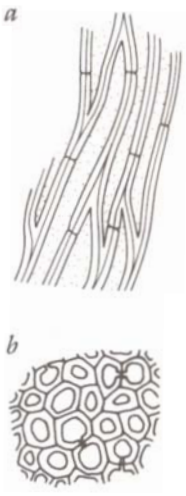



*Figure 1.25. Fiber tracheids of dicot wood in (a) longitudinal view and (b) cross section.*

# Secondary Xylem

## Cell Types

The three cell types of secondary xylem include (1) the water-conducting tracheary elements, the tracheids and vessels; (2) supporting fibers; and (3) the metabolic tissue, ray parenchyma cells.

### Tracheary Elements

The fibers of wood pulp paper are familiar to most everyone. Here the word fiber is used to refer to all the wood cells, most of which are tracheary elements. Tracheids are the main tracheary cells of softwood, and vessel members are the main tracheary cells of hardwood. Thus tracheids and vessel members serve to distinguish the two types of pulp paper. The most significant difference in the two types of cells is that the vessel members are open at the ends, which have perforation plates allowing free movement of water from one cell to another, whereas the tracheids lack perforations or open-ended walls. The column of vessel members is called a vessel. The morphology of the perforation plate is used for identification of hardwood species (Figure 1.24). The water moves from one tracheid to another by bordered pits on their radial walls. The bordered pit is made up of pit pairs on the secondary walls of two adjacent cells, which bulge out like two inverted saucers. Between the pits is the middle lamella complex, which acts as a valve membrane to open or close the pits. The presence of bordered pits always indicates a gymnosperm wood. There are also pits on the radial walls of vessel members, but they do not have the complex bordered pit of the tracheids. The size, arrangement, and morphology of these pits are used to aid identification of hardwood species.

### Fiber Tracheids

Fiber tracheids are fiberlike tracheids in the secondary xylem of hardwoods (dicots). They differ from softwood tracheids in having thicker walls and pits with lenticular openings rather than circular openings. The secondary cell wall may be lignified and in dicot reaction wood the cells are rich in gelatinous hemicellulose and are called gelatinous fibers (Figure 1.25).

### Parenchyma Cells

The parenchyma cells vary considerably in shape and cell content. The wood rays are made up of groups of parenchyma cells that are species-specific in cell size and arrangement. Within the rays the parenchyma cells may be of two different types (heterocellular), either procumbent or upright in orientation, or they may all be the same (homocellular). The ray cells have simple pits joining them to adjacent tracheids and vessels.

## Comparison of Softwood and Hardwood Structures

The following are only a few of the salient anatomical differences of wood that are used as aids to identification. Identification keys are given in the references. The keys are usually dichotomous keys, which means that at each step there are two choices—that is, the presence or absence of a specific characteristic. If the characteristic is not present, then one proceeds to the next two alternatives.

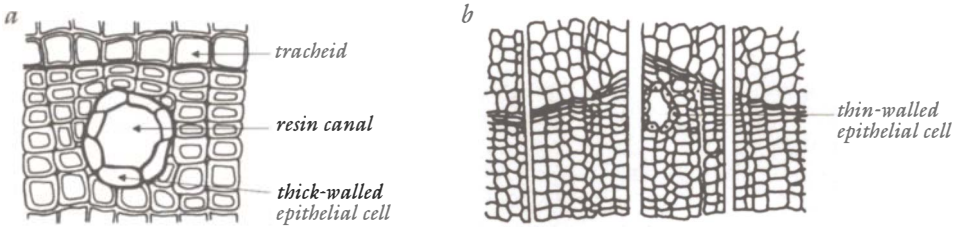



*Figure 1.26. Transverse section of secondary xylem showing a resin canal with (a) thick-walled epithelial cells and (b) thin-walled epithelial cells.*

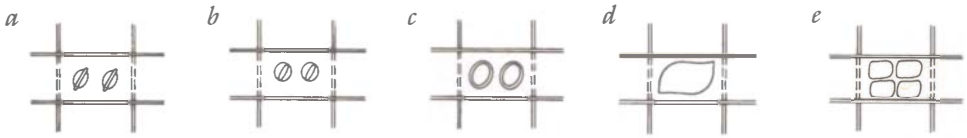



*Figure 1.27. Types of pit pairs occurring in the cross fields of coniferous woods: (a) piceoid, (b) cupressoid, (c)taxodioid, (d,e) fenestral pinoid.*

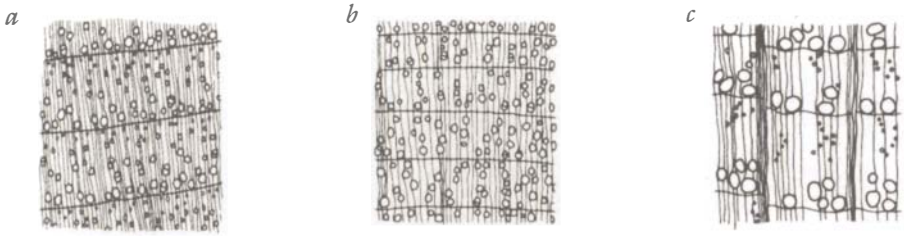



*Figure 1.28. Variation in size and distribution of vessels in hardwood growth rings: (a) diffuse porous with late wood vessels smaller than early wood, (b) diffuse porous with late and early wood vessels similar in size, (c) ring porous.*

### Softwood (Coniferous Wood)

All softwoods have tracheids; no vessels are present. Bordered pits are present on the radial walls of the tracheids.

The following features vary with softwood species:

- Resin canals may be present or absent; epithelial cells, secretory cells that produce resin, may be thin- or thick-walled (Figure 1.26).
- Pitting in field crossings of ray parenchyma cells and tracheids may be one of four types (piceoid, cupressoid, taxodioid, and fenestral), illustrated in Figure 1.27.
- Ray tracheids, thick-walled cells that run radially along the outside of the ray parenchyma and have bordered pits and no protoplast, may be present or absent.

### Hardwood

All hardwoods have vessels and thick-walled fibers. The arrangement and variation in size of the vessels are features used for identification. Within a growth ring the vessels may be all one size or may vary in size from large early wood vessels to small late wood vessels (Figure 1.28). The vessels may be distributed evenly throughout the growth ring (diffuse porous) or concentrated along the beginning of a growth ring (ring porous).

Perforation plates are of various shapes. The perforation plate may be a simple opening (simple) or the plate may have parallel bars of various thicknesses (sclariform) across it (Figure 1.29).

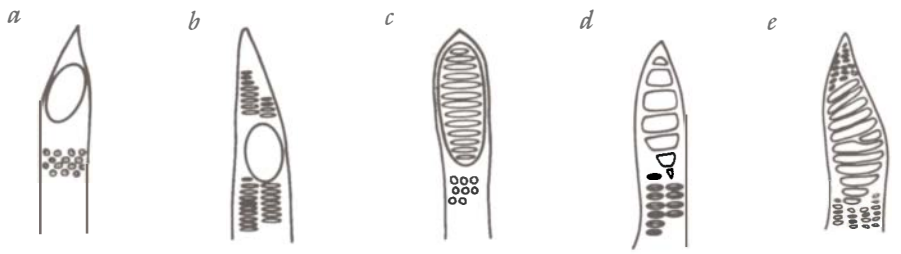



*Figure 1.29. Variations in perforation plates of vessel members: (a,b) simple perforation plates, (c,d,e) variations in sclariform perforation plates.*

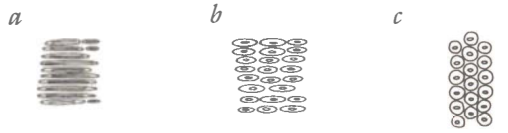



*Figure 1.30. Pitting patterns on vessel radial walls: (a) sclariform, (b) opposite, and (c) alternate.*

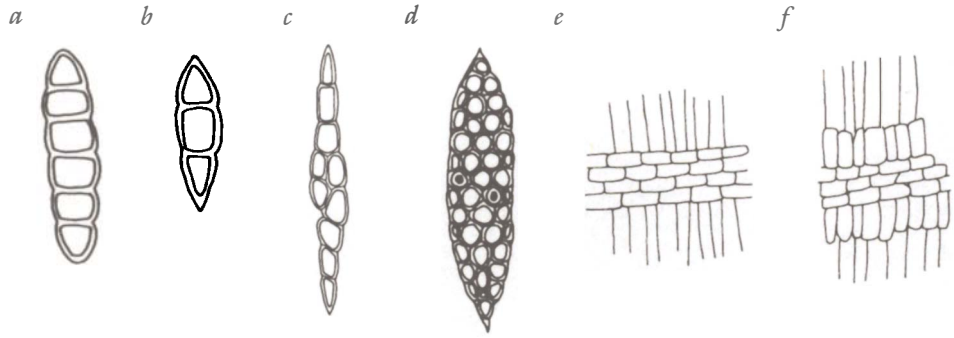



*Figure 1.31. Hardwood ray shapes and cell arrangements: (a,b) long and short homocellular rays (tangential), (c) biseriate heterocellular ray (tangential), (d) multiseriate homocellular ray (tangential), (e) homocellular ray (radial), and (f) heterocellular ray (radial).*

Pitting on vessel walls varies in size, shape, and pattern. The pits may be circular, oval, or sclariform; they may be arranged in rows opposite or alternate to each other in the adjacent row (Figure 1.30).

Tertiary wall thickenings are described and illustrated in Figure 1.16.

Hardwood rays vary in size and arrangement of cells (Figure 1.31). The hardwood rays may be one cell wide (uniseriate) or made up of two (biseriate) or many cells (multiseriate) in width. The parenchyma cells may be all one shape (homocellular) or made up of different shapes (heterocellular).

## Comparison of Trunk, Branch, and Root Tissues

The basic cells and organization of the tissues in the wood, branches, and roots of deciduous and coniferous trees are the same. The same cellular characteristics used to identify wood species are in the trunk, branches, and root. The differences in the tissues are in the size and number of cells. Even though the trunk is circular, wood tissue seen under a microscope will show a horizontal and vertical arrangement of cells because the cells are large and the growth ring curvature is lost in the small fragment. Artifact materials generally utilize small roots and branches, so the curvature of the growth rings is prominent. In branches, the wood is denser and cells are smaller and have much thicker walls than in roots, whereas root tissue is more porous and contains a larger number of parenchyma cells and resin canals than branch wood (Figure 1.32).

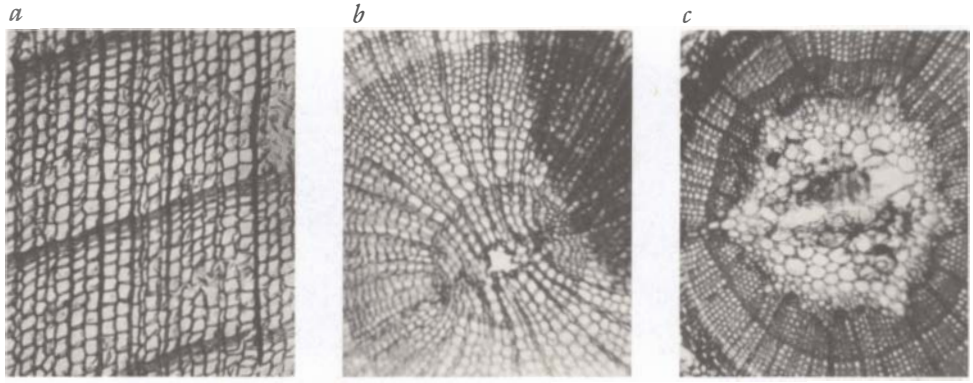



*Figure 1.32. Comparison of trunk, root, and branch wood (xylem) seen in cross section at the same magnification. (a) Trunk wood shows vertical and horizontal arrangement of cells and only one growth ring. (b) Root wood shows curvature of many growth rings, large, thin-walled tracheids and many parenchyma wood rays. (c) Branch wood shows growth-ring curvature and small thick-walled cell and central pith.*

## Secondary Phloem

The primary and secondary phloem contain the same cell types (see section on primary phloem tissue cells). The cell types of the secondary phloem are the sieve elements and the companion cells of the sieve elements, the sclerenchyma fibers, the sclereids, and the parenchyma cells (longitudinal and ray). Coniferous phloem and dicot phloem are similar in structure. They are composed of alternate layers of fibers separated by sieve element cells and parenchyma cells (Figure 1.33). The presence of the thin-walled parenchyma cells adjacent to strong fibers allows the tissue to separate easily into sheets of cells. This is the reason that it is used as a fibrous material in artifacts. The newly formed secondary phloem adjacent to the vascular cambium is living tissue and the cells are functional in food storage and transport. Older secondary phloem that has taken over the function of protective bark has gone through cellular changes. The fibers remain the same size and shape, the sieve elements collapse, but the parenchyma cells enlarge and produce tannin and polyphenolics to waterproof the tissue. This older secondary phloem fragments easily and is not used in making artifacts.

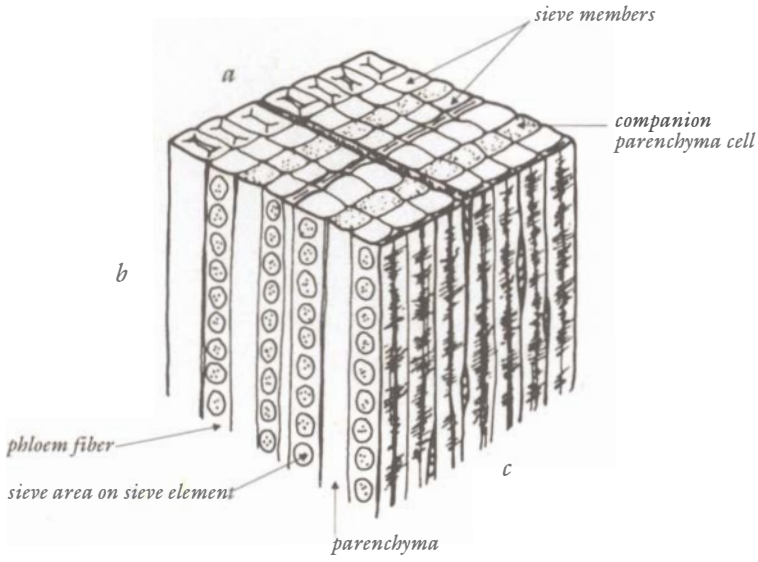
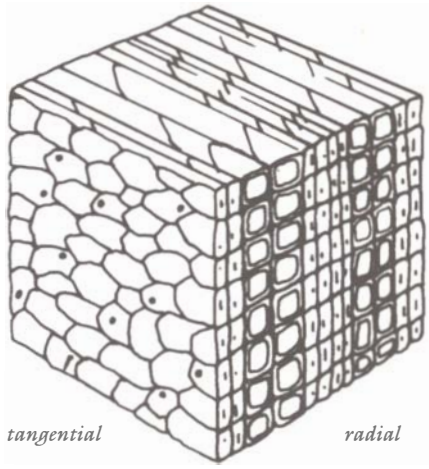



*Figure 1.33. Three-dimensional structure of secondary phloem of western red cedar showing layers of fibers between two sieve elements and a parenchyma cell. (a) Transverse, (b) radial, and (c) tangential views.*

*Figure 1.34. Three-dimensional diagram of the cork cells of the phellem of birch. The long axis of the cells is around the tree trunk.*




## Periderm

The periderm is the protective bark of secondary origin. The basic cells of the periderm are the cork cambium, which is embryonic tissue that gives rise to the phellem cells toward the outside and phelloderm cells toward the secondary phloem. Phellem cells are commonly called cork cells. Phelloderm cells are parenchyma cells. All barks contain the same cells, but there are differences in cell size and arrangement that aid in identification.

Cork cells of the phellem are heavily suberized cell walls. Suberin is a waxy substance whose chemical characteristics are discussed in the section on the chemistry of cell walls. Tannins give the brown-to-red color to the cell walls of certain trees—for example, cherry bark. The phellem develops in growth rings similar to wood. The thick-walled late cells adjacent to the thin-walled early cells are weak points that allow the bark to exfoliate off a tree trunk, as in birch bark (Figure 1.34). It is only the phellem of the periderm that is used for decoration and construction of artifacts. Some of the conifers and eucalyptus trees lose the periderm after the first years of growth, and the secondary phloem takes over the function of the bark.

In some old coniferous trees, such as pines, the periderm is made up of old dead tissue that is irregular and corky and is called the rhytidome (Figure 1.35).

*Figure 1.35. Transverse surface of trunk of large coniferous tree showing irregular rhytidome of the bark.*

# Chemistry and Structure of the Cell Wall

A basic understanding of the chemicals in the cell wall is necessary to understand the reasons for the use of specific plant materials in artifacts, as well as their inherent weaknesses and reactions with conservation treatments. Many conservation treatments use chemicals that could dangerously alter the chemicals in the cell walls and cause further deterioration. Even such a simple treatment as washing with water may have deleterious effects on some water-soluble materials. Thus a knowledge of the chemicals in plant materials is necessary before logical treatments can be devised. The majority of the following text on the chemistry of the cell wall has been excerpted from an article by the author (Florian 1987), but the emphasis has been altered for this manual.

## The Chemicals of the Cell Wall

### Cellulose

#### Location

Cellulose microfibrils are embedded in an amorphous matrix of hemicellulose, pectin, small amounts of protein, and sometimes lignin in primary and secondary cell walls.

#### Structure and Organization

Cellulose is a carbohydrate polymer made up of glucose monomers in long, chainlike molecules. Many of these long chains form fibrous polymers that involve different levels of organization (molecules, macromolecules, microfibrils, macrofibrils).

The mechanical strength of cellulose is a result of the strong bonds between the glucose units, the great length of the molecules, and the strong intermolecular bonding of the macromolecular chains. Cellulose is a highly polar polymer. This means that one side of the molecule is negatively charged and the other side is positively charged. This explains the strong intermolecular bonding.

#### Crystalline and Amorphous Regions

Cellulose has regions called micelles in which the long cellulose molecules fit tightly together over a long region and are held strongly together by their own hydrogen and other secondary bonds. The micelles are the crystalline regions of the molecule. The long cellulose molecules may pass through the micelles into an amorphous region where the cellulose chains are not held together but lie more or less at random. Solvents and enzymes rarely can penetrate micelles, whereas they may easily penetrate the randomly oriented molecules in the amorphous region. Materials that penetrate the amorphous regions are readily bonded to the available hydrogen's dipolar and secondary bonds, and cause swelling, chemical reactions, and even dissolution of the cellulose. The more micellar the regions, the more insoluble the chemical.

### Hydration and Swelling

In hydrated cellulose, water molecules are held by secondary force but most abundantly by chain segments in amorphous regions causing swelling. Dry cellulose is inflexible or brittle, but cellulose with 12% moisture content (MC) at 60% to 80% RH is quite flexible. Water therefore acts as a plasticizer for cellulose.

In most dehydrated organic colloids, rehydration is possible. But with waterlogged cellulose, the strong intercellulose bonds bring the molecules tightly together during dehydration, eliminating moisture and causing extreme shrinkage; this makes it impossible to rehydrate. One of the greatest problems with conservation of cellulosic materials is how to retain sufficient moisture between the cellulose molecules to retain flexibility and prevent extreme shrinkage.

When swelling is extreme, the micellar structure is destroyed and the cellulose is no longer crystalline. The change from crystallinity to amorphous state can be observed by polarized light. Crystalline regions show positive birefringence, the ability to refract light, while amorphous regions have negative birefringence.

A simple demonstration of the crystalline state of cellulose can be made by using two sheets of polarizing film, one placed between the source of light and the microscope and the other between the object and the eye. The light passing through the polarizing film vibrates in only one plane. If the two polarizing films are at right angles to each other with regard to their plane of polarization, no light penetrates and the field in the polarizing microscope appears dark. If a crystalline structure such as cellulose is placed between the two polarizing films, some light reaches the eye. Because of its crystalline nature and the associated property of light refraction, the cellulose changes the plane of polarization of the light that reaches the polarizing film above the objective and thus permits some light to pass through it and enter the eye.

Extreme swelling of cellulose may occur in strong alkaline solutions (10% to 22% KOH). Under these extreme conditions, cellulose may swell enormously but will not dissolve. On drying, this cellulose adopts a different crystalline state called Cellulose II, as compared to native Cellulose I.

### Effect of pH and Salts on Swelling

Research on the role of pH and salts on the swelling of wood pulp and superabsorbent cotton shows that the swelling is greatest at about neutrality and is depressed at both low and high pH values. At all pH values, swelling is further reduced by the presence of salt. This phenomenon is due to the osmotic gradient caused by the presence of bound ionizable groups in the macromolecular network of cellulose. In pure water, they are in excess in the cellulose; thus the water moves in to satisfy the osmotic gradient, causing swelling.

Extreme pH values release bound ionizable groups, thus changing the osmotic gradient and reducing swelling. The addition of neutral salts equalizes the osmotic gradient and also reduces swelling.

In reference to conservation treatments of plant fiber materials, if such materials are placed in deionized or fresh water, excessive swelling may occur. Such swelling may cause irreversible bond breakage and deformation of the cellulose fibers, giving them weaker mechanical strength and greater chemical solubility.

It is interesting to note that in the paper industry the use of reduced absorption at low pH has recently been exploited to produce both an economical drying process and a conversion of the acid groups of sulfite and kraft pulps from the free acid to the sodium salts, which results in a 20% to 30% increase in the tensile strength of the paper. Certainly this information has some implications for conservation of cellulosic materials.

### Depolymerization of Cellulose

Cellulose can be depolymerized and broken into soluble monomer units only under extreme conditions. This process may occur very slowly by oxidation, acid hydrolysis, or gamma radiation. Its rate may be increased by moisture, high temperature, and light.

### Biodeterioration

Enzymatic degradation does occur readily with cellulytic bacteria and fungi, but the microorganisms require condensed or free water for growth. In wood, microscopic analysis of the damage shows bacterial pitting and fungi digestive troughs in cell walls aligned along the angle of deposition of the cellulose macrofibrils and in bordered pits. The cellulose has been enzymatically dissolved. This would cause local physical weakening of the cell wall. Brown rot fungi of wood enzymatically remove all the cellulose and leave the brown lignin; hence the name brown rot.

## Lignin

### Location

Lignin is found only in cell walls of land plants, and most commonly in perennial plants. It imparts rigidity to the cell wall, providing strength for upright growth. Lignin makes up 15% to 35% of the chemical constituents of supporting tissue and 60% to 90% of it is located in the middle lamella primary wall complex. Lesser amounts are located in the secondary and tertiary walls.

Lignin in cell walls varies in amount depending on the cell or tissue type and species origin. For example, 19% to 25% is present in hardwood fibers and 25% to 30% in softwood fibers. Epidermal hairs such as cotton hairs and collenchyma cells (a primary mechanical tissue) may not contain any lignin. Along with hemicelluloses and pectins, lignin fills the interstices between cellulose microfibrils. It appears that, because of its insolubility, lignin is chemically bound to the hemicelluloses. Lignin and carbohydrate polymers in the cell wall protect each other by blocking solvents—or at least retarding their entrance. In woods with hemicellulose loss, the lignin is exposed to chemical change. Analysis of waterlogged woods usually shows a decrease in hemicelluloses. Lignin is extremely persistent; it has been found in nearly normal amounts, although chemically altered, in 100-million-year-old wood from a land burial site. Lignin is the precursor of coal.

### Structure and Organization

Lignin is composed of a group of similar, very large amorphous aromatic polymers with little opportunity for cross-linkage or crystallinity. Because it cannot be extracted from cell walls without chemical alterations, the exact structure of native or first-formed protolignin in cell walls is not known. Because of differences in their molecular structures, lignins are divided into three categories: softwood, hardwood, and grass or annual plant lignin.

### Reactivity

Lignin is a highly reactive substance, with free groups (hydroxyl, methoxyl, and carbonyl) that readily undergo bonding. In the analysis of many ancient woods, extracted lignin shows an increase in methoxyl content over modern wood.

### Solubility

Lignin is insoluble in water and is less hygroscopic than cellulose or hemicellulose. It is sensitive to alkaline degradation.

### Physical Characteristics

Lignin imparts rigidity to cell walls, but abnormally high amounts in cell walls cause brittleness. Lignin is thermoplastic: it softens at 80 °C to 120 °C and liquifies at 140 °C to 145 °C. Chemically altered lignin loses its thermoplastic qualities.

## Hemicellulose

### Location and Function

Hemicelluloses are located in all layers of the cell wall. They are concentrated in primary and secondary walls mixed with lignin and cellulose and are also present in the cellulose-free middle lamella associated with lignin.

Exactly how hemicellulose associates with cellulose is not completely clear, but it is considered to be found in cell walls in more or less intimate association with cellulose. Lignin bonds chemically to hemicellulose but not to cellulose. It appears that hemicellulose is a protective colloid acting as a hydrated amorphous matrix surrounding cellulose fibrils, preventing aggregation, hydrogen bonding, and cocrystallization of the cellulose fibers.

Removal of hemicelluloses has been shown to increase the crystallinity of fibers, indicating increased cellulose–cellulose bonding. Cellulose–hemicellulose association is flexible, whereas cellulose–cellulose bonding is rigid, with low strength properties. In the paper industry, pulp with hemicellulose has greater wet strength; it is also used for surface finishing of some papers.

The amount of hemicellulose in cell walls varies with the different cell types and plant species. For example, the hemicellulose content in wood (xylem) is 25% to 40%, in jute fibers 25%, in cotton hair 1%, and on ivory nut cell walls 90%.

### Structure and Solubility

Hemicelluloses are amorphous carbohydrate polymers. They are short chains, usually branched structures, without microfibrillar structure. They consist of a mixture of several different monomers or residues (the pentose sugars, D-xylose, D-mannose, D-glucose, D-galactose, L-arabinose) and uronic acids (4-0-methyl-D-glucuronic acid, D-glucuronic acid + D-galacturonic acid). The amounts and selection of the residues vary with plant species. The characteristic feature of all hemicelluloses is the presence of the acidic D-glucuronic + D-galacturonic acid residues. The uronic acids allow large amounts of water to be absorbed during hydration. They have a similar role to hylauronic acid in animal tissue and the acids in pectin.

Hemicelluloses are soluble in alkaline conditions and some of the low-molecular-weight polymers may be extracted by water. They are readily hydrolyzed by acids and the enzymatic activity of bacteria and fungi.

## Pectic Substances

### Location and Function

Pectic substances are located mainly in the middle lamellae and primary wall. The amounts of the pectic substance vary greatly with cell types. For example, wood (xylem) contains 0.5% to 1.5% (of dry weight), bark 7% to 30%, cotton (primary wall) 9%, and collenchyma (supporting cells in stems and leaves) 45%. Pectic substances are hydrophilic and act as a molecular colloid in cell walls. They can form gels; the rigidity of the gel depends on the length of the polymer. They form a part of the continuous amorphous matrix between cellulose microfibrils in primary walls. They give rigidity to cell walls, acting as both intercellular cement and cement between the amorphous cuticle and the surface of epidermal cells. For plant parts, such as leaves, commonly used in artifacts, the intercellular cementing feature of the pectic substances is of utmost importance. Loss of the pectic substances may cause loss of tissue integrity and the cuticle. The pectic substances may also play an important role in permeability of the cell wall to ions. *In vivo* studies show that Na, K, Ca, Fe, and P04 are absorbed in the pectin-like substance of the cuticle.

### Structure and Reactivity

Pectic substances are linear polymers made up of polygalacturonic acids and are usually called polyuronids. They are negatively charged and acidic in nature. Pectic substances are a group of related substances (protopectin, pectin). The terminology of these substances depends on their solubility and chemical structure.

Protopectin is the native first-formed pectic substance in plant tissue. It is water insoluble and probably derives its insolubility from being complexed with calcium ions. It can be dissolved by using sequestering agents or calcium binders such as ammonium oxalate in acid and also by hot dilute alkaline conditions.

Pectin is soluble in warm water and, on cooling, is capable of forming gels, as in jam or jelly. Pectin is made of two chemically different acids, pectic acid and the more abundant pectinic acid. The primary difference between the two is in the amount of methoxyl side chains, which are formed on changing the COOH group to $COOCH_3$ group. Pectic acids are low in methoxyl content, insoluble in acid, and

form insoluble salts (pectates) with metal ions. The more abundant pectinic acid is high in methoxyl content, is soluble at low pH, and forms soluble salts (pectinates) with metal ions.

The pectic substances may be bound to the insoluble protopectin by covalent or secondary bonds with each other or other cell wall polymers, calcium binding, or mechanical intermeshing of filamentous polymers of pectic substances with other cell wall polymers.

The pectic substances can be readily hydrolyzed by acids and enzymes. Many bacteria and fungi are capable of using them as nutrients. The retting of flax, hemp, and jute to make free fibers and the pounding of logs to make them more permeable to impregnation treatments depend on bacterial hydrolyses of the pectic substances.

Water-soluble pectic substances may be coagulated by ethanol or acetone and lose their water-binding capacity. They are also soluble in warm glycerol.

## Protein

The protein in the cell walls is not the protein of the living protoplast but a structural protein, a hydroxyproline-rich glycoprotein called extensin.

Collagen, the fibrous protein of leather, is also rich in hydroxyproline. This similarity of these two proteins makes an interesting case for a common ancestry. Extensin is found in primary cell walls from 1% to 5% of dry weight. An integral part of the cell wall, it has been suggested that extensin is a structural protein involved in cell wall plasticity during growth (hence its name), that it limits swelling of cell walls, and that it may impart rigidity to the cell walls by cross-linkage with cellulose. The loss of this protein certainly must influence the strength characteristic of the cell wall.

## Suberin and Cutin

Suberin and cutin are not structural polymers; they are the polymers that provide the basis of the protective covering of the weather-exposed surfaces of higher plants, such as the cuticle of the outer epidermis of leaves, stems, and fruit, and the suberized cork cells of bark. They are amorphous hydrophobic materials composed of polyesters of glycerol esters of hydroxy-fatty acids. Each contains different types and homologs of these acids. Suberin has a longer chain length than cutin. Suberin is deposited in lamellae inside the primary cell wall, whereas cutin is deposited extracellularly on the outer surface of epidermal cells.

Wax and tannin may also be associated with both polymers. The tannins are water soluble, the waxes are soluble in organic solvents, and the suberin and cutin are soluble in boiling alcoholic alkali. Suberin is more soluble than cutin. It may be saponified at room temperature by alkali and is soluble in hot glycerol. Cutin and suberin are extremely persistent in nature. In precambrian sediments, the nonhydrolyzable fraction is shown to contain the cutin-suberin group.

## *Editor's Note:*

Artifacts comprised of parts of deciduous trees and shrubs have two very important diagnostic features that allow their identification when the plants are not in leaf. These features are evident on the branches and persist on bark stripped from the tree or shrub. Lenticels are spongy areas in the cork surfaces of stems and branches that allow an exchange of gasses between internal tissues and the outer atmosphere. Transpiration also occurs through these pores as the loss of water as vapor. In young stems these are represented by stomates (stomata), and with age they become heavily suberized as they are incorporated into the periderm of vascular plants. They may consist of a single layer of cells (as in *Sambucus*, the elderberry bush), or they may exhibit multiple layers when seen in transverse section (as in *Aristolochia*, Dutchman's pipe). Viewed macroscopically, they vary in size and color and exhibit diverse patterns of distribution. When combined with other external features on a strip of bark, these are excellent in providing a diagnosis of the plant species in question. Oak bark (*Quercus* sp.), for example, has large, conspicuous lenticels on the young branches.

A second feature that proves useful in wintering deciduous plants is the scar left by the absent leaf. An abscission layer forms in order to seal the area left after the leaf drops. This is initiated early in the growing season, so at the time of abscission the resulting leaf scar is clean and reveals a characteristic shape within which specific patterns of vascularization are evident. These patterns are formed by the position of the vascular bundles that formerly supplied the leaf with nutrients and carried away photosynthates to other parts of the plant. The number, size, shape, and vascularization patterns of these leaf scars are excellent diagnostic tools in artifacts utilizing large strips of bark, such as baskets. Guides to trees and shrubs of the temperate areas of the world rely heavily on lenticels and leaf scars for botanical identification.

A third category of diagnostic evidence derived from macroscopic examination of bark is bud scale scar rings. In deciduous hardwoods, the terminal growth ceases at the end of each growing season. At the tip of the shoot there is a terminal bud constituted by overlapping primordial leaves and, in some instances, a floral primordium. The scales that cover these areas of terminal growth (leaf and floral meristems) are usually covered with a heavy cuticle and may also have copious amounts of resins (as in *Populus*, poplar). At the resumption of the next season's growth, the scales fall off and growth resumes, leaving a ring where individual scales were attached. This area is known as the bud scale scar ring. The size of individual scales, the number of scales as revealed by the scars, the size of the ring, and the distance between these rings are all useful in identifying bark of unknown origin. It is important to remember that the distance between the bud scale scar rings may, in part, be a function of the growing season.

# References


**Culter, D.C.**

1978 *Applied plant anatomy.* London: Longman Group Ltd.

**Dilcher, D.L.**

1974 Approaches to the identification of angiosperm leaf remains. *The Botanical Review* 40(1):1–157.

**Esau, K.**

1965 *Plant anatomy.* New York: John Wiley and Sons.

1977 *Anatomy of seed plants.* New York: John Wiley and Sons.

**Florian, M-L.E.**

1987 Deterioration of organic materials other than wood. In *Conservation of marine archaeological objects.* C. Pearson, ed. London: Butterworths.

**Hayward, H.E.**

1938 *The structure of economic plants.* New York: MacMillan.

**Metcalfe, C.R.**

1963 Comparative anatomy as a modern botanical discipline (Systematic anatomy of monocots). In *Advances in botanical research*, Vol. 1. R.O. Preston, ed. New York: Academic Press.

**Panshin, A.J., and C. de Zeeuw**

1970 Structure, identification, uses and properties of the commercial woods of the United States and Canada. In *Textbook of wood technology*, Vol. 1. New York: McGraw-Hill.

# 2 Identification of Plant and Animal Materials in Artifacts

*Mary-Lou E. Florian*

This chapter will provide the conservator with a methodology for the identification of some plant and animal materials, as well as general concepts of the structure of such materials. The focus here is not so much on species identification, but rather on accurate documentation and ethnographic studies. The need to identify these materials comes from the need to understand their apparent and future deterioration patterns and inherent stability. This information will give the conservator a basis for logical decisions concerning conservation treatment, repairs, stabilization, and storage.

Most of the species used as examples in the text are North American, but this does not limit the utility of this chapter. For conservators dealing with basketry from any ethnographic group, the goal is to identify the plant parts or animal materials; no matter what the species origin, material from related species will be similar in structure. Also, many materials are tissues, which have a universal function, and the basic structure is similar regardless of species origin.

This chapter first introduces materials and methods. Following this the materials to be identified are first grouped into fibrous materials of plant and animal origin and then groups of plant parts.

The first plant part group includes stems, rhizomes, and roots. Stems from herbaceous monocots, seaweed, ferns, and horsetails are commonly used in basketry. These plant parts are grouped together because of a common circular structure in some cases, such as in monocot stems, rootlets, and seaweed stipes, as well as for common anatomy found in stems and rhizomes (underground stems). The next plant part group addressed is herbaceous monocot leaves, which are used extensively throughout the world in many types of artifacts. This is followed by a section on tissue from woody plants, secondary phloems, tree barks, and wood. Finally a section is presented on identifying the origin of the wood: branch, root, or trunk.

Throughout the chapter, details on the anatomy of specific materials are presented as an aid to interpretation and identification. Some sections are presented in more depth than others. This is a result of the author's research in these materials. Because this information is not present in the literature with reference to cultural material, it is presented here as a basis for others to build on. The manual is structured in such a way that students can add to it materials of their own interest.

# Sampling

Sampling means to remove from an artifact minute pieces of the materials to be used for identification. The first premise of sampling is an awareness of the preciousness of the artifact and of the ethical issues involved. That is, sampling must not destroy the aesthetics or stability of the artifact, introduce confusing tool marks, or destroy potential research information.

The purpose of sampling must be clearly defined in advance. Valid reasons for sampling include:

- Documentation (verification, research, and authenticity)
- Restoration (using compatible materials for repair)
- Conservation treatment (understanding material/treatment interaction)

It must be clearly understood that sampling should be done only when required for valid and specific purposes.

Some artifacts simply do not have material that can be sampled without destroying some aspect of the artifact, such as very tightly woven basketry without loose ends or fragmented areas.

## Sampling Procedures

1. Because one is sampling a precious artifact, it is essential to protect it from damage while sampling. One needs to ensure that the sample is from the specific component needing identification and that it is recorded appropriately. The first step is to clean an area in preparation for the artifact and to collect the necessary equipment:
    - single-edged razor blade
    - forceps
    - clear adhesive tape
    - scalpel
    - cotton gloves
    - index cards
    - water bottle with eye dropper
    - labels
    - glass microscope slides
    - magnifying lens
    - glass coverslips (22 mm, No. 1)
    - scissors
    - color pencils/pens
2. Place the artifact in a clean area. Carefully study its construction using cotton gloves to hold it. Look for a small piece of material that can be removed without interfering with any aspect of the artifact. The fragment removal should not destroy the research potential, aesthetics, integrity, or stability of the artifact. Record the spot on an index card. To prevent contamination or confusion, make a diagram or photo of the artifact; clearly mark the component, color, and region

sampled. It is important to indicate clearly which element of a complex artifact has been sampled.

3. Obtain the sample—a minute (less than 1 $mm^2$) sample is usually all that is needed. Use only material still attached (that is, fragments from ends or fractured regions) or free pieces that you are certain came from the artifact. The sample can be removed by using a sharp razor blade, scalpel, or scissors. The force of cutting the sample should not interfere with the stability of the artifact. In some cases the sample is so small that static electricity will cause it to fly away; this can be prevented by slightly wetting the edge of the blade with a moist finger tip. Place the small sample directly on the index card, cover it with clear adhesive tape, and number the sample. Another sampling technique involves the removal of small fragments still attached to the artifact by placing a small piece of adhesive tape on the fragment and applying enough pressure to cause it to adhere, then lifting the tape and, if necessary, cutting the fragment loose. The tape can then be affixed to an index card coded with the artifact number and conveniently filed in the laboratory for future analysis.
4. The orientation of the sample is important. If the material is obviously not wood, a true cross section is probably all that is needed. For wood materials all three orientations are necessary for species identification (transverse, radial, and tangential). If it is possible to cut accurately oriented sections, these extremely small samples can be placed directly on a glass microscope slide and covered with a glass coverslip in preparation for examination. For temporary storage, the glass coverslip can be secured with adhesive tape; then the slide can be secured to the index card.
5. The index cards should be stored in an index box and can be cross-indexed for future reference.
6. Remove the artifact. Do not keep artifacts in the laboratory, where chemicals or staining solutions are used.

## Preparation and Staining of Microscope Slides of Basketry Materials

1. Prepare wet mounts of the plant materials; observe and determine if the sections are true cross sections, and so on (follow procedures in text). Use the plant material appropriate to your immediate interest and prepare as standards for future reference.
2. Experiment with a few stains, such as toluidine blue, iodine potassium iodide, sudan III, safranin 0, phloroglucinol, and ferric sulfate. Record the results of the staining reaction and make before-and-after observations.
3. Make the slides permanent for future reference using the methods discussed in this chapter.

   *Suggested plant materials, section orientations, and stains*

   - *Typha* leaf; cross and longitudinal sections; all stains
   - *Scirpus* stem; cross and longitudinal sections; all stains

- *Picea* root wood; cross, tangential, and radial sections; safranin 0 and toluidine blue stains
- *Thuja plicata* secondary phloem; cross, tangential, and radial sections; safranin 0 and toluidine blue
- *Populus*, *Epilobium*, or *Eriophorium* hairs; whole mounts; phloroglucinol stain only
- *Urtica*, manila, cotton, and linen fibers; whole mounts; phloroglucinol stain only
- *Prunus* true bark; sudan III or IV, ferric chloride

## Materials, Supplies, and Equipment

### Supplies

- microscope glass slides (frosted ends)
- glass coverslips (22 mm, No. 1)
- slide labels
- bibulous paper
- single-edged razor blades or stainless steel pencil knife

### Solutions and Use

Dropping bottles of:

- water
- toluidine blue (dichromatic; primary and secondary tissue)
- aniline blue (protein stain)
- safranin 0 (nonspecific plant tissue)
- sudan III (suberin, cuticle, and oil stain)
- iodine potassium iodide (starch stain)
- xylene (for clearing)
- Permount/Canada balsam (for permanent slides)
- ethyl alcohol (for dehydration)
- phloroglucinol (lignin stain)
- bromophenol blue (protein stain)
- ferric sulfate (tannin stain)
- 5% sodium hydroxide (for swelling reactions)
- 25% hydrochloric acid (lignin stain component)
- 0.5% acetic acid (bromophenol blue component)

### Microscope Equipment

- stereo dissecting microscope
- compound microscope
- polarizing lenses for compound microscope

- lens paper
- demonstration microscope with camera and No. 52 black-and-white Polaroid film

## Cutting Sections of the Sample

Many of the samples removed will not be oriented or thin enough to be viewed directly with the microscope, and will require sectioning. Remove the sample from the index card. In many cases, the clear adhesive tape can be cut from the card and placed on the microscope slide with the sample side up. Place the sample to be sectioned on a glass slide in a small drop of water. Place the slide under the dissecting microscope (maximum 10x).

Observe the reaction of the material to water. Swelling indicates a protein material, whereas unfolding or opening out suggests a plant material. Record on the index card any reactions of the sample; this may be an important aid to identification. Leave for a few minutes to allow it to soften.

Observe and record distinctive morphological features of the material, such as:

- Torn or cut surfaces, which indicate fabrication methods
- Intact surfaces: upper and lower epidermis, or outer epidermis of circular structure
- Exfoliation of tissue layers
- Markings: colored regions, surface patterns, parallel vascular bundles
- Plant part: leaf, stem, fibers

While observing the sample under the microscope, place the index finger of the left hand—or right hand if left-handed—on the sample with the tip of the fingernail holding the edge of the sample firmly against the slide. Hold the single-edged razor blade firmly between the thumb and index finger of your free hand and place the fresh cutting edge of the blade on the sample with the side of the blade against the fingernail.

To make a cross section, slide the razor blade down the nail and make a series of cuts through the edge of the material without moving the sample, but pushing the blade harder against the nail, barely lifting the edge of the blade above the top of the sample. Check under a compound microscope to determine if the sections are true cross sections. Use the same procedure for radial and tangential cuts. Orient the sample so that you are always cutting down, if possible. Sometimes it is necessary to take a surface cut. To do this, hold the sample as above, but slide the razor blade flat over the surface away from your finger, gently nicking the surface of the sample before sliding the blade.

## Orientation of Sections

- Leaf or stem of monocots, rhizoids: cross section
- Wood, branch, roots: cross, tangential, and radial sections
- Secondary phloem, true bark: cross section

- Seed hairs: whole mounts
- Fibers: whole mounts or cross section and plant tissue fragments

Often it is possible to cut oriented sections directly from the artifact. If these are removed they should be placed directly on glass slides (not on index cards) and covered with a glass coverslip that can be attached by adhesive tape for temporary storage. When required for staining or other procedures the tape can be cut and the coverslip removed.

## Wet-Mount Preparation of Microscope Slides

Remove the uncut portion of the sample and replace on the index card. The next step is to make a wet-mount microscope slide. While observing under the dissecting microscope, use dissecting needles to separate the small sections.

If whole mounts of hairs or fibers are required, a small fragment of the material is placed in a drop of water on the glass slide. With dissecting needles, separate the fibers and spread over an area of the cover glass.

For sections and whole mounts, if there is granular dirt or extraneous material, try to remove it before placing the coverslip on the sample. To place the coverslip on the sample, place at a 45° angle to the slide and touch the edge of the drop of water, then let it fall down slowly so as to push out the air. Observe under the compound microscope; if there is an air bubble or space, place a small drop of water at the edge of the coverslip; it will move in under the coverslip.

## Slide Preparation of Archaeological Artifact Material

Because the material may be brittle, dry, deteriorated, and covered with soil, standard histological techniques may not be useful for slide preparations. In such cases the most successful techniques are simple free-hand sectioning and, when necessary, progressive squashing.

First place the fragment in a drop of water on a microscope slide. Then, under a dissecting binocular microscope, thin (approximately 20 μ) true transverse, tangential, and radial sections are cut with a single-edged razor blade. The sections are left in the water, covered with a glass coverslip, and observed directly under the compound light microscope. In most cases, no further treatment is required. In a few cases the material is stained with safranin or toluidine blue for contrast, or dehydrated and cleared with xylene to enhance line details.

If the sections are heavily encrusted with soil, they are gently squashed and progressively observed under the microscope until the cellular structure becomes apparent. Granular soil should be removed before squashing. The squashing technique involves placing bibulous paper over the coverslip, holding it down firmly at the edge of the coverslip with the fingers and tapping the paper over the coverslip with a hard eraser or the end of a pencil.

If the material is so friable that oriented sections are impossible, the material is placed on a glass slide in a drop of water and teased apart with dissecting needles, then covered with a glass coverslip and squashed as described above. In

extreme cases of very friable material, the material may be placed in molten embedding wax to consolidate it. Xylene must be used to clear wax-embedded sections.

## Methods of Observation

### Light Microscopy

The material is observed under the microscope with transmitted light and/or crossed nicols (polarized light). Observed features such as tissue organization, cellular structure and details, birefringent pattern and color, presence of crystals, and so on, should be recorded on the index card or in a log book.

### Photography

Photomicrographs using black-and-white Polaroid film in a camera attached to the microscope or SEM may be taken in some cases to document distinctive or unusual features, for future comparative study, and for measurements as aids to identification.

### Scanning Electron Microscopy (SEM)

In some cases, distinctive cellular characteristics may not be observed under the compound light microscope. SEM may assist in some cases, but it has only limited value. The preparation of the material for SEM observation is very simple because the material is already dry. No fixation or special drying pretreatments are required. Dry thin sections are placed directly on the wet graphite glue, or friable dry material can be fractured by crumbling with the fingers directly onto wet graphite glue, on the SEM stub. The preparations are then spattered under vacuum with graphite prior to observation.

## Staining Samples

In most cases staining is not required. Polarized light can be used to give excellent contrast for unstained tissue. If staining is required, the following staining procedures can be used for specific materials or to determine the presence of different chemical components.

### Aniline Blue: Protein Stain

Use 0.1% aqueous solution. Place a drop on the material to be observed or at the edge of the cover glass already in place and draw it through by placing a small piece of torn bibulous paper against the coverslip edge at the opposite side of the coverslip. Observe under a microscope. The blue color will penetrate first the edges of protein-containing materials and may or may not completely stain it. Hair and feathers (or any keratin material), skin (rawhide), muscle, blood cells, protoplasm of living fungi, green algae, and lichen will stain.

## Iodine Potassium Iodide: Starch Stain

Dissolve l g potassium iodide in 100 cc of water. Add 1 g iodine flakes. Place a drop on the material to be analyzed or draw a drop through the prepared slide as described above. Under the microscope, purple-black starch grains can be observed. A pink color may indicate microorganism degradation of a starch.

## Sudan III: Fat Stain

Mix 0.5 g sudan III or IV in 100 cc of 70% alcohol (ethyl or methyl). Place a drop on the material to be analyzed or draw a drop through the prepared slide as described above. Surface films of plant or animal oil, oil in plant tissue (cutin, suberin), adipose tissue, and free animal fat stain red.

## Safranin 0: General Plant Stain

Mix 0.1% safranin 0 in water. Place a drop on the material to be analyzed or draw a drop through the prepared slide as described above. Let stand for 1 minute. Remove the excess stain by drawing water through the preparation as described above. Wash off stain with water. Plant parts such as pollen grains, seed coats, grain glumes, woody tissue, and epidermal cells stain red.

## Phloroglucinol: Lignin Stain

Solution A: 1 g phloroglucinol in 50 ml alcohol (ethyl or methyl)
Solution B: 25% hydrochloric acid solution
Add phloroglucinol solution to material to be stained. Let stand 1 minute. Add 1 drop hydrochloric acid solution. Leave for 5 minutes. To enhance the reaction, the material can be air dried and then rehydrated.

☞ *NOTE: Cautiously replace the acid solution with water, draw the acid out with bibulous paper, and place the wet paper in a special acid waste container. Do not get acid on hands or in eyes or on the microscope objectives. Do not place slides that are wet with the acid solution under the microscope. Discard the used slides in a special waste container.*

## Bromophenol Blue (Aqueous): Protein Stain

Solution A: 10 g mercuric chloride, 100 ml 70% to 95% ethyl alcohol (not denatured), 0.1% bromophenol blue
Solution B: 0.5% acetic acid
Add a drop of stain (Solution A) to material on a slide. Leave for 5 minutes. Draw off the stain with bibulous paper and wash material with tap water. Remove tap water and add a drop of Solution B. Stains basic proteins blue to blue-green.

## Ferric Sulfate: Tannin Stain

Use 0.1% ferric sulfate in water. Make a wet-mount slide, draw off the water and replace with staining solution. Stains tannin dark brown to purple-brown.

### Toluidine Blue: Dichromatic Stain

Use 0.1% aqueous solution. Make a wet-mount slide, draw off the water and replace with the stain. Then draw off the stain and replace with tap water. General stain for woody tissue. Stains primary cell walls purple and secondary walls blue to blue-green.

## Preparation of Permanent Slides

The following is a simple method that prevents loss of material and allows the tissue to remain flat. While the sections are still in water make sure they do not overlap and remove excessively thick pieces that are not useful. Leave the slides overnight to dry with the coverslip on.

Once dry, do not remove coverslip. Place a drop of xylene at the edge of the coverslip and draw it through with bibulous paper. Then apply a drop of Canada balsam or Permount to the edge of the coverslip and allow it to flow under the coverslip. Small weights may be placed on the coverslip to encourage flattening of the tissue. Leave in fume hood to dry. More Permount may be needed after initial drying if air spaces are present. At no time should the coverslip be removed.

Some sections are better observed in water because they swell and stretch out. Permanent slides of this material can be made by applying a very small amount of celloidin or clear nail polish to two sides of the coverslip to secure it over the sample. (Practice is needed to prevent the nail polish from going under the coverslip.) Leave to dry thoroughly. Store in this form. To view, simply place a drop of water at the edge of the coverslip; it will seep in and reswell the section for observation.

## Labeling and Storage of Slides

If frosted ends are on the slide, use a sharp pencil; if not, use a gummed label. Record the artifact accession number code for the material sample, the orientation of section, and the stain, if one was used. Date and initial.

When the slides are thoroughly dry, they can be stored flat in slide trays or upright in slide boxes. It is advisable to store them in a relatively dry place (preferably not more than 50% relative humidity). This precaution will prevent the Canada balsam from becoming opaque at the edge of the slide.

Make sure the identification of the material and slide storage location are recorded in the accession catalog. If the identification is not positive, indicate by qualifying with a term such as "tentative," "indeterminate," or "possible."

## Standards of Documented Materials

In proceeding with the identification of material of a specific group of artifacts, the conservator needs to prepare standard reference slides of plant species parts that have been identified by botanists and, according to the record, have been used for the specific artifact in question. Such preparations can then be used for comparison, interpretation, and study. A literature review of the anatomy of the plant species should also be undertaken to assist in interpretation.

# Identification of Plant and Animal Fibers

This section deals with the methods used to identify plant fibers—and a few common fibers of animal origin—used in basketry. The methods involve the microscopic examination of the fiber and its associated cells for salient cell characteristics and cell contents; and tests such as staining reactions, solubility tests, burning reactions, and odor tests.

Plant tissues that resemble fibers may be used in cordage on baskets—e.g., red cedar secondary phloem tumplines, wrapping, and so on. It is difficult to draw a clear line between plant fibers and fibrous tissues. In this text, the term fiber refers to single cells or groups of cells mainly of one cell type that have been isolated from a plant part. Because plant tissue has a variety of cell types, it is included in a separate section of this chapter.

Fibers may be present in the basic structure or auxiliary parts of the artifact, or in the form of native or conservation mends, and thus may include commercially made as well as native fibers. Furthermore, the source of native fibers may range widely. Some fibers may be vascular bundle sclerenchyma caps or sheaths from monocot leaves; others may be primary phloem sclerenchyma fibers with secondary cell walls from the stems of dicots; still others may be hairs from seeds or seed coats, and even fruit. Fibers of animal origin may include rawhide, tanned leather, sinew, hair, or modified hair such as quills, baleen, and whiskers.

Plant fibers that have been fabricated by crude retting or simply by stripping the fibers from the plant usually include remnants of other associated plant tissue with characteristic cells or cell contents, such as crystals, which aid in identification. Commercial fibers generally are free of extraneous material; thus identification is completely dependent on the fiber characteristics. Direction of the twist in the thread and composition of the thread are additional aids in determining whether the fiber is of native or commercial origin.

Information on materials and methods (slide preparation, staining tests, and so on) presented in a separate section apply to plant fibers as well as plant parts and tissue. A few additional tests are used, which will be described where appropriate, but in most cases all that is required for natural fiber identification is a microscopic study.

The text contains information on the individual fibers, in some cases, including their origin and history of use. It also describes salient morphological, staining, and other characteristics with appropriate illustrations. Where possible, keys to identification using some of these characteristics are presented. The chapter does not include all plant fibers used throughout the world—an impossible task—but rather emphasizes plant fibers used in western North America. Some common protein fibers of animal origin are also included.

Identification of native fibers is almost impossible without a guide to the possible choices of materials. Before attempting identification, the artifact documentation and literature on materials used by the tribe or linguistic group should be reviewed to narrow down the possible plant origin of the fibers. Standards of those materials can then be selected for comparative analysis. For conservation needs, species identification often is not required; knowing the plant part, tissue, or fiber may

be sufficient for conservation implications. Identification of plant origin of mends is important to differentiate between native and museum repairs. Species identification is essential for purposes of authentication, documentation, and for anthropological research on issues such as trade or ecology.

## Identification of Plant Hairs

### Laboratory Instructions for Plant Hairs (Fruit, Flower, or Seed)

1. Prepare wet-mount microscope slides of a few plant hairs of any of the following materials:
    - *Gossypium hirsutum* (cotton)
    - *Asclepias speciosa* (milkweed)
    - *Populus balsamifera* (poplar)
    - *Epilobium angustifolium* (fireweed)
    - *Eriophorium angustifolium* (cotton grass)
    - *Typha latifolia* (cattail)
    - *Ceiba pentandra* (kapok)
2. Observe with transmitted and polarized light and identify characteristics such as:
    - cells: multicellular or unicellular
    - shape: flattened, circular with trapped air
    - bases: recurved, markings
    - cell wall joint: smooth or nodular (irregular)
    - walls: thick or thin
3. Stain for lignin with phloroglucinol stain. Note that heating over candle flame may enhance the reaction.
4. Draw and record your observations. Use the information supplied to assist in interpretation and identification.
5. Using the key supplied, identify unknown material.

### Key to Identification of Some Fruit and Seed Hairs Used in Ethnographic Material

This key includes only a few species that may be found in some North American artifacts. However, specialized keys can be created for specific species related to the geographic area of one's own study.

**Multicellular Hairs**

1. Hairs up to 50 µ plus in width at base; cell wall joins nearly smooth; cells 15 µ average width; base of hair lignified:
    - cotton grass (*Eriophorium angustifolium*)
2. Hairs average 20 µ to 30 µ in width; cell wall joins nodular; cells 10 µ average in width; cell walls not lignified:
    - cattail (*Typha latifolia*)

**Single-Celled Hairs**

*Hairs flattened and collapsed*

1. Hairs thin-walled; large center lumen; folded and flattened; hairs up to 50 µ in width:
    - milkweed (*Asclepias speciosa*)
2. Hairs thick-walled; small central lumen; ribbonlike twists; hairs average 15 µ to 20 µ in width:
    - cotton (*Gossypium hirsutum*)

*Hairs circular with trapped air bubbles in water mounts*

1. Hairs fine; average width 5 µ to 10 µ
    - poplar cotton (*Populus balsamifera*)
2. Hairs greater than 10 µ in width; hairs with bulbous recurved bases;
    a. cell walls not lignified:
        - fireweed (*Epilobium angustifolium*)
    b. cell walls lignified:
        - kapok (*Ceiba pentandra*)

## Origin and Structure of Some Common Plant Hairs

In ethnographic materials, seed, fruit, and seed-pod hairs have been used as fillers in textiles and as adsorbent material. Their use in basketry is not well documented. Because commercial cotton is frequently used, it is necessary to be familiar with the native materials with which it might be confused.

The photomicrographs of plant hairs that follow illustrate the salient features used for identification. Cotton, milkweed, poplar, and fireweed are sources of seed hairs. Cotton grass and cattails are sources of perianth bristles and kapok is a source of seed-pod hairs. The microscope slides used were simple wet-mount preparations made by teasing out a small piece of material in a drop of water and covering it with a glass coverslip. The photographs were made by the author using a Nikon microflex with Polaroid attachment and Polaroid type 52 film.

***Gossypium hirsutum* L.**

*Description.* Cotton thread has several characteristics that aid in identification. Its most outstanding feature is that the thread or string is made up of several twists and each twist is made up of spun cotton hairs (fibers) with no extraneous plant material. The cotton hairs are single cells that come from the fruit or boll of the cotton flower. The single cells have a characteristic flat, ribbonlike twist (Figure 2.1). The twist in the cell, or convolutions, change direction about every 0.4 mm along the cell. In cross section, cells appear flattened and pear-shaped. The flatness is due to collapse of the cell lumen. In a cotton hair-cell, the cell lumen is seen as a thin central darker line. The cells are 12 µ to 25 µ wide.

Cotton fibers are nearly 100% cellulose and will give a negative phloroglucinol test for the presence of lignin, whereas lignin containing bast and sclerenchyma fibers (linen, stinging nettle, sisal, manila) will give a positive phloroglucinol

test. Schaffer (1981) has used these tests successfully for some ethnographic textiles. The cotton cell wall has both primary and secondary walls, and thus shows dichromatic colors with toluidine blue. The primary wall stains blue and the secondary wall stains purple.

*Summary of Salient Characteristics*

- single cells
- flat ribbonlike twist to cells
- central lumen
- appears pear-shaped in cross section
- negative lignin test
- positive dichromatic reaction with toluidine blue

*Distribution.* Cosmopolitan in use because of extensive agricultural production and trade.

### *Asclepias speciosa* Torr. (milkweed)

*Description.* A bushy, herbaceous perennial, average height 1 m, woolly with overall grey-green color. The fruit (capsule) is up to 10 cm long, recurved, spindle-shaped, and covered with spines. When ripe, the capsule splits along one side to release a multitude of brown seeds. Each seed has an apical tuft of silky seed hairs. The seed hairs are single cells, with thin walls and a large lumen (Figure 2.2). The width varies up to 50 μ.

*Distribution.* Throughout northwest North America. Grows in open clearings, burned and logged-off areas, and along roadsides.

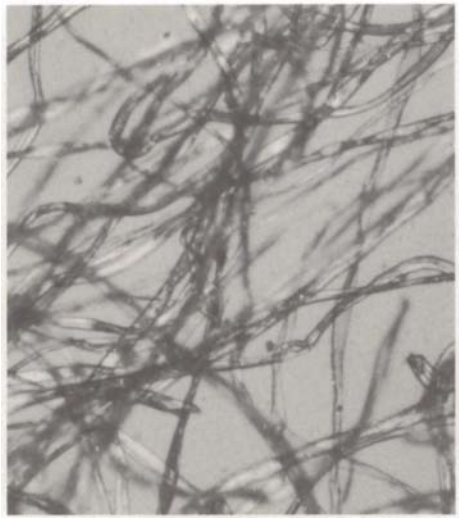


*Figure 2.1.* Gossypium hirsutum *(cotton). Indiviual cotton hairs with distinctive, flat, ribbonlike twist and central dark line indicative of a lumen (standard).*

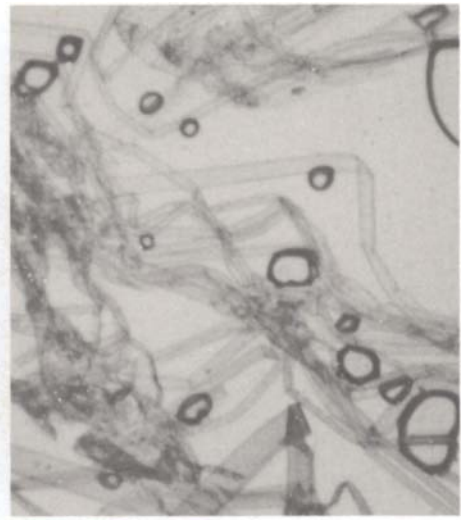


*Figure 2.2.* Asclepias speciosa *(milkweed). Single-celled seed hairs, flattened, folded, thin-walled with large lumen. Width variable up to 50* μ.

***Populus balsamifera* L. sp. *trichocarpa* (T. & G.) Brayshaw (black cottonwood) and *P. balsamifera* L. sp. *balsamifera* (balsam poplar)**

*Description.* Rough-barked deciduous poplar trees; the flowers are long, hanging catkins. At maturity the female catkins are covered with a soft cottonlike down of seed hairs. The seed hairs are single cells with thin lignified walls and a large lumen (Figure 2.3). They are 5 μ to 10 μ wide.

*Distribution.* Poplar trees are found throughout northwestern North America (except Queen Charlotte Islands), but black cottonwood is found mainly in the western region and balsam poplar in the interior.

***Epilobium angustifolium* L. (fireweed)**

*Description.* A tall herbaceous perennial (up to 2 m in height) with narrow willow-like leaves and spikes of red-purple flowers. The long narrow capsules split longitudinally on all sides and expose rows of seeds, each with a tuft of apical seed hairs. The seed hair is a single cell with a thin wall and large lumen (Figure 2.4). The base is bulbous and recurved.

*Distribution.* Throughout northwestern North America. Grows in open clearings, burned and logged-off areas, and along roadsides.

***Eriophorium angustifolium* Roth. (cotton grass)**

*Description.* This grasslike bog or marsh plant has flowers with perianth bristles that elongate when the fruit ripens, forming silky-cottony heads. The perianth bristles or hairs are multicellular. The hair is up to 50 μ wide at the base. On the average, single cells are 15 μ wide. The cells at the base are lignified (Figure 2.5).

*Distribution.* Throughout northwestern North America. Restricted to open bog or marsh areas.

***Typha latifolia* L. (cattail)**

*Description.* This grasslike plant grows up to 2 m in height, with long narrow leaves, flowers in large dense spikes, and nutlike fruit with attached bristles (hairs) that make up a downy mass. The hairs are multicellular, with an average width of 20 μ to 30 μ. The individual cells average 10 μ in width. The cell walls are nodular at joins and are not lignified (Figure 2.6).

*Distribution.* Distributed throughout northwestern North America. Restricted to open, wet marsh areas.

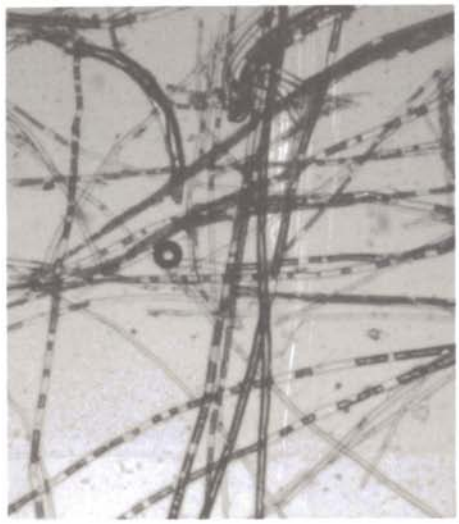
***Ceiba pentandra* D.C. (*Eriodendron anfractuosum* Gaertn. L.; kapok)**

*Description.* The large podlike fruits are lined inside with fine single-celled hairs. The long hairs are circular, usually greater than 10 μ in diameter. Air is often trapped inside the lignified cell wall (Figure 2.7). The bases of the cells are bulbous and recurved.

*Distribution.* The tree is found in tropical regions of both hemispheres. Chief commercial producers are Indonesia, Thailand, Cambodia, Laos, and Vietnam.

*Figure 2.3 (left).* Populus balsamifera *(poplar). Single-celled, circular seed hairs with trapped air bubbles (in water mounts). Hairs fine—5 µ to 10 µ wide. Lignified cell walls.*

*Figure 2.4 (right).* Epilobium angustifolium *(fireweed). Single-celled, circular seed hairs with trapped air bubbles (in water mounts). Bulbous recurved bases. Seeds present in material with attached hairs. Cell wall not lignified.*



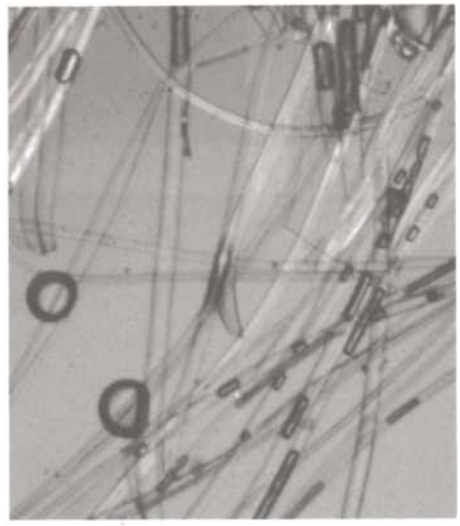
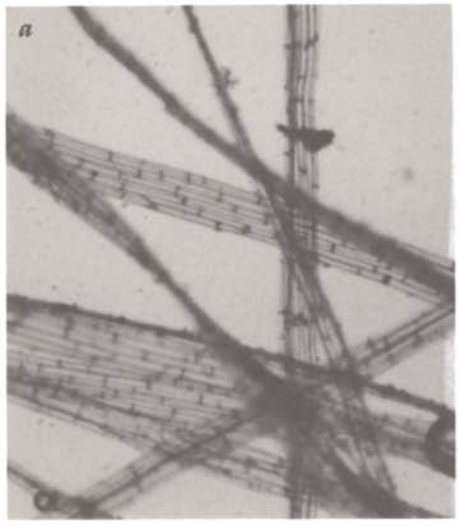


*Figure 2.5. (a) and (b)* Eriophorium angustifolium *(cotton grass). Multicellular hairs (perianth bristles), up to 50 µ wide at base. Cells are smooth where cell walls join, cell width averages 15 µ. Base of hair lignified.*



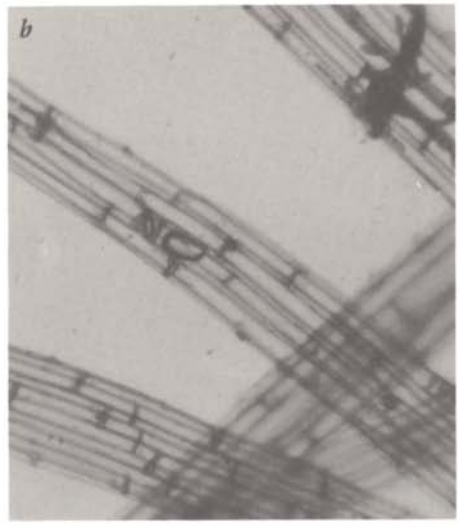
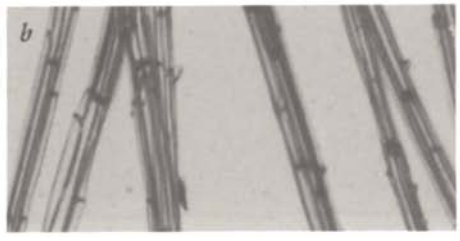
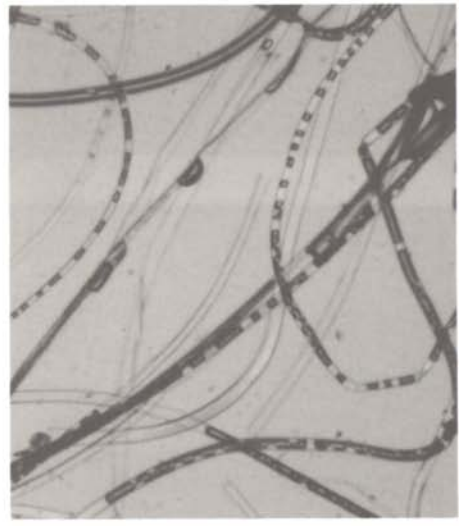




*Figure 2.6 (left). (a) and (b)* Typha latifolia *(cattail). Multicellular hairs (perianth bristles). Hairs average 20 µ to 30 µ wide. Cells nodular where cell walls joins. Cell width averages 10 µ. Cell walls not lignified.*

*Figure 2.7 (right).* Ceiba pentandra *(kapok). Single-celled long hairs from wall of seed pod, circular, with trapped air bubbles. Bulbous recurved bases. Lignified cell walls.*

### Examples of Ethnographic Use of Plant Hairs

Turner (1979) describes as follows the use by different Northwest Coast Indian groups of fireweed, poplar, and cattail seed hairs (cotton) in artifacts:

**Fireweed Cotton**

- combined with mountain goat wool for wearing by the Squamish and most Puget Sound groups
- mixed with a dog wool for wearing by the Saanich and other Vancouver Island groups and the mainland Squamish
- mixed with duck feathers for weaving by the Quinault and Skokomish
- mixed with duck feathers for use by the Saanich Indians to stuff mattresses

**Poplar Cotton**

- used by Thompson and Lillooet Indians to stuff pillows and mattresses

**Cattail Cotton**

- used by Interior Salish groups to stuff pillows and mattresses
- used by the Okanagan and other groups to dress wounds and as baby diapers
- sometimes spun with dogwood for weaving blankets

## Plant Leaf and Stem Fibers

### Laboratory Instructions

1. Make wet-mount microscope slide preparations of longitudinal (surface) and cross sections of the following plant fibers:
   a. Phloem (bast) fibers
      - *Urtica dioica* (stinging nettle)
      - *Apocynum androsaemifolium/cannabinum* (Indian hemp)
      - *Linum usitatissimum* (linen)
   b. Leaf sclerenchyma bundles or vascular bundle sheaths
      - *Agave sisalana* (sisal)
      - *Musa textilis* Neé (manila)
2. Observe with transmitted and polarized light:
   - presence of fibers only in threads
   - presence or absence of extraneous tissue
   - crystals, stegmata
   - protoxylem spiral thickenings
   - stomatal complex, shape, and pattern
   - epidermal cell pattern
   - cross section bundle shape, cell shape
   - fiber markings or nodes, regular striations

3. Test for crystals by burning a fragment and examining the ash as a wet mount under polarized light.
4. Draw and record your observations. Use the detailed description of the fibers of the sample species to assist with interpretation of your observations.
5. Using the key supplied, identify unknown artifact material.

## Identification of Monocot Leaf Fibers

The commonly used plant fibers are sclerenchyma bundles and vascular bundle sheaths of monocot leaves and phloem fibers of herbaceous dicot stems. The fibers have been removed from the plant part and fabricated to different degrees to obtain threadlike fibers that can be spun or twisted together for additional strength.

Leaf fibers are sclerenchyma bundles associated with the epidermis or vascular bundle caps or sheaths stripped or retted from the monocot leaf. Because the monocots have parallel veins, the sclerenchyma bundles also run the length of the leaf. The leaf fibers contain a compact group of sclerenchyma cells and are often associated with some adjacent cells, such as epidermal cells or mesophyll cells. Commercially, they are called hard fibers.

In the monocot leaf, the arrangement of the sclerenchyma bundles assists in species identification, and the individual leaf fiber is identified by shape, cell size, and extraneous cells or cell content. The extraneous cells may be epidermal cells with silica or opal bodies, stomata, tannin bodies, protoxylem vessels, and so on. Cell contents may include phytoliths, silica bodies, starch grains, crystals, and so on.

## Origin and Structure of Some Common Monocot Leaf Fibers

### *Musa textilis* Neé (manila hemp, abaca, manila)

*Description. Musa textilis* Neé is a herbaceous banana plant with overlapping leaf sheaths rising from a root stock. The large leaf sheaths are supported by many stiffened vascular bundles. The basic fiber or manila cordage is the discrete bundle of sclerenchyma cells that stiffen the vascular bundle, called the vascular bundle sheath.

These fibers (vascular bundle sheaths) are mechanically removed from the leaf sheath and cleaned. In making rope, many fibers are twisted together and two or three of these twists are twisted together to make two- or three-ply rope.

In the process of removing the fibers, remnants of tissue from the leaf sheath are retained—even after cleaning. In both new and old manila cordage, it is these tissue remnants that aid in its identification.

*Salient Characteristics Used for Identification.* In visual examination of manila artifact cordage, the basic fiber—the discrete bundles of sclerenchyma fiber cells—can be observed. Thin cross sections of an individual bundle may show the typical oval-shaped fiber bundle (Figure 2.8a) and the individual fiber cells that are 16 μ to 32 μ wide, irregularly round or oval, with a large rounded lumen (Harris 1954). In artifact material the cells may have collapsed and such details are not as easily distinguished. Details of cross striations and node markings of the individual fiber cells, which are often used for textile or paper fiber identification (Collings and Milner 1982, Hall 1951), cannot be used because the individual cells have not been

separated by retting and also because the markings are usually masked or distorted by deterioration.

The remnants of the leaf-sheath tissue previously mentioned are: large parenchyma cells and tannin cells in rows or isolated; birefringent epidermal glandular guard cells with a distinctive shape and arrangement of accessory cells associated with a pigmented region (the artifact material usually has a characteristic deep red color that may be a result of this pigment); rows of silica cells, each cell with an asymmetrically placed circular silicon body or a void indicating the location of the silicon body; and vascular bundle tissue with protoxylem spiral thickenings.

*Summary of Salient Characteristics*

- cordage fiber is an oval-shaped (in cross section) bundle of sclerenchyma cells (Figure 2.8a)
- presence of parenchyma cells (Figure 2.8b)
- rows or isolated tannin cells (Figure 2.8b)
- distinctively shaped birefringent epidermal glandular guard cells (Figure 2.8b)
- rows of silica cells
- protoxylem cells with spiral thickenings
- characteristic deep red color to tissue

*Distribution.* Manila is endemic to the Philippines and has been exported widely since the nineteenth century.

### *Agave* Sp. (sisal)

Sisal is a trade cordage. There are many agave species used for commercial sisal. The common sisal *Agave sisalana* L. is indigenous to Central America. It was introduced to Spain in 1528 and to Florida in 1836 and from there to Africa and Indonesia (Bally 1953). The species *Agave deserti* was used in North American basketry (Coville 1902).

*Description.* The sisal agave plant looks like a common century plant with a rosette of thick leaves that range from 0.75 m to 1.75 m in length. The large thick leaves are supported by many stiffened vascular bundles that run parallel to the length of the leaf. The basic fiber of the sisal cordage is the discrete bundle of sclerenchyma cells that stiffens the vascular bundle, called the vascular bundle sheath. Sisal fibers are mechanically removed from the leaf and cleaned. Sisal cordage is fabricated by twisting together the fibers. These twists are then twisted together to make two- or three-ply cordage. In the process of removing the fiber, remnants of leaf tissue remain attached—even after cleaning. In both new and artifactual sisal cordage these tissue remnants aid identification.

*Salient Characteristics Used for Identification.* In visual examination of sisal cordage it is possible to observe the basic fiber—the vascular bundle sheath. In cross section, the sheath is usually crescent-shaped (Figure 2.9a), depending on species origin (Nutman 1937) and the individual cells, which average 24 μ in diameter, are sharply polygonal with a rounded lumen (Harris 1954). In artifact material the cells may be collapsed, making details difficult to observe. In longitudinal view the sheath shows discrete sclerenchyma bundles composed of groups of uniform cells (Figure 2.9b).

The remnants of the leaf tissue previously mentioned are protoxylem cells with spiral thickenings, sclariform pitted vessels and large rod-shaped calcium oxalate crystals (Figure 2.9c). Often the spiral thickenings are free from the xylem cells and are found scattered around the tissue. The calcium oxalate crystals are extremely persistent, and even in badly deteriorated sisal they retain their original shape and strong birefringence of a full range of interference colors. The size of the crystal is approximately the width of the lumen of the sclerenchyma cells (average 24 μ) and two to three times longer than it is wide. Crystals are commonly used for textile fiber identification (Schaffer 1981, Harris 1954).

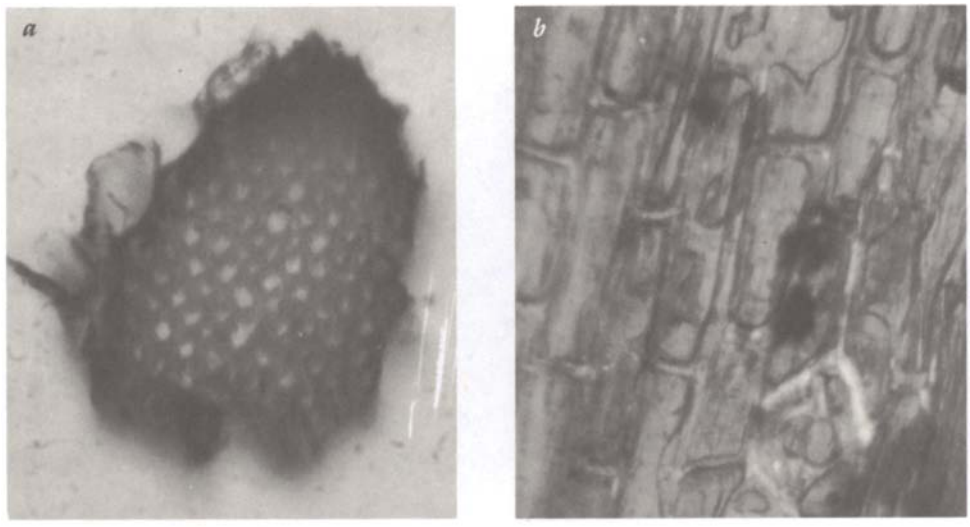



*Figure 2.8. (a)* Musa textilis *Neé (manila). Cross section of a leaf sheath fragment from manila rope. The birefringent fiber bundles are oval shaped and are made up of a number of individual fiber cells (ultimates) that are irregularly round to oval, with a large lumen, average 16 μ to 32 μ in diameter. (b)* Musa textilis *Neé. Surface view; shows large parenchyma cells, rows of tannin cells, and birefringent epidermal glandular cells with a distinctive cell shape and arrangement.*

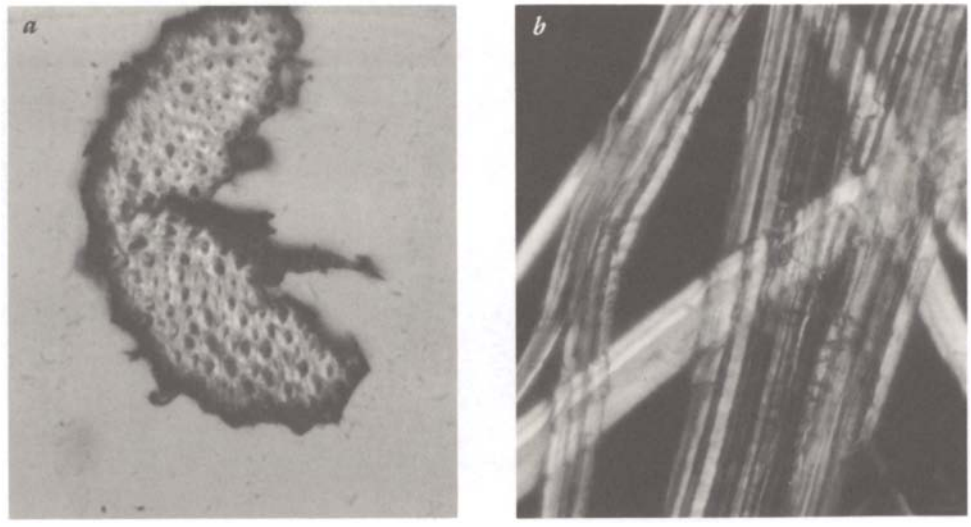



*Figure 2.9. (a) Sisal material showing a discrete bundle of sclerenchyma cells, which is crescent-shaped in cross section. (b) Sisal material showing discrete sclerenchyma bundles without extraneous tissue.*

*Summary of Salient Characteristics*

- cordage fiber is a discrete bundle of sclerenchyma cells that is crescent-shaped in cross section (Figure 2.9a)
- spiral thickenings of protoxylem cells (Figure 2.9c)
- sclariform pitted vessels (Figure 2.9c)
- strongly birefringent rod-shaped calcium oxalate crystals with full range of interference colors (Figure 2.9c)

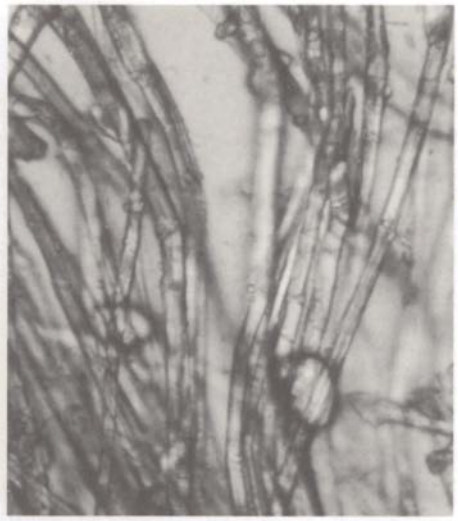



*Figure 2.9 (c, left). Sisal material showing birefringent rod-shaped crystals under polarized light and remnant of protoxylem tertiary spiral thickenings.*

*Figure 2.10 (right). Linen fiber with separate ultimates.*

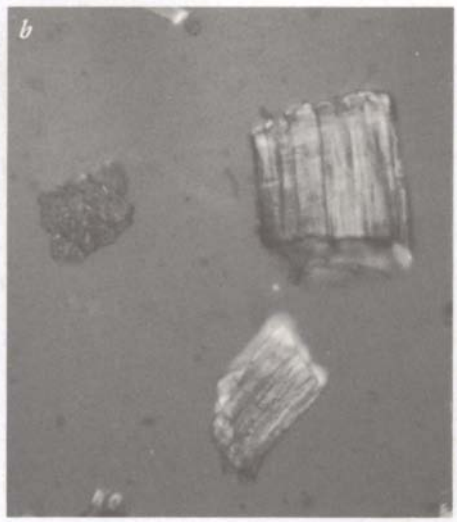




*Figure 2.11. (a) Jute fibers made up of a number of ultimates. (b) Cross section of jute fibers showing the polygonal cells with a prominent lumen.*

## Identification of Phloem Fibers from Stems of Herbaceous Dicots

The term bast used in commerce refers to primary phloem fibers from a dicot stem. These fibers are soft as compared to those of the monocot leaf fibers. The dicot fibers are the result of secondary thickening of the stem. They are located in the cortical region associated with the central vascular bundle(s). The individual cells (ultimate fiber) are elongated, thick-walled cells usually with pointed interlinking end walls. The fibers may be used in the form of bundles of cells or as retted individual ultimates. The ultimates or cells show a full range of interference colors.

### *Linum usitatissimum* L. (flax)

*Description.* The plant is an annual that grows up to 1 m in height. The fibers are obtained from the stem of the flax plant. They may be in groups of 12 to 40 ultimates if raw flax or in single fibers if heavily retted. Some of the cortical cells may adhere to the fiber bundles.

*Salient Characteristics Used for Identification.* The ultimate fiber has thick walls and a small lumen. Along the length of the fiber are transverse dislocations, which are called cross-thatches or nodes (Figure 2.10). The width is usually constant throughout the length of the fiber. The fiber length varies from 9 μ to 70 μ and its width from 5 μ to 38 μ (Figure 2.10).

*Distribution.* Cosmopolitan in distribution because of extensive agricultural production and trade.

### *Corchorus capsularis* L. (jute)

*Salient Characteristics Used for Identification.* The fiber lies along the length of the plant stem in the form of annular layers of fibers. Fibers may be 1.5 m to 3 m long, with individual cells ranging from 1 mm to 6 mm in length (Figure 2.11a). In cross section, the group of cells may vary from 6 to 50 individual cells with thick walls, polygonal in shape, and 12 μ to 18 μ in diameter (Figure 2.11b).

The thickness of the cell wall may be variable along the length of the cell, but the width of the cell remains constant. The tips of the ultimates are pointed and along the length of the ultimate there are typical nodes or cross-thatches, characteristic to all bast fibers.

Jute has a strong positive test for lignin; it has a higher lignin content than flax and hemp.

*Distribution.* Cosmopolitan due to industry and trade.

### *Cannabis sativa* L. (hemp)

*Salient Characteristics Used for Identification.* The commercial hemp or true hemp is from *Cannabis sativa.* The fiber is very similar to flax. The length of the ultimate is 5 mm to 55 mm and its width 10 μ to 15 μ. The microscopic appearance of the ultimate shows variation in the width of the cell; the lumen is broad and the cell walls are thick, though thinner than flax. The ultimate has characteristic longitudinal striations not found in flax (Figure 2.12). The cellulose macrofibrils in the cell wall run in a Z-twist as compared to the S-twist in flax. Hemp has more lignin than flax. Unless the fibers have been boiled or bleached, crystals are present in the ash.

*Distribution.* Indigenous to Eastern Asia, but cosmopolitan due to industry and trade.

*Figure 2.12 (left). True hemp showing ultimates separating and characteristic markings along the ultimates.*

*Figure 2.13 (right). Separated ultimates of ramie.*

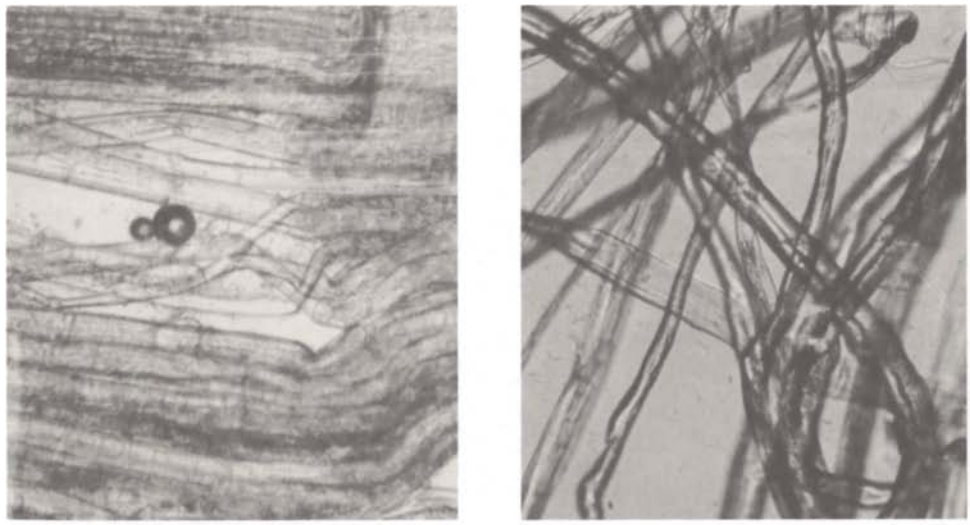


*Figure 2.14. Stinging nettle. (a) Surface view of ultimates and groups of phloem fibers showing strong birefringence and typical crossbars or thickenings along the cell wall. (b) Birefringent phloem fibers are shown at top and bottom of the photomicrograph and rows of crystal druses in parenchyma cells in the central region.*

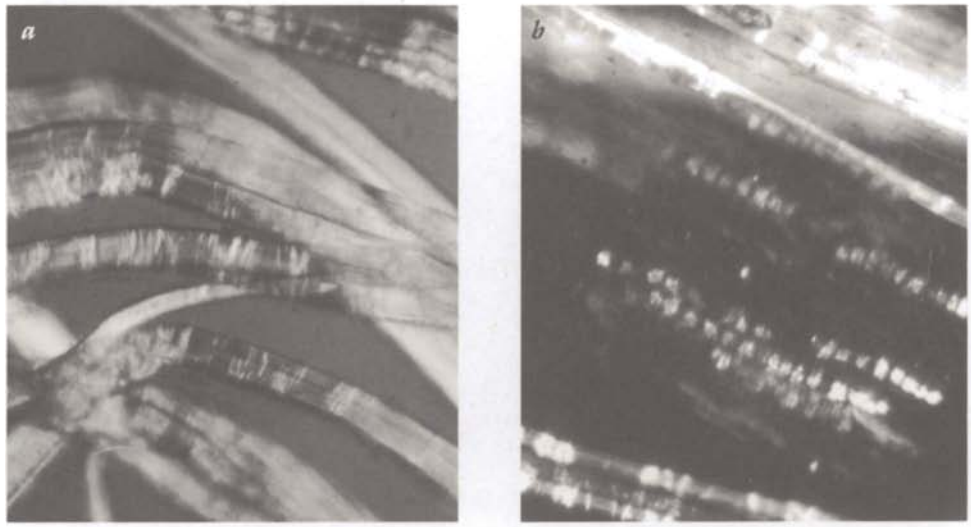
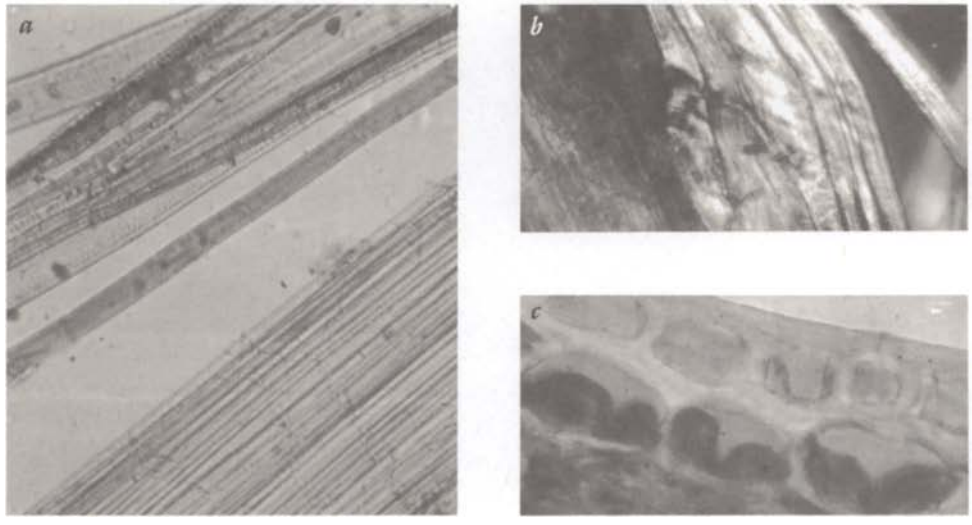



*Figure 2.15. (a) Bast fibers of* Apocynum cannibium *L. and* Asclepias speciosa. *The striations of the* Apocynum *distinguish the two. Whereas the* Apocynum *fibers have characteristic striations along the length of the fiber, this is not the case in* Asclepias *fibers. (b)* Apocynum androsaemifolium, *which is also an Indian hemp. It has the same characteristic striations observed in* Apocynum cannibium *L. (Figure 2.15a). (c)* Asclepias speciosa, *showing distinctive hypodermis with tannin-rich cell contents.*



### *Boehmeria nivea* Gaud. (ramie or China grass)

*Salient Characteristics Used for Identification.* Ramie comes from the stem of plants that belong to the nettle family (Urticaceae). The ultimates (Figure 2.13) are exceptionally long, on the average 150 mm. The diameter of the cells is 25 μ to 75 μ, making ramie the widest of the commercial bast fiber cells. The cell wall is usually filled with cell contents. The typical nodes of bast fibers are present. Like jute, the thickness of the ultimate varies throughout its length. It is almost pure cellulose; thus it will give a negative lignin stain.

*Distribution.* Cosmopolitan due to widespread cultivation and trade.

### *Urtica dioica* L. (stinging nettle)

*Salient Characteristics Used for Identification.* The fibers come from the stem of the nettle plant. The ultimates are similar to flax. The identifying characteristic is the presence of crystal druses (compact masses of small crystals within a single cell).

The fibers (Figure 2.14a) show a full range of interference colors, but in deteriorated artifact material that has been chemically altered by the burial environment the cells may have lost their birefringence. Rows of crystal druses (Figure 2.14b) present in parenchymatous tissue are salient characteristics for the identification of stinging nettle. In some cases the crystals have been removed by the burial environment and replaced with a dark deposit, making their position and size still observable.

*Distribution.* Stinging nettle is a weed in the northern hemisphere.

### *Apocynum* and *Asclepias:* A Comparison of the Bast Fibers

In a specific study on some North American native fibers, it was essential to distinguish between fibers from *Apocynum cannibium* (Indian hemp) and *Asclepias speciosa* (milkweed). The result of the comparison follows:

*Summary of Salient Characteristics*

- *Apocynum* fibers have characteristic striations along the length of fiber; not present in *Asclepias* fibers (Figure 2.15a,b)
- *Apocynum* ultimate cells rounder in cross section than *Asclepias*
- *Apocynum* ultimates loosely associated in the fiber and separate easily into individual ultimates; *Asclepias* ultimates firmly cemented together
- epidermis of *Asclepias* has characteristic tannin-positive hypodermis (Figure 2.15c); *Apocynum* does not

## Identification of Protein Fibers of Animal Origin

### Laboratory Instructions

1. Make wet-mount microscope slides of longitudinal and cross sections of the following animal fibrous material:
    - gut
    - sinew
    - rawhide
    - tanned leather
    - baleen
    - horn
    - tortoise shell
    - silk
    - spider web
    - hairs
2. Using the key to identification supplied, observe the following:
    - swelling reaction
    - fibrils: orientation (random, parallel)
    - birefringence: color and pattern
    - surface scales
    - melanin bodies
    - cell structure and shape in cross section
    - circular gland cell remnant in gut
3. Compare the following tests on protein with plant material supplied:

    **Aniline Blue Staining Tests**
    - selectively adsorbed rapidly at edges of protein
    - positive for wool, silk, tendon, sinew, hide
    - little staining with baleen or modified hairs
    - does not readily stain cellulosic material

    **Solubility**
    - 5% sodium hypochlorite (bleach) dissolves protein; compacted keratin materials are slow to dissolve; hair, silk, hide, and tendon dissolve readily

    **Heat-and-Flame Test**
    - bubbles and curls away from flame
    - keratin protein materials smell like burning hair
    - burns slowly and is self-extinguishing
    - ash is black, crunchy, and crushable (weighted silk leaves a skeleton of the fiber)
4. Draw and record your observations. Use the following detailed description of the animal fibrous materials to assist you in interpretation and identification.
5. Using the key supplied, identify unknown artifact material.

## Key to Identification

This key was devised for a research project on Native North American thread and cordage. It is presented here for reinforcement of the salient features used in identification. The introduction of plant materials here was necessary because they were used as cordage and visually were indistinguishable from some protein fiber. The basic characteristics of protein fibrous materials, with the exception of hair, are common to many species and thus have universal value.

**Noticeable Swelling in Water**

1. Fibrils present
    a. Fibrils show parallel orientation and an undulating linear pattern; full range of interference colors at extinction with polarized light; absorbs aniline blue rapidly at margins; shrinks on heating; increased swelling in strong alkaline solution:
        • sinew
    b. Fibrils that show random orientation may show variable thicknesses; interference colors mainly white; absorbs aniline blue rapidly at margins; shrinks on heating; increased swelling in strong alkaline solution:
        • hide
2. No fibrils present
    a. Negative birefringence; has distinct outer rind (epidermis) in cross section; stains with safranin to show a pattern of collapsed cells of plant material (often mistaken for hide):
        • bull kelp

**No Obvious Swelling in Water**

May unfold, but individual components do not noticeably increase in volume.

1. Individual fibers
    a. Individual fibers solid or with central medulla; circular to oval in cross section; surface scales present; variable diameter of 10 μ to 20 μ:
        • hair
    b. Individual fibers solid; single or groups of two fibers gummed together; fibers triangular in cross section; no surface scales; average diameter 12 μ:
        • silk
    c. Individual fibers solid; variable in width; diameter less than 10 μ; extraneous particulate material usually present:
        • spider web
2. Group of compacted fibers or compact tissue
    a. No obvious cellular structure at 100x magnification; melanin particles present; full range of interference colors; hollow tubes with angular edges in cross section; may be associated with lamellar plates:
        • baleen
    b. Obvious cellular structure of variable shaped cells with tissue organization; negative melanin bodies; negative protein stain reaction:

- plant parts

c. Obvious cellular structure of variable shaped cells with tissue organization; circular groups of glandular tissue and blood capillaries present:

- gut or caecum

The materials presented are common protein fibrous materials. Because of the universality of the fibrous proteins keratin and collagen, species identification using this methodology (with the exception of hair characteristics) cannot be done. However, the chemical and structural aspects investigated are not only an aid to identification but are also required for a better understanding of deterioration and conservation needs.

## Structure of Some Common Protein Materials

### Hair

*Description.* Hairs are multicellular structures. There are three cellular components: the flattened outer cuticle cells, the long, many-sided, central cortical cells, and the inner network of medulla cells.

The outer flattened overlapping cuticle cells are called scales (Figure 2.16b). The shape and number of layers determine the scale pattern, which varies with the different type of hair and animal species and is used as an aid to identification. The keratin of the cuticle is amorphous, with a higher degree of cross-linkage than the inner cortical cells, which makes them more rigid. Thus they stretch and swell less than the adjacent cortical cells. A thin epicuticle membrane covers the external surface of the scales. It contains 5% lipids, which impart the hydrophobic nature to the surface of hairs. A protein cell membrane complex cements the scales.

The cortex is made up of spindle-shaped cells that give the hair its flexibility. The cells are densely packed, interlocked with fingerlike cellular projections, and cemented together by the cell membrane complex. The shape of the cortical cells are an aid to identification.

The medulla, when present, forms a central core of various constructions depending on hair type and animal origin (Figure 2.16a). It is an open network of large cells with vacuoles that may be filled with air; these provide buoyancy and thermal insulation. The medulla is brittle and rigid, giving stiffness to hairs. It may be continuous or interrupted along the length of the hair and it may have ladderlike markings that aid in species identification.

*Deterioration.* Loss of the cell membrane complex, which is easily enzymatically hydrolyzed, will cause separation (fibrillization) of scales and cortical cells.

*Modified Hairs.* Hairs can be modified for protection, as in the case of quills or vibrissae (whiskers). They have the same cellular characteristics as hairs.

### Rawhide, Leather, and Sinew

*Description.* Rawhide and leather are skin products. Rawhide has not been physically altered during fabrication, whereas leather has been altered by a tanning process. Both are composed of randomly oriented collagen bundles in the dermis of the skin (Figure 2.16c).

Collagen is one of the most abundant fibrous proteins in the animal kingdom. It is the main fibrous protein in skin, sinew, cartilage, and bone. These protein fibers show the typical physical characteristics of protein—that is, swelling in water, shrinking on heating, and interference colors of birefringence (when present). In deteriorated collagen in which the crystallinity has been destroyed, the material does not show the interference colors.

Sinew is another word for tendon. Tendons attach muscles to bone. They are made up of tough collagen fibers that are closely packed in parallel bundles (Figure 2.16d). Sinew is used without any physical alteration except hydrating and chewing to soften.

*Salient Characteristics Used for Identification.* Typically, skin fibers used in basketry are thin strings of rawhide, leather, or sinew. Hide and leather are have randomly oriented fiber bundles which appear endless, are without cellular detail, and vary in width according to species. The collagen bundles in sinew are arranged parallel to each other.

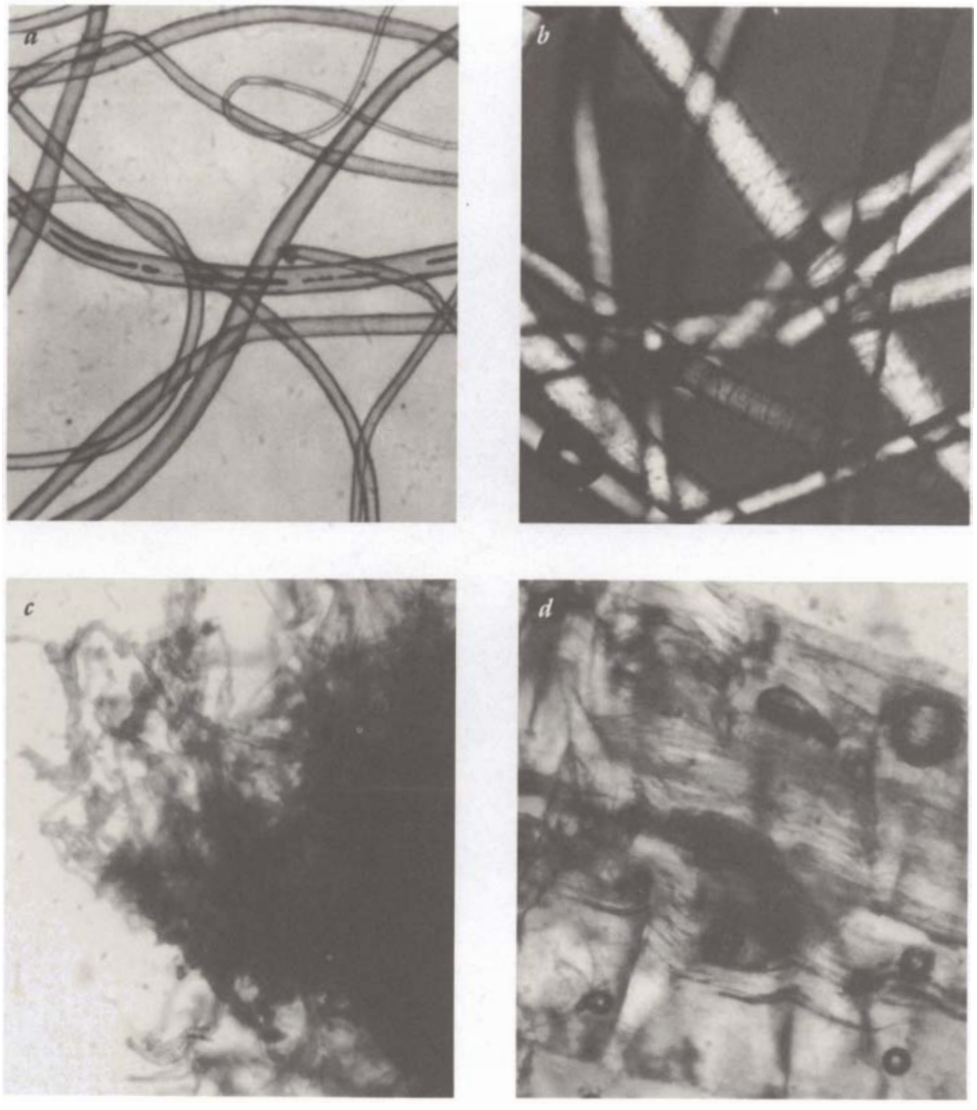



*Figure 2.16. Structure of protein materials. (a) Sheep hairs (wool) with transmitted light. Some hairs show dark interrupted medulla inside the broad cortex. The scale pattern can be seen on the surface of a few hairs. (b) Sheep hairs under polarized light, showing brilliant birefringence. Details of the scale pattern are also enhanced. (c) Randomly oriented collagen bundles in leather. (d) Parallel collagen bundles and undulating birefringent pattern in sinew material used for cordage.*

### Silk: Silkworm and Spider

*Description.* Commercial silk is an extracellular continuous proteinaceous filament produced by the domesticated silkworm caterpillar *Bombyx mori* to make a cocoon. Tussah or wild (raw) silk is produced by caterpillars of the *Antherae* genus, which are not domesticated. Raw silk fibers show a composite structure of two triangular fibers called brins (fibroin) cemented together by an amorphous protein called sericin. Spider webs are single filaments with irregular surfaces.

*Summary of Salient Characteristics*

- all silk is triangular in cross section
- spun silk consists of degummed individual fibers
- wild silk is extruded as two connected filaments
- spider web is a single filament with an irregular surface
- white birefringence interference for all silk and web

### Baleen and Horn

Baleen (Figure 2.17) is basically fused hair. In cross section, one may see several hair-like structures that contain concentric melanin rings of varying colors and density. The central medulla region is empty. The margin where the hairs contact each other is usually angular. Horn, like baleen, is also fused cellular hair. The individual cells are not observable using water mounts at 100x magnification. However, the tissue does show characteristic layers of cells.

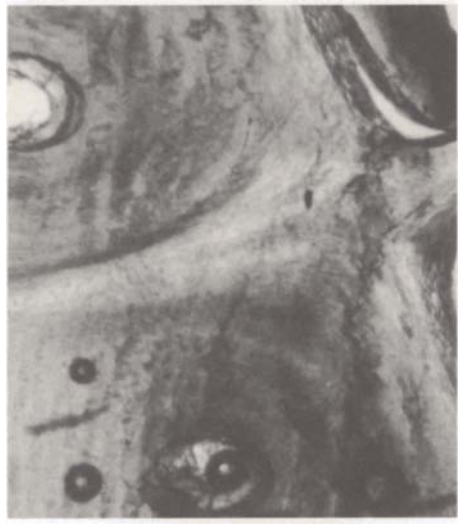


*Figure 2.17. Cross section of fused hairs of baleen showing circular deposition of melanin bodies around empty medulla.*

# Identification of Plant Parts and Tissue

The usual method of identification for plant material is through cellular structure and tissue organization. In some cases, this approach may not be possible with artifact material. Yellow and red cedar bark and stinging nettle stems may have been shredded, rubbed, and beaten; cedar withes may have been heated prior to mechanical removal of the bark, then beaten, steamed, and twisted; and bull kelp may have been dried and oiled. These methods of fabrication obviously destroy some cellular structure and tissue orientation and integrity.

The cellular structure and tissue integrity may also be destroyed or distorted due to deterioration from neglect or during use. In such cases, where the cellular structure and tissue orientation of the material are destroyed, a special approach to identification based on deterioration patterns and the presence of remnants of tissue or cells can be used. Details of identification based on deterioration patterns will be given where appropriate.

The information presented is not intended to teach how to identify species origin of plant parts. Its function is to give an introduction to the methodology used and an approach that will assist in identifying deteriorated materials. The documentation of species used in artifacts is a rigorous task that requires initial research into the ethnobotany of the tribe of provenance of the artifact and preparation of standard materials for comparison. The purpose of the information presented here is not only to give the necessary background for species documentation, but also to allow conservators to determine the plant part of a specific material in an artifact to determine logical treatment or need for repairs.

The photomicrographs for this section were made by the author using a Nikon microscope with polarizing lenses and Polaroid back. The film used was Polaroid type 52 black-and-white film. The slides were wet mounts, and artifact material was often used so photographs would resemble material likely to be identified by conservators rather than tissue photographed for histological cellular details.

## Identification of Stems, Rootlets, and Rhizomes

Stems, rootlets, and rhizomes are grouped together because of a common circular structure. Stems, rhizomes (underground stems), and true roots are plant parts that have commonly been used in the fabrication and decoration of cultural material. Stems and rhizomes are similar in anatomy. True roots have a simple central vascular bundle as compared to the large number of distinct bundles in monocot stems or rhizomes.

### Laboratory Instructions

1. Prepare wet-mount microscope slides of longitudinal and cross sections of:

   **Stem**

   - *Scirpus lacustris* (bulrush)
   - *Typha latifolia* (cattail)
   - *Juncus effusus* (rush)

- *Elymus mollis* (dunegrass or straw)
- *Nereocystis luetkeana* (bull kelp stipe)

**Petiole**

- *Adiantum* (maidenhair fern)

**Rhizome**

- *Equisetum* (horsetail)

**Rootlet**

- *Yucca*

2. Observe with transmitted and polarized light and identify the following characteristics with the aid of the photomicrographs:

**Surface (longitudinal section)**

- epidermal cell pattern and outline
- stomatal pattern and complex
- vascular bundle arrangement

**Cross section (transverse section)**

- sclerenchyma/collenchyma pattern
- vascular bundle arrangement
- stem cavity/margin or pith
- chlorenchyma arrangement
- starch grains (iodine potassium iodide stain)
- silica bodies/sclereids/tannin bodies
- phytoliths
- indication of fabrication/split/dye

3. Whenever possible, compare with leaf sections, e.g., using a *Typha latifolia* leaf.
4. Draw and record your observations. Label all parts. Use the detailed description and illustrations to assist in interpretation and identification.
5. Identify the unknown artifact material.

## Structure of Monocot Stems

Monocot stems from grasslike plants of the sedge, grass, lily, cattail, and other families have been used all over the world for the fabrication of cultural material. The leaves are flattened and elongated with parallel veins. The stems are round or three-sided and also have parallel veins. Even though different species were used, there is a common anatomy. The species selected for this section are common North American species but the information presented is essential for identification of any monocot stem.

### *Scirpus* sp. (tule, sedge, bulrush, rush)

*Description. Scirpus* (tule) plants are grasslike with fibrous rhizomes. The plants usually grow in wetlands. The stems are usually swollen and rounded and up to a meter in length. It is these long, thin stems that are used in artifacts. The leaves are usually very small or reduced to sheaths.

*Salient Characteristics Used for Identification.* In fabrication of cordage the outer region of the stem is split off and twisted into twine. In cross section the outer rind of the stem shows an alternating pattern of large and small sclerenchyma bundles. The chlorenchyma tissue contains tannin bodies. The interior of the stem is netlike, made up of vascular bundles joined together by parenchyma cells delineating large air cavities (Figure 2.18).

The air cavities are formed by natural enzymatic deterioration of stellate cells that originally filled the cavity. In some of the air cavities the stellate cells are still present. In the outer epidermis, stoma are distributed in a regular pattern. Often the stomatal complex can be used as an aid to species identification. The details of the stomatal complex of *Scirpus lacustris* show the Cyperaceae characteristic of having only one lateral contact cell to each guard cell.

In deteriorated tule artifact material the cells have collapsed and separated. The resultant tissue is compacted but the salient features used for identification are observable (Figure 2.19).

*Summary of Salient Characteristics*

- parallel longitudinal sclerenchyma and vascular bundles of monocots
- an outer row of small sclerenchyma bundles and inner row of larger vascular bundles in the rind
- presence of tertiary sclariform thickenings of protoxylem vessels
- presence of tannin cells

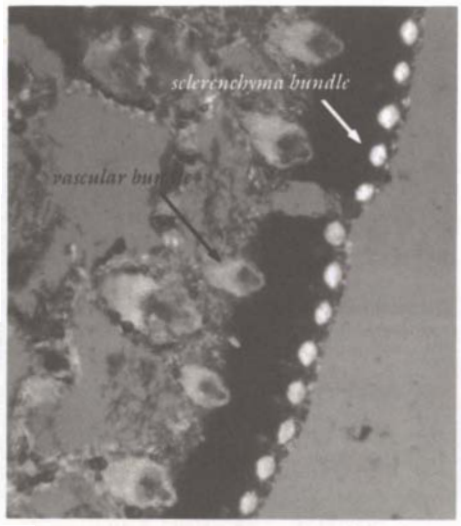



*Figure 2.18 (left).* Scirpus acutus *Muhl. ex Bigel. Cross section of stem.*

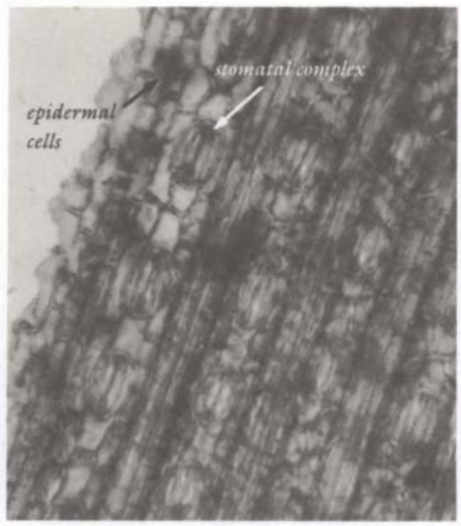



*Figure 2.19 (right).* Scirpus acutus *Muhl. ex Bigel. Surface of stem showing parallel vascular bundles, stomatal complex, and epidermal cells.*

**Other Monocots**

Illustrations are provided for a number of other monocot stems, showing the variety of arrangements in the rind, sclerenchyma bundles, sheaths, and vascular bundles (Figures 2.20 through 2.23).

*Figure 2.20 (left). Cross section of* Typha latifolia *L. showing outer rind with small vascular bundles with sheaths, and inner band of sclerenchyma tissue. The inner vascular bundles have the shape characteristic of a sclerenchyma sheath.*

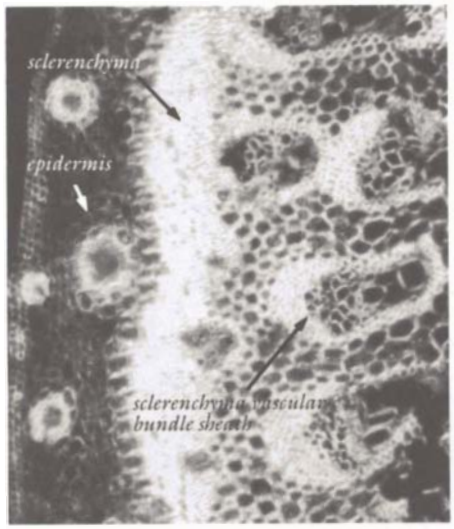



*Figure 2.21 (right). Cross section of circular stem of* Juncus effusus *L. showing outer rind with sclerenchyma bundles and inner rings of vascular bundles with sclerenchyma sheaths. The aerenchyma shows typical stellate cells.*

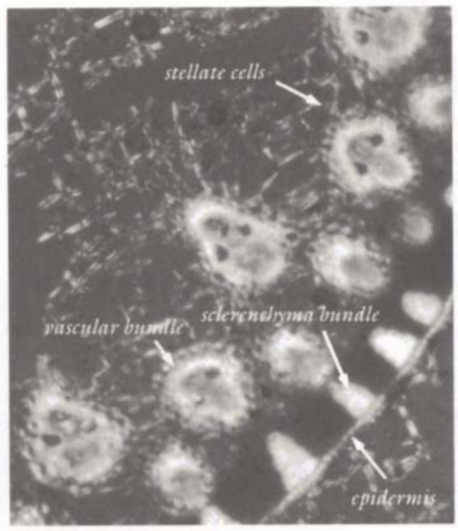



*Figure 2.22 (left). Cross section of straw (Gramineae—grass family)stem showing typical outer rind of thick-walled cells and typical arrangement of cells in vascular bundle. The inner margin shows the margin of desorption of parenchyma tissue that occurs to make the stem hollow.*

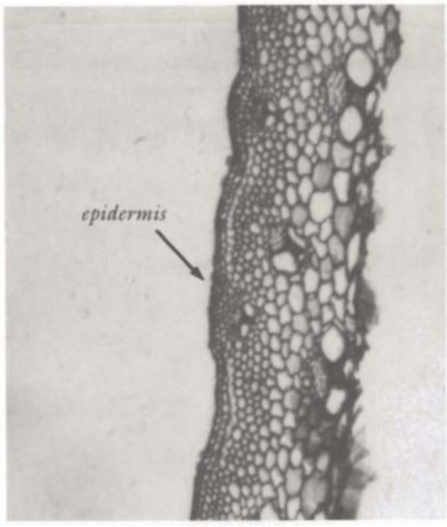



*Figure 2.23 (right). Cross section of stem of* Elymus mollis *Trin. showing outer rind of thick-walled cells, typical Gramineae vascular bundle arrangement, and inner parenchyma cells.*

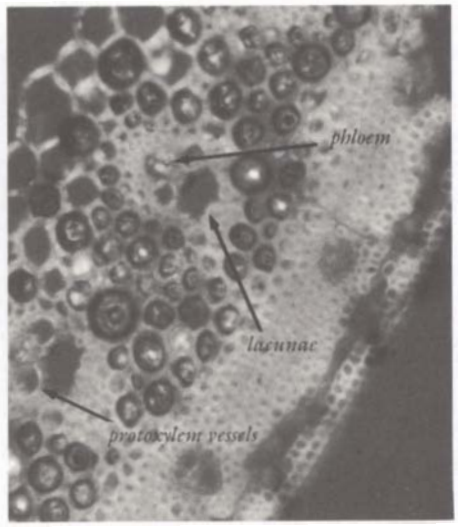



*Figure 2.24 (left). Cross section of collapsed stipe of the bull kelp,* Nereocystis luetkeana *(Mertens) Postels and Ruprecht, showing collapsed cortical cells and outer rind of pigmented epidermis and chlorenchyma cells.*

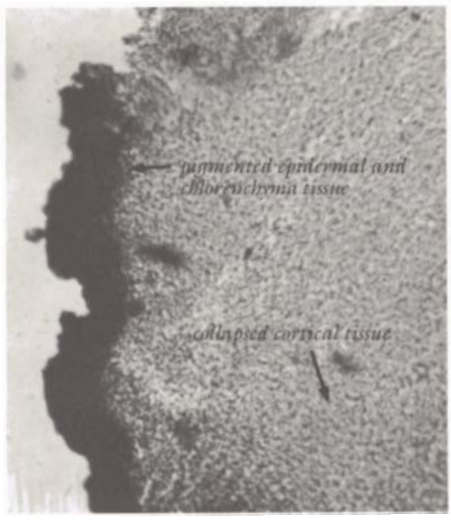
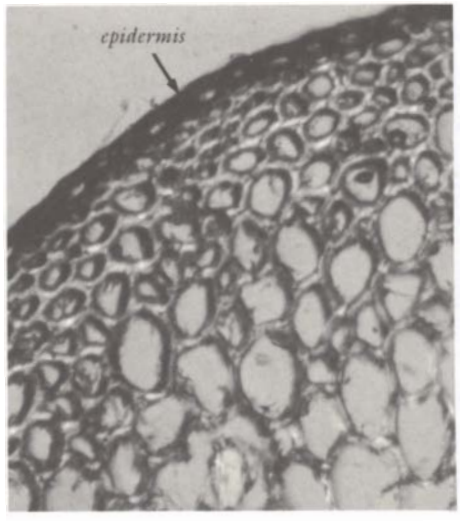



*Figure 2.25 (right). Cross section of frond stem (petiole) of the fern* Adiantum pedatum *L. showing the colored outer epidermis and thick-walled cortical cells. The shiny black stems are used for imbrication in baskets.*



## Structure of Bull Kelp or Seaweed Stipe

Seaweeds are algae; they do not have true stems or roots. The plant body is called a thallus and is made up of groups of similar cells. In some species, such as the bull kelp, these cells take on the form of a long stemlike structure called a stipe and rootlike structures called holdfasts. Along the North American Pacific coast, the distribution area of the bull kelp, the stipe was a ready-made piece of cordage for aboriginals.

***Nereocystis luetkeana* (Mertens) Postels and Ruprecht (Bull kelp stipe)**

*Description.* Bull kelp is a brown marine algae. It has a very long ropelike stipe which has a bulbous float at its upper end from which several thin leaflike blades arise, and an interwoven mass at the other end, which acts as a holdfast on a solid substrate at the sea bottom.

The stipe has three regions seen in cross section: the outer epidermis, the central medulla, and, between these two, the cortex. The outer epidermis or epidermal meristem is composed of five to ten layers of cells covered with mucilage in which diatoms are commonly caught. The epidermis contains the chloroplasts that impart the brown color to the tissue.

The cortical cells are thin-walled isodiametric cells which collapse dramatically on drying. The medulla cells are variable in size; some are small, branching filaments and others large trumpeted sieve tubes. The cells are loosely and randomly organized.

*Changes Due to Deterioration.* During fabrication or drying, the thin-walled cells of the cortex and medulla collapse and the stipe shrinks and becomes compacted. On rehydration, the collapsed cells do not regain their original shape.

*Summary of Salient Characteristics.* The identification of *N. luetkeana* stipe material used in cordage is based on the following specific deterioration patterns (Figure 2.24):

- cross section of partially rehydrated cortex shows characteristic pattern of collapsed cortical cells
- distinct structural demarcation of outer pigmented epidermis, which easily separates as a rind on sectioning from the cortex
- epidermis has characteristic dark grey-green color; cortex/medulla complex is light tan

## Details of the Structure of Ferns and Horsetails

The ferns and horsetails have underground rhizomes with true roots. Stems grow out along the length of the rhizome. Many leaves grow out at nodes along the stem. Often the stem of the fern and the rhizome of the horsetails are heavily pigmented. This material is used for decoration in cultural material. The tissue arrangement in the frond stem (petiole) of the fern *Adiantum pedatum* and the rhizome of the horsetail *Equisetum arvense* are illustrated in Figures 2.25 and 2.26a,b.

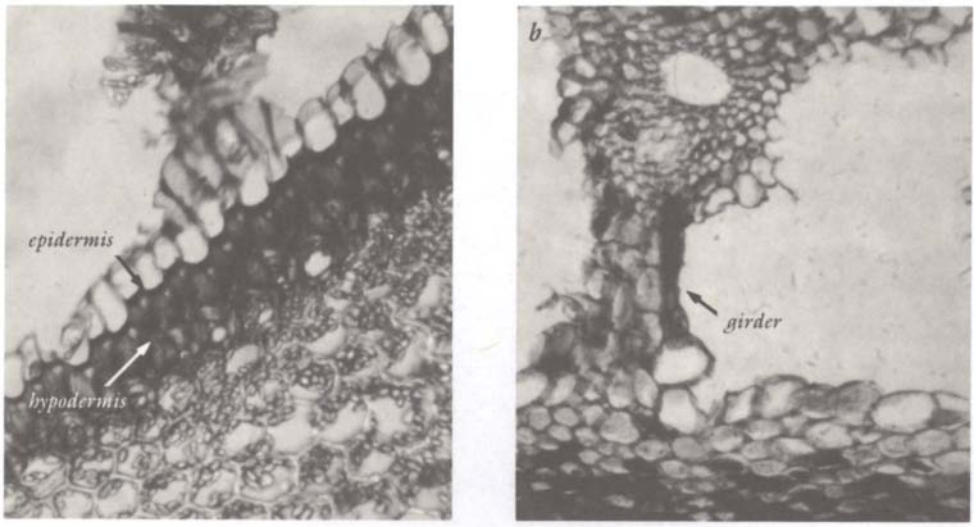



*Figure 2.26. Cross section of rhizome of the horsetail,* Equisetum arvense *L. (a) Outer colored epidermis and hypodermis, and inner cortical cells filled with starch grains. (b) Outer rind and one of the many vascular bundles supported by parenchyma girders in the central region of the rhizoid.*

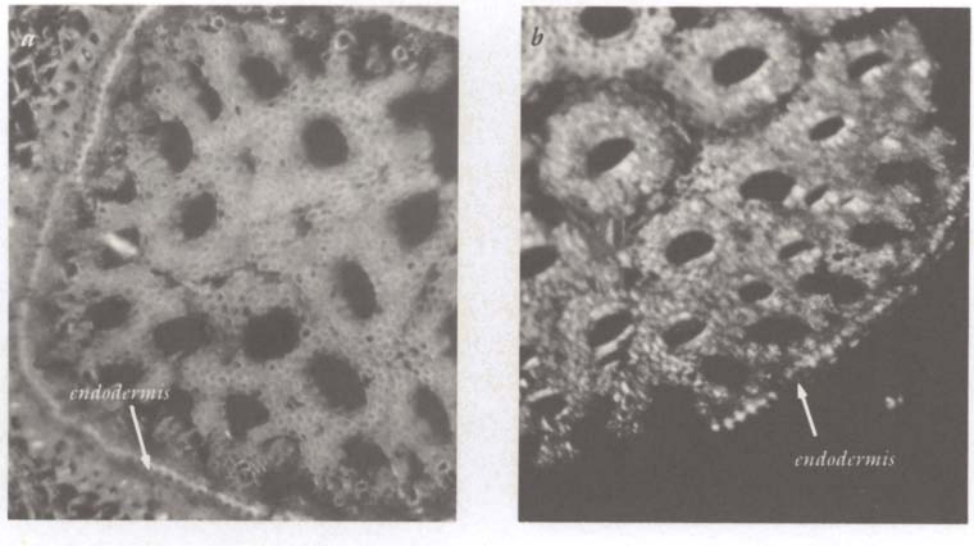



*Figure 2.27. Cross section of* Yucca *sp. rootlet. (a) Outer cortical tissue, distinctive endodermis, and central core of vascular tissue. (b) Fabricated into cordage. All the tissue external to the endodermis has been removed, exposing the colored endodermis.*

## Structure of Yucca Rootlets

### *Yucca* sp.

*Salient Characteristics Used for Identification.* The yucca rootlet is a true root. It has an outer epidermis and central core of vascular tissue separated by cortical tissue (Figure 2.27a). The central core of vascular tissue is surrounded by a layer of thick-walled cells called the endodermis. These cells may contain suberin and may be pigmented orange or brown. In fabrication of the rootlets, the outer epidermis and cortex are removed, exposing the colored endodermis. The fabricated material is the endodermis and central stele (Figure 2.27b). This material is used for its strength and color.

## Identification of Monocot Leaves

### Laboratory Instructions

1. Make wet-mount microscope slides of longitudinal and cross sections of the following monocot leaf materials:
    - *Yucca*
    - *Carex obnupta* (swamp grass)
    - *Typha latifolia* (cattail)
    - *Phyllospadix scouleri* (seagrass)
    - *Xerophyllum tenax* (squaw grass)
    - *Zea mays* (corn)
    - *Hierochloe odorata* (sweet grass)
    - *Zostera* (eel grass)
2. Observe with transmitted and polarized light and identify the following characteristics with the aid of the photomicrographs:

    **Surface (longitudinal section)**
    - epidermal cell pattern and outline—silica/cork cells
    - stomatal pattern and complex
    - vascular bundle arrangement
    - protoxylem thickenings
    - parenchyma/chlorenchyma

    **Cross section (transverse section)**
    - sclerenchyma arrangement (polarized light)
    - vascular bundle arrangement (metaxylem, protoxylem cells, phloem)
    - lacunae, aerenchyma/stomata cavities, diaphragm, partitions
    - chlorenchyma arrangement
    - starch grains (iodine potassium iodide)
    - silica bodies, tannin bodies
    - phytoliths
    - indication of fabrication (split/dyed)
3. Compare with leaf sections whenever possible.
4. Draw and record your observations. Label all parts. Use these illustrations to assist in interpretation and identification.
5. Identify the unknown artifact material.

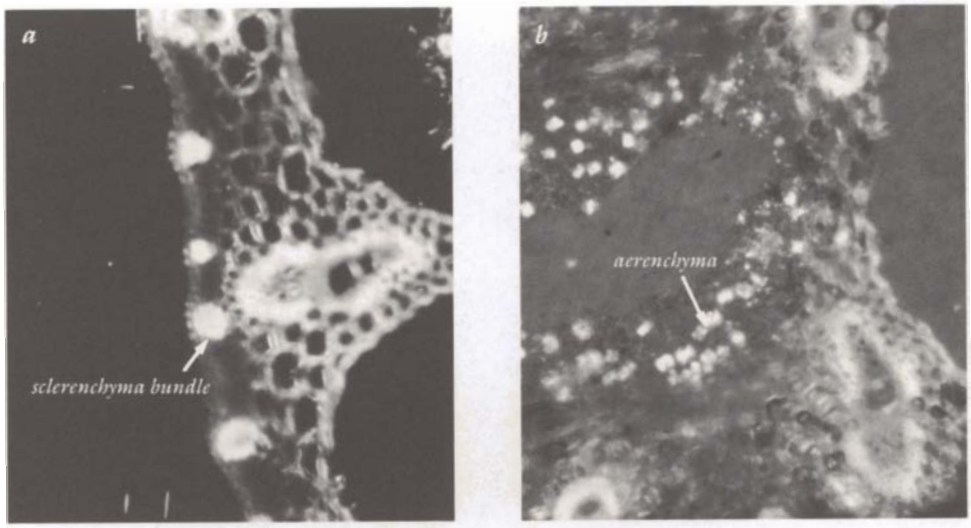



*Figure 2.28. Cross section of leaf of cattail,* Typha latifolia *L. (a) Sclerenchyma bundles along with sheathed vascular bundles associated with the upper epidermis. The shape of the vascular bundle sheath is species specific. The needlelike phytoliths are free from the leaf tissue. (b) The intact bundles of phytoliths in the aerenchyma tissue.*

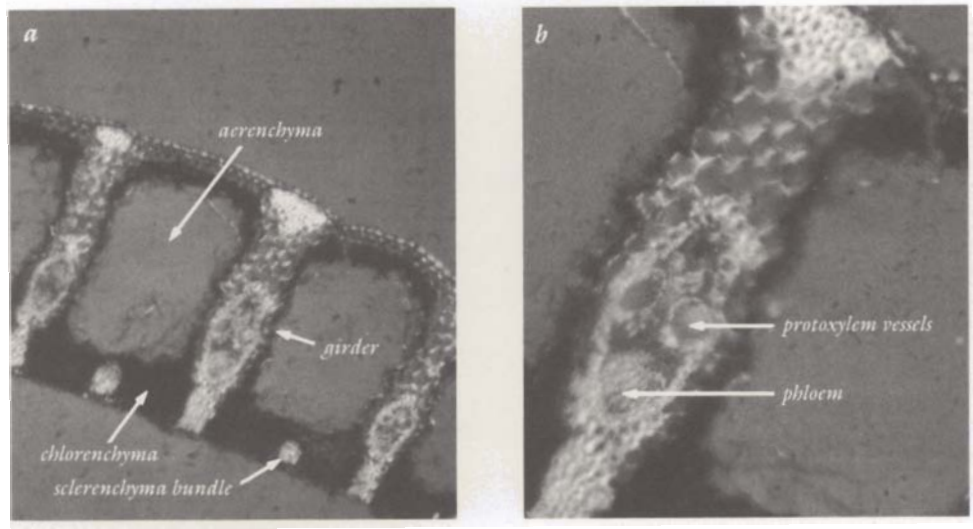



*Figure 2.29. Cross section of swamp grass leaf,* Carex obnupta *L. (a) Girders with the vascular bundle separated by aerenchyma regions. Discrete sclerenchyma bundles are in the dense chlorenchyma tissue next to the lower epidermis. (b) Higher magnification of girders with the vascular bundle and the associated sclerenchyma.*

## Variations in the Anatomy of Monocot Leaves

Monocot leaves, because of their thin elongate structure, are logical materials for weaving and cordage. The strength in the leaf is due to the parallel veins and their strengthening sclerenchyma bundles, which also give strength to the material used in weaving or cordage. The basic anatomy of the monocot leaf is presented in the chapter on anatomy. Variations due to species differences are seen in the following illustrations, which are common North American species. Understanding these variations will assist in interpretation of other species. A few species may present specific conservation problems but, on the whole, the problems are common to all monocot leaves. Anatomical variations of the monocot leaf in the species *Typha latifolia*, *Carex obnupta*, *Scirpus* sp., and *Xerophyllum tenax* are illustrated in Figures 2.28 through 2.31.

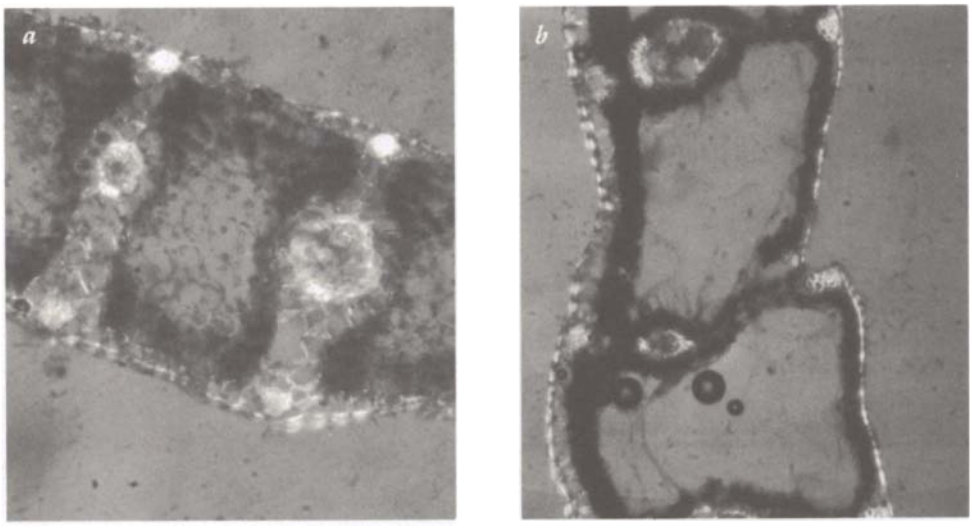



*Figure 2.30. Cross sections of the leaves of two species of* Scirpus maritimus *(a) and* S. microcarpus *(b), showing an example of the species-specific arrangement and shape of sclerenchyma bundles and vascular bundle sheaths.*

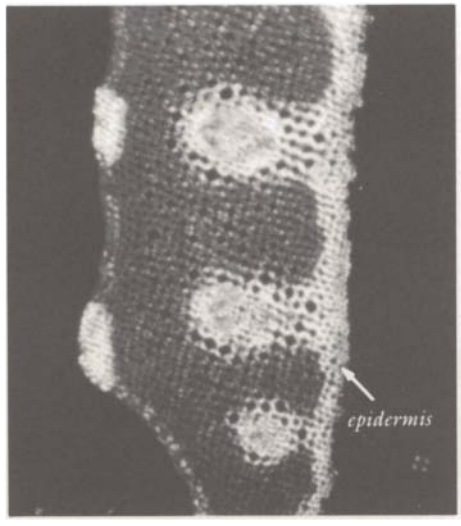



*Figure 2.31. Cross section of squaw grass,* Xerophyllum tenax *(Pursh) Nutt, showing the thick-walled cells of the epidermis and adjacent cortical cells and typical Liliaceae vascular bundle arrangement.*

***Phyllospadix scouleri* Hooker (seagrass, ribbon grass, basket grass leaf)**

*Description. Phyllospadix* is common along the shore of the Pacific coast of North America and Japan. It is a sea grass found in surf regions near rocks, attached to the bottom by rhizomes. The leaves of *Phyllospadix* are tough strap-like blades that average 0.5 m in length and 1 mm in width. When dry, they appear black and have a ribbonlike twist throughout their length. The leaves are commonly used for imbrication on baskets.

*Salient Characteristics Used for Identification.* In cross section, leaves show a continuous epidermis of thick-walled epidermal cells, elongated inwards and containing chlorophyll (Figure 2.32), above small bundles of nonlignified fibers. The central leaf region shows a few poorly developed vascular bundles and collapsed aerenchyma tissue. In surface view the chlorophyll-containing epidermis has a distinctive pattern of mostly triangular shapes. Like most aquatic vascular plants, the epidermis has no stomatal complexes. The small birefringent fiber bundles parallel the length of the leaf, a typical monocotyledon characteristic. Individual fibers are nonlignified cellulosic secondary thickenings deposited in the primary wall.

### *Zostera marina*

*Description. Zostera marina* is usually found in mud or in sandy bottom areas. It has a broader leaf than *Phyllospadix*, averaging 5 mm wide. The leaf anatomy also differs in having well-developed air canals separated by distinct girders and thick-walled epidermal cells, less elongated than *Phyllospadix*, and a surface epidermal pattern of nearly hexagonal shapes (Figure 2.33).

*Changes Due to Deterioration.* The artifact material may lose birefringence and most cellular detail except the continuous outer epidermis, with the characteristically elongated epidermal cells. The general shape of the cross section of the leaf is retained; it shows typical fracturing as seen in the standard material.

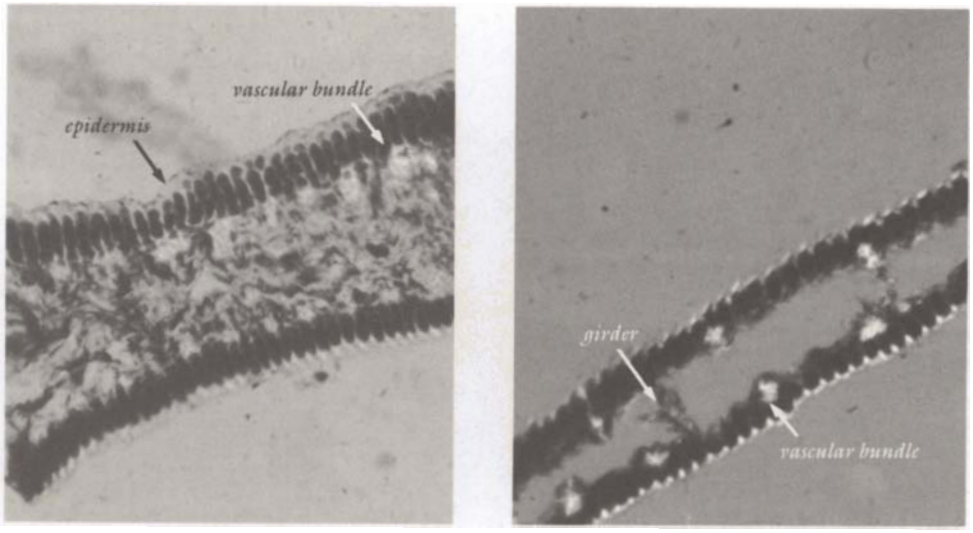



*Figure 2.32 (left). Cross section of sea grass,* Phyllospadix scouleri *Hooker, showing outer birefringent walls of columnar pigmented epidermal cells and internal rows of small vascular bundles in the cortex.*

*Figure 2.33 (right). Cross section of eel grass leaf of* Zostera marina *var.* latifolia *Morong showing girders between the upper and lower epidermis and the rows of small vascular bundles.*

## Identification of Secondary Phloem Tissue

### Laboratory Instructions

1. Make wet-mount microscope slides of cross, tangential, and radial sections of:
   - *Thuja plicata* (western red cedar)
   - *Artemisia tridentata* sp. (giant sagebush)
   - *Acer* sp. (maple)
   - *Chamaecyparis nootkatensis* (yellow cedar)
2. Observe with transmitted and polarized light and identify the following characteristics with the aid of the photomicrographs and the chapter on plant anatomy and specified stain:

   *Cross section*
   - shape of phloem fibers
   - arrangement of phloem fibers
   - other phloem fibers
   - growth rings

*Tangential*

- size and shape of phloem rays
- markings/pitting of phloem fibers

*Radial*

- arrangement of phloem rays
- crystals
- sieve elements (toluidine blue)
- starch grains (iodine potassium iodide)
- resin/tannin bodies (ferric sulphate)

3. Draw and record your observations. Label all parts. Use the following descriptions and illustrations to assist in interpretation and identification.
4. Identify the unknown artifact material.

## Introduction

The secondary phloem of some trees, both softwood and hardwood, is made up of sheets of strong fibers. The sheets can be easily removed from the trunks of large trees and fabricated into smaller sheets or strands and used for weaving or cordage. The strength of this material comes from the intertwining and inherent strength of the fibers. In the softwoods the secondary phloem that is used in cultural material is found on the outside of the tree trunk and is mistakenly called bark. The true bark in such species is only present in twigs up to two to four years old. The secondary phloem of the dicot trees is located inside the true bark. In these cases the true bark is removed and the secondary phloem sheets taken from the inside surface. The following are descriptions and illustrations of secondary phloem of some common North American species. The interpretation of these species will provide background for the interpretation and identification of species worldwide.

## Details of the Structure of Secondary Phloem

### *Thuja plicata* Donn. (western red cedar bark)

*Description.* The tissue that is usually called bark is actually secondary phloem tissue, which has a very different cellular organization from true bark. (See the section on Identification of True Bark Tissue.) The phloem on the cedar tree trunk takes the place of true bark. The outer shredding phloem is dead tissue, but the phloem adjacent to the wood in the trunk of the tree is the living phloem often called "the inner bark." In the living phloem, nutrients are stored and transported to protoplasm throughout the tree. New phloem is produced each year and shows annular growth rings. After several years as functional tissue the phloem tissue becomes senile, and takes on a mechanical protective bark function, becoming dead outer phloem.

Secondary phloem is a highly organized tissue with three basic types of cells, (a) the sieve cells, in which protoplasm transport occurs, (b) the phloem parenchyma, in which nutrients (starch) are stored, and (c) the phloem fibers, the cells that give the tissue its mechanical strength.

*Salient Characteristics Used for Identification.* The most distinctive features of *Thuja plicata* phloem are the shapes and layers of the fibers (Figure 2.34a). In

cross section, the phloem fibers are in layers of two distinct shapes: a layer of thick-walled, almost square fibers (average 40 μ) alternating with at least three layers of radially flattened, thin-walled rectangular fibers (average 35 μ x 15 μ). The fibers are birefringent and have a full range of interference colors. They have distinctive blind pits along the radial walls, giving the walls a nodular appearance. The layers of these phloem fibers alternate with a group of two sieve cells between which is a parenchyma cell filled with starch. The parenchyma and sieve cells are not birefringent.

Living phloem—that is, phloem that was living when removed from the tree—contains starch grains in the parenchyma cells and calcium oxalate crystals deposited between the cell walls. In polarized light, the crystals are birefringent and show a distinct pattern of deposition.

In senile phloem (dead mechanical tissue), an insoluble resinous material is deposited in the parenchyma cells and both the starch grains and the calcium oxalate crystals are metabolically removed (Figure 2.34b).

In the dead phloem, the thin-walled parenchyma and sieve cells are easily fractured, causing layer separation or exfoliation, which is essential to allow tangential expansion of the growing tree trunk. Phloem that was dead when removed from the tree shows these features.

*Changes Due to Fabrication.* The usual method of fabrication involves soaking and heating. This does not alter the shape of fiber cells, but it encourages separation of the tangential layers of fibers and results in loss of tissue integrity. The calcium oxalate crystals or porous resin are not removed.

*Changes Due to Deterioration.* The fiber cells are very persistent and remain as diagnostic features even in badly deteriorated material. The birefringence of the fibers may be reduced, but there are usually regions of the fibers that show the full range of interference colors. The blind pits on the radial walls of the phloem fibers may be exaggerated by chemical or bacterial leaching and assist in identification. Even in badly deteriorated material the phloem fibers remain in sheets or layers and in cross section, even if cell collapse has occurred, the phloem fibers can be seen to have two characteristic shapes: square and rectangular.

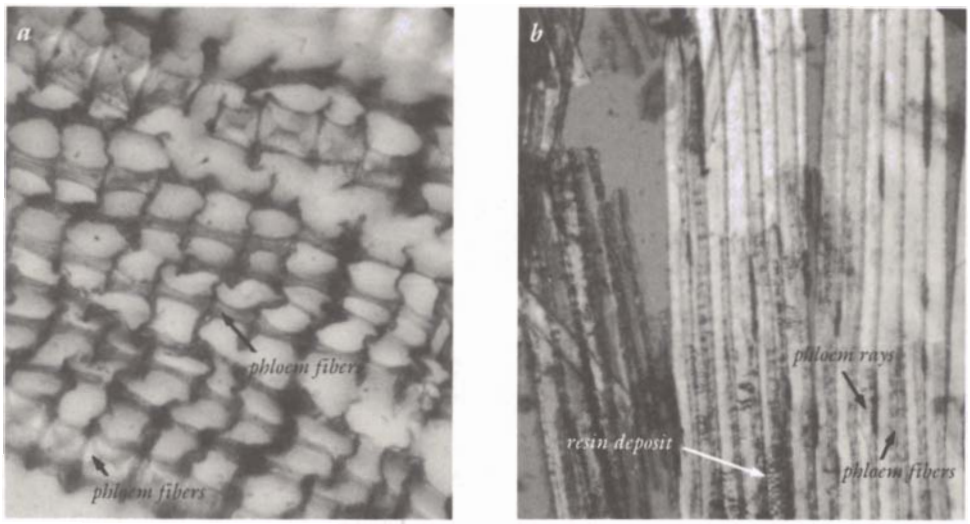



*Figure 2.34. Secondary phloem of western red cedar,* Thuja plicata *Donn. (a) Cross section showing the rows of thick-walled phloem fibers, of two different with phloem parenchyma and sieve elements. (b) Tangential surface showing phloem rays, fibers, and resin deposits in the remnant parenchyma cells.*

*Summary of Salient Characteristics*

- phloem fibers of two cell shapes (rectangular and square) in cross section
- continuous rows of birefringent phloem fibers alternating with three non-birefringent cells (two sieve cells and one parenchyma cell)
- porous appearing resin inclusions in parenchyma cells in "dead" tissue or starch grains in parenchyma tissue and the presence of calcium oxalate crystals in "living" tissue
- nodular appearance of radial wall of phloem fibers due to large blind pits

***Chamaecyparis nootkatensis* (Lamb.) Spach. (yellow cedar bark)**

*Description.* The secondary phloem contains phloem fibers, sieve cells, parenchyma cells, starch grains, and calcium oxalate crystals (Figure 2.35a,b) in "living" tissue, all of which are similar to *Thuja plicata* in physiological activity and function.

The majority of the phloem fibers are of one morphological form, radially flattened, thin-walled, and on the average 35 μ by 10 μ in size. These fibers are birefringent and show only a white interference color. The fibers do not show distinctive pitting on the radial walls. In addition to these common phloem fibers, large sclereid-like phloem fibers occur sporadically in the layers of phloem fibers and only rarely form a continuous layer (Figure 2.35c).

In cross section these sclereids average 30 μ (tangential) by 50 μ (radial). They are birefringent and show a brilliant full range of interference colors. They commonly show angular markings associated with pits (these large sclereids or phloem fibers are not mentioned in the literature reviewed).

*Changes Due to Fabrication.* Yellow cedar secondary phloem is soaked and extensively beaten during fabrication, which causes disorganization of the tissue and separation into individual cells. Rarely do the layers of phloem fibers remain intact. The fabricated material is fibrous, soft, and light tan in color.

In some cases, crystals of calcium oxalate are present and take on a specific pattern of distribution that reflects their concentrated deposition between cell walls near regions of sieve plates and pits of phloem. The large sclereids are randomly oriented in the disorganized fabricated tissue.

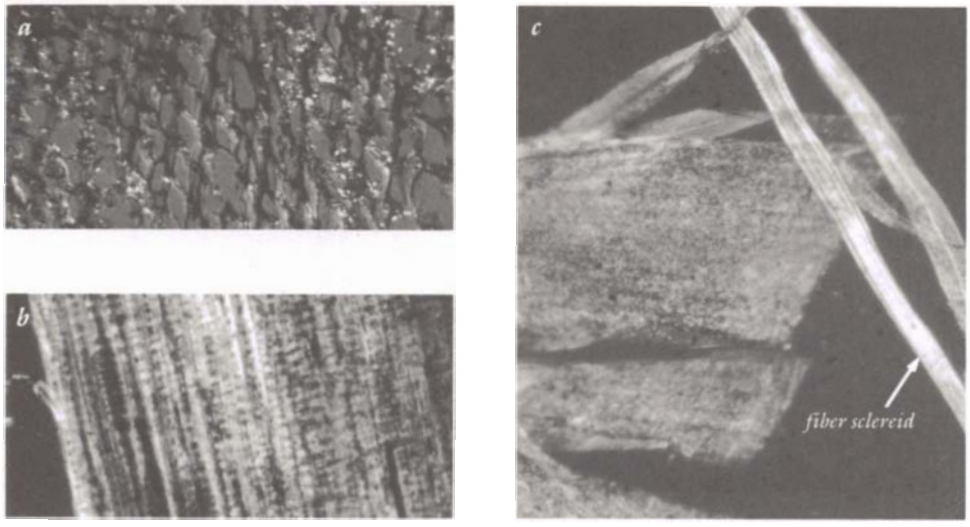



*Figure 2.35. Secondary phloem of yellow cedar,* Chamaecyparis nootkatensis *(Lamb.) Spach. (a) Cross section showing thin-walled phloem fibers alternating with parenchyma and sieve cells. Birefringent calcium oxalate crystals are associated with the tissue, indicating that the tissue was metabolically active when harvested. (b) Tangential surface showing characteristic pattern of deposition of calcium oxalate crystals which identify the tissue as secondary phloem. A few uniseriate phloem rays can be seen in thin sheet of phloem fibers. (c) Tangential surface of secondary phloem and associated large fiber sclereid.*

*Changes Due to Deterioration.* In badly deteriorated tissue, the small phloem fibers may have lost all their birefringence, and it is difficult to determine cell size or shape. The large sclereids retain their normal birefringence and full range of interference colors.

*Summary of Salient Characteristics*

- tissue easily separates into individual cells
- friable, light tan color
- main phloem fiber (undeteriorated) has positive birefringence of white interference color; average cell size is 35 μ (tangential) by 10 μ (radial);
- deteriorated phloem fibers may have negative birefringence
- calcium oxalate crystals may be present and show the typical phloem deposition pattern
- the rare large phloem fibers (sclereids) are randomly distributed; average size in cross section is 30 μ (tangential) by 50 μ (radial); birefringent, with a full range of brilliant interference colors


*Figure 2.36 (left). Tangential surface of secondary phloem of maple,* Acer *sp. (a) Typical pattern of phloem rays in the thin sheet of phloem fibers. As compared to the next microphotograph, the small size of the phloem rays suggests inner or metabolically active phloem. (b) Typical pattern of phloem rays in the thin sheet of phloem fibers. As compared to (a) the large size of the phloem rays suggests outer senile dead phloem.*

*Figure 2.37 (right). Tangential surface of secondary phloem of big sagebrush,* Artemisia tridentata *Nutt., showing typical pattern of phloem rays in the thin sheet of phloem fibers.*

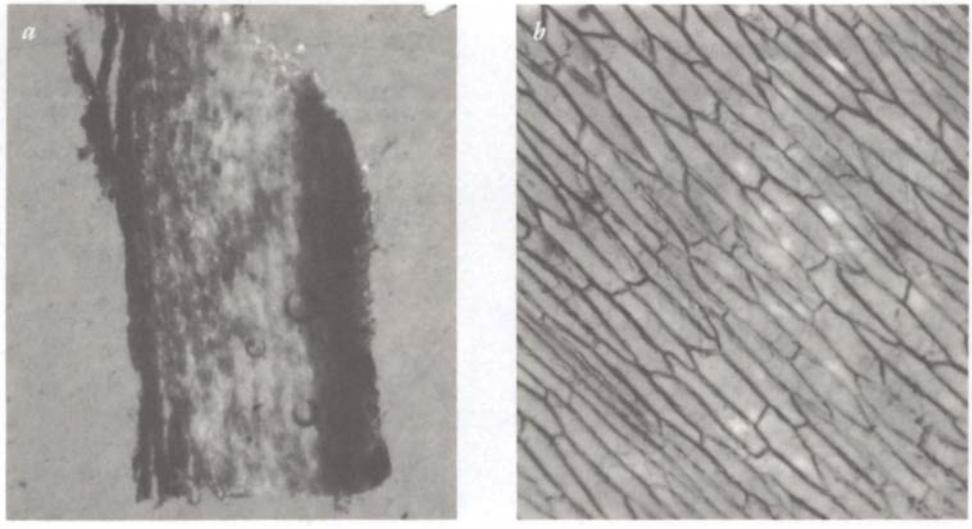



*Figure 2.38. (a) Cross section of cherry,* Prunus emarginata *(Dougl.) Walpers, showing growth rings of collapsed phellem cells. (b) Tangential surface of bark showing shape of phellem cells.*

# Identification of True Bark Tissue

## Laboratory Instructions

1. Prepare wet-mount microscope slides of cross, tangential, and radial sections of:
    - *Prunus emarginata* (bitter cherry) bark
    - *Betula* (birch) bark
2. Observe with transmitted and polarized light and identify the following characteristics with the aid of the photomicrographs and the chapter on plant anatomy:
    - shape of phellem cells
    - compaction of phellem cells
    - early and late phellem cell size variation
    - staining reaction with: toluidine blue, sudan III, and ferric sulfate
3. Record your observations and the details of the staining reactions. Use the detailed descriptions and illustrations to assist in interpretation and identification.
4. Identify the unknown artifact material.

## Introduction

True bark is the smooth shiny outer surface of cherry tree trunks, the white sheets of the birch tree, and the corky chunks of the cork oak. Although different in appearance, all composed of one type of cell, which is waterproofed with the waxy material suberin. Suberin is the main component of cork cells. Cherry bark is used for decoration, but lacks structural strength due to the brittle nature of the compacted cells and the lenticel areas of weakness. Large sheets of birch bark are used in making containers; they, too, lack structural strength and usually require additional support.

## Structure of True Bark

***Prunus emarginata* (Dougl.) Walpers (bitter cherry)**

*Description.* Cherry bark is a true outer bark. The tissue is composed of annual layers of cork (phellem) cells. The walls of the phellem cells are made up mainly of suberin, an unsaturated fatty acid that makes the cell wall impermeable to water and gives the cells a yellow-red color. The phellem cells are oriented with their long axis around the circumference of the tree (the opposite of wood); thus, in tangential sections, the bark appears as a dense tissue of long narrow cells. In radial section, the annual rings of the bark tissue are apparent and the phellem cells are seen as if in cross section. In artifact material, the cells have collapsed and the tissue is compacted. Cross section shows dense long phellem cells in annual rings (Figure 2.38a,b). In radial and cross section, the cells are usually not apparent, but the pattern of the annual ring is obvious by deterioration.

*Salient Characteristics for Identification*. Cherry bark, even when badly degraded, has a distinctive golden to red color. Birch bark can be distinguished from cherry by the distinct variation of cell size and the concentration of pigmentation in the late phellem cells of each annual ring. Filaments of saprophytic fungi or lichen are commonly associated with the tissue and are an aid to identification of bark.

## Identification of Wood Tissue

### Laboratory Instructions

1. Prepare wet-mount microscope slides of cross, tangential, and radial sections of these softwood and hardwood materials:

   *Hardwood*

   - *Quercus alba* (white oak)
   - *Tilia americana* (lime, linden, basswood)
   - *Acer* sp. (maple)
   - *Ulmus americana* (elm)
   - *Carya* sp. (nut)

   *Softwood*

   - *Thuja plicata* (western red cedar)
   - *Pinus* sp. (pine)
   - *Picea* sp. (spruce)

2. Observe with transmitted and polarized light and identify the following characteristics with the aid of the photomicrographs:

   **Cross Section**

   *Hardwood*

   - vessel arrangement/porosity/ring or diffuse
   - pattern/parenchyma or fibers
   - arrangement of parenchyma (at growth rings/around vessels)

   *Softwood*

   - resin canals
   - growth rings
   - parenchyma

   **Tangential**

   - wood rays
   - crystals

   **Radial**

   *Hardwood*

   - vessel pitting
   - perforation plates
   - spiral thickenings in fibers or vessels

   *Softwood*

   - cross-field pitting
   - border pits
   - ray tracheids
   - end wall of ray parenchyma
   - spiral thickenings in tracheids

3. Proceed to wood species identification using the key to wood identification supplied for your specific species. Draw and record your observations. Use the detailed descriptions and illustrations to assist in interpretation and identification; note the following:
    - resin canals
    - end wall of ray parenchyma
    - ray tracheids
    - cross-field pitting
    - spirals
    - others
4. Identify the unknown artifact material.

## Introduction

Wood is the internal supporting structure of trees. It is a specific tissue called xylem, which is made up of a group of cells that function for transport of water and for mechanical strength. The anatomy of the wood varies with species, allowing species identification. The different arrangement and amounts of the cells gives the different structural qualities to the different woods. The variation in the strength characteristics of balsa wood and oak are a result of these different cell arrangements as well as cell structure. But both can easily be identified as wood because of common cell types present and basic organization. The use of split elm is logical because of anatomical features allowing easy splitting. The use of alder or maple for carving is also possible because of the specific wood anatomy.

Wood identification is a discipline in itself. The information presented here illustrates the complexity of wood, the variety of cells present, and the inherent weaknesses of some cells, which may cause conservation problems in artifacts.

## Details of the Anatomy of Softwoods

### *Thuja plicata* Don Donn. ex D. Don (western red cedar)

*Description.* The wood of the branch, root, and trunk has the same anatomical characteristics; thus identification is keyed to species origin of coniferous wood.

*Changes Due to Fabrication.* In fabrication, cedar withes were heated prior to mechanical removal of the bark, then beaten, steamed, worked until soft and pliable, and finally twisted together. The mechanical and physical damage due to fabrication does not interfere with identification of the wood species. Even in badly split branch fragments, true cross, tangential, and radial sections can be made easily, and the salient characteristics used for identification can be observed readily using a water-mount slide preparation.

*Changes Due to Deterioration.* Withes, consisting mainly of sapwood, are prone to chemical or biological deterioration. As a result, the shape of the taxodioid cross-field pits is often altered, but the pattern of deterioration usually reflects the original shapes. Sometimes the pits are not readily apparent, but staining with safranin or toluidine blue does assist in this situation.

Branches often contain compression wood, which is formed by anomalous growth to compensate for branch weight or wind force in order to maintain the normal tree form in relationship to gravity and light. A similar reaction occurs in hardwoods. Compression wood is identified by a spiral pattern of cellulose deposition in the secondary wall in the wood tracheids. These may be easily mistaken for spiral thickening in the tertiary wall, a normal anatomical characteristic of some wood species (Douglas fir, yew), which is used in wood identification.

Sapwood is prone to soft rot in which the fungi filaments selectively lyse the cellulose from the secondary cell wall leaving spiral lytic troughs. These spirals reflect the natural spiral orientation of cellulose fibrils in the cell wall. These spirals also could be mistaken for spiral secondary or tertiary wall thickening, but under polarized light, the spiral lytic troughs show loss of birefringence due to the loss of cellulose, whereas spirals in compression wood and tertiary thickenings show increased birefringence due to the increase of cellulose.

*Summary of Salient Characteristics*

- end walls of ray parenchyma cells are smooth and indentured
- height of wood rays 1 to 12 cells
- taxodioid pits in cross fields (Figure 2.39)
- absence of resin canals
- absence of ray tracheids

***Picea sitchensis* (Bong.) Carr. (Sitka spruce root)**

*Description.* The root wood has the same basic anatomical characteristics as the trunk wood; thus identification keys (Panshin and de Zeeuw 1970, Friedman 1978) based on wood anatomy can be used (Figure 2.40a,b).

*Changes Due to Fabrication.* Bundles of long spruce roots were scorched over a hot fire, enough to heat the wood of the root but not to burn through the bark. Next, each root was pulled through a split stick to remove the bark, then split in half. The halves were pulled over a flat object until they were completely flexible, then dried. Flattening may be due to collapse on drying or mechanical pressure causing cell collapse. Spruce root cordage has a midline on the inner cut surface due to the presence of large coalescent resin canals in the central region that collapse on drying, forming a depression.

The mechanical and physical damage caused by fabrication should not interfere with wood species identification.

*Summary of Salient Characteristics*

- presence of resin canals with surrounding thick-walled epithelial cells
- presence of ray tracheids
- presence of piceoid pits in cross fields
- nodular end walls of ray parenchyma cells

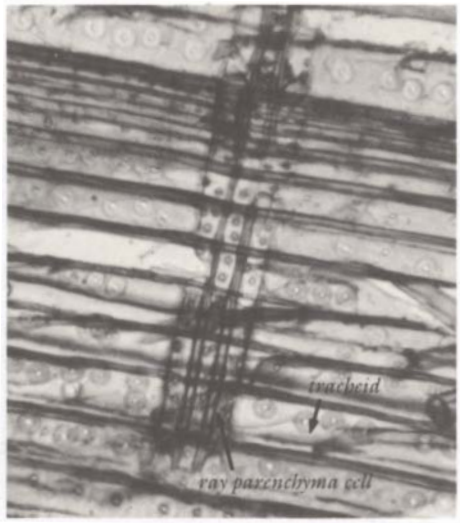
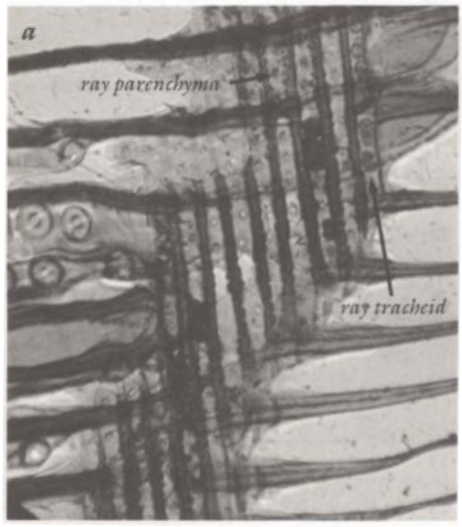



*Figure 2.39. Tangential section of wood of western red cedar,* Thuja plicata *Donn., showing taxodioid pits in the crossfields of the ray parenchyma. The ray parenchyma walls are smooth and ray tracheids are not present.*



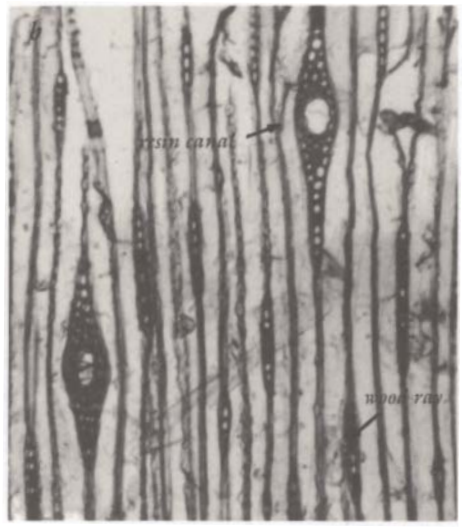




*Figure 2.40. Tangential section of wood of Sitka spruce,* Picea sitchensis, *(a) Piceoid pits in the crossfields of ray parenchyma. The ray parenchyma cells are nodular and ray tracheids with half-bordered pits are on the outside of the ray parenchyma. (b) Two resin canals, with thick-walled epithelial cells, in the wood rays.*

## Identification of Wood Origin (Branch, Root, or Trunk)

### Laboratory Instructions

1. Make wet-mount microscope slides of cross sections of root, branch, and trunk wood of the following softwoods:
   - *Thuja plicata* (western red cedar)
   - *Picea sitchensis* (Sitka spruce)
   - *Pinus* sp. (pine)
2. Observe with transmitted and polarized light and identify the following characteristics with the aid of the photomicrographs and the chapter on plant anatomy. Compare and draw to show differences in:
   - density and width of growth rings
   - tracheid cell size and shape and cell wall thickness

- presence of parenchyma (longitudinal)
- measured width of ray parenchyma cells
- overall shape and section (indication of fabrication)
- resin canals (if present)

3. Make tangential and radial sections of root or branch wood for species identification. Proceed as for wood identification.
4. Identify the unknown artifact materials using the following illustrations to assist in interpretation.

## Details of the Variation in Wood from Branch, Root, and Trunk

The wood of branch, root, and trunk can be easily distinguished. The main differences are the density and size of the cell and their circular or linear arrangement. The wood from trunks or large branches shows the linear, orderly arrangement of the tissue with a gradation from a few layers of smaller thick-walled late wood tracheids to mainly larger thin-walled early wood tracheids.

In the branch (withe), the tracheids are all thick-walled and have an overall orderly and very compact arrangement that—unless it is over several centimeters in diameter—will show circular growth rings.

The root is similar to branch wood in having a circular arrangement of cells, but in the root the cells are larger, have relatively thin walls, are often collapsed, and the overall tissue has an open and disorganized appearance. Resin canals (when present) may be confluent or join together in a row. Often there may be more than the normal (for trunk wood) number of rows of bordered pits in the wood tracheids. The longitudinal parenchyma in roots are very prominent and the width of the ray parenchyma cells is significantly greater than in the wood of trunk or branch. Structural differences among branch, root, and trunk wood are illustrated in Figures 2.41 to 2.47, showing cross, radial, and tangential sections of *Thuja plicata*.

*Figure 2.41 (left). Cross section of a root of western red cedar,* Thuja plicata *Donn., showing loose open tracheids and circular growth rings with a few thick-walled late-wood cells.*

*Figure 2.42 (right). Cross section of a twig of western red cedar,* Thuja plicata *Donn., showing dense thick-walled tracheids and circular growth rings with many thick-walled cells.*

*Figure 2.43 (left). Cross section of heartwood of western red cedar,* Thuja plicata *Donn., showing tracheids and linear growth rings with thick-walled late wood cells.*

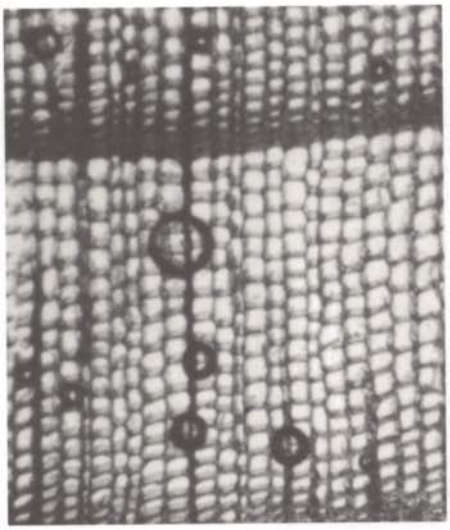


*Figure 2.44 (right). Radial section of root of western red cedar,* Thuja plicata *Donn., showing ray parenchyma cells of the wood ray and tracheids with bordered pits on the radial walls. The wide ray parenchyma cells—as compared to those in the trunk—are characteristic of root tissue.*

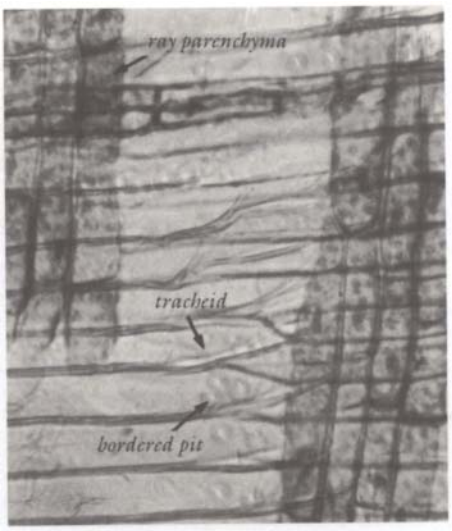



*Figure 2.45 (left). Radial section of trunk wood of western red cedar,* Thuja plicata *Donn., showing narrow ray parenchyma cells of the wood ray and tracheids with bordered pits on the radial walls.*

*Figure 2.46 (right). Tangential section of root of western red cedar,* Thuja plicata *Donn., showing ray parenchyma cells of the wood ray and tracheids with bordered pits on the radial walls. The wide ray parenchyma cells are characteristic of root tissue.*

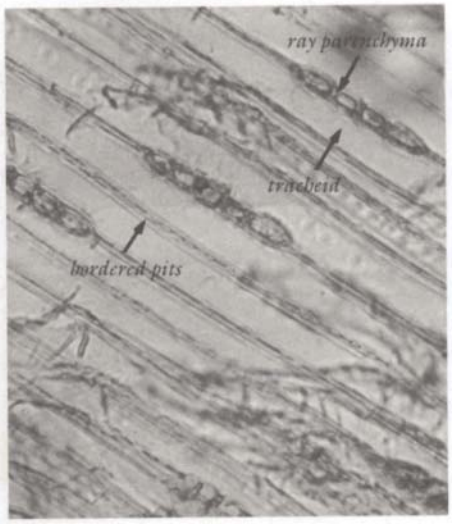
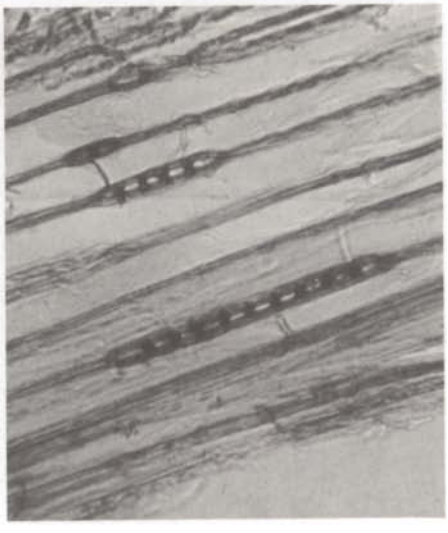



*Figure 2.47. Tangential section of trunk wood of western red cedar,* Thuja plicata *Donn., showing narrow ray parenchyma cells of the wood rays and tracheids with bordered pits on the radial walls.*



# Cited References


**Bally, W.**

1953 Hard fibers (Agava, abaca, and New Zealand flax). *CIBA Review* 99:3542-3564.

**Collings, T. and D. Milner**

1982 The identification of non-wood papermaking fibers: Part 3. *The Paper Conservator* 7:24-27.

**Coville, F.V.**

1902 Plants used in basketry. In *Aboriginal American basketry.* O.T. Mason, ed. U.S. National Museum Report No. 484.

**Friedman, J.**

1959 *Wood identification by microscopic examination. A guide for the archaeologist on the Northwest Coast of North America.* Heritage Record No. 5. Victoria, BC: British Columbia Provincial Museum.

**Hall, W.J. (ed.)**

1951 *Identification of textile materials.* Manchester: The Textile Institute.

**Harris, M. (ed.)**

1954 Handbook of textile fibers. Washington, D.C.: Harris Research Lab, Inc.

**Nutman, F.J.**

1937 Agava fibers, part I: Morphology, histology, length, grading problems. *Empire Journal of Experimental Agriculture* 5:75-11.

**Panshin, A.J., and C. de Zeeuw**

1970 *Textbook of wood technology.* 3rd ed. New York: McGraw-Hill.

**Schaffer, E.**

1981 Fiber identification in ethnological textile artifacts. *Studies in Conservation* 26(3):571-585.

**Turner, N.J.**

1979 *Plants in British Columbia Indian Technology.* British Columbia Provincial Museum Handbook 38.

# Additional Reading

## Monocotyledon Anatomy


**Brown, W.V.**

1959 Leaf anatomy in grass systematics. *Botanical Gazette* 119:170–178.

**Cutler, D.F.**

1969 Anatomy of monocotyledons. In *Juncales*, Vol. IV. Oxford: Clarendon Press.

**Greiss, E.A.M. and K. Naguib**

1954–55 An anatomical study of some sedges in relation to plant remains of ancient Egypt. *Bulletin de l'Institut d'Egypte* 37:235–271.

**Kaul, R.B.**

1971 Diaphragms and aerenchyma in *Scirpus validus*. *American Journal of Botany* 58:808–816.

**Korsno, E.**

1954 *Anatomy of weeds*. Oslo, Norway: Grondahl & Sons.

**Metcalfe, C.R.**

1960 Anatomy of the monocotyledons. In *Gramineae*, Vol. I. Oxford: Clarendon Press.

1963 Comparative anatomy as a modern botanical discipline (with special references to recent advances in the systematic anatomy of monocotyledons). In *Advances in Botanical Research*, Vol. I. R.O. Preston, ed. New York: Academic Press.

1971 Anatomy of the monocotyledons. In *Cyperaceae*, Vol. V. Oxford: Clarendon Press.

**Monoyer, A.**

1933 Contribution à l'anatomie du genre *Scirpus*. *Memoires de la Societé royale des sciences de Leige*, Series 3, 18:1–184.

**Ogden, E.C.**

1974 Anatomical patterns of some aquatic vascular plants of New York. Bulletin #424. Albany, NY: N.Y. State Museum and Science Service.

**Parry, D.W. and F. Smithson**

1964 Types of opaline silica depositions in the leaves of British grasses. *Annals of Botany* 28(109):169–185.

**Plowman, A.B.**

1906 The comparative anatomy and phylogeny of the Cyperaceae. *Annals of Botany* 20 (127):1–35.

**Tomlinson, P.B.I.**
1969 *Anatomy of the monocotyledons. II: Palmae, III: Commelinales—Zingiberales.* Oxford: Clarendon Press.

## Pteridophytes

**DeBary, A.**
1938 *Comparative anatomy of the vegetative organs of the phanerogams and ferns.* F.O. Bowe and D.H. Scott, trans. Oxford: Clarendon Press.

**Ogura, Y.**
1972 Comparative anatomy of vegetative organs of the Pteridophytes. In *Encyclopedia of plant anatomy*, Vol. VII. Berlin: Gebruder Borntraeger.

**Parihar, N.S.**
1965 An introduction to embryophyta. In *Pteridophytes*, Vol. II. Allahabad, India: Indian University Press.

## Potamogetonaceae (Pond Weed, Seagrass)

**Chrysler, M.A.**
1907 The structure and relationships of the Potamogetonaceae and allied families. *Botanical Gazette* 44(3):161–188.

## Laminariales (Seaweed, Bull Kelp)

**Smith, A.I.**
1939 The comparative histology of some of the Laminariales. *American Journal of Botany* 26:571–585.

## Roots and Branches

**Fegel, A.C.**
1941 Comparative anatomy and varying physical properties of trunk, branch and root wood in certain Northeastern trees. In *Bulletin of the New York State College of Forestry Technology.* Publication No. 55. Syracuse, NY: Syracuse University Press.

**Lebedenko, L.A.**
1962 *Comparative anatomical analysis of mature wood of roots and stems of some woody plants.* Translation RTS 2194. Yorkshire: National Lending Library of Science and Technology, Boston Spa.

**Patel, R.N.**
1971 Anatomy of stem and root wood of *Pinus radiata* D.Don. *New Zealand Journal for Science* 1(1):37–49.

## Secondary Phloem (Inner Bark) and True Bark


**Abbe, L.B. and A.S. Crafts**

1934 Phloem of white pine and other coniferous species. *Botanical Gazette* 100:695–722.

**Chang, Y.P.**

1954a Anatomy of common North American pulpwood barks. *Technical Assn. of the Pulp and Paper Industry Monograph Series* (14). New York, NY.

1954b *Bark structure of North American conifers.* Technical Bulletin No. 1095. Washington, DC: U.S. Department of Agriculture.

**Den Outer, R.W.**

1967 *Histological investigation of secondary phloem of Gymnosperms.* Mededelingen Landbouwhogeschool Wageningen. Wageningen, Netherlands: H. Veenman & Zonen N.V.

**Diettert, R.A.**

1938 The morphology of *Artemisia tridentata* Nutt. *Lloydia* 1(1–4):4–74.

**Esau, K.**

1969 The phloem. In *Encyclopedia of plant anatomy*, Vol.V. Berlin: Gebruder Borntraeger.

**Isenberg, I.H.**

1943 The anatomy of redwood bark. *Madrona* 7(3):85–90.

**Jensen, W.**

1949 The connection between the anatomical structure and chemical composition and the properties of outer bark of white birch. *The Finnish Paper and Timber Journal* 31(7):113–116.

**MacDaniels, L.H.**

1918 The histology of the phloem in certain woody Angiosperms. *Journal of Botany* 5:347–378.

**Martin, R.E. and J.B. Christ**

1970 Elements of bark structure and terminology. *Wood and Fiber* 2(3):269–79.

**Srivastava, L.M.**

1964 Anatomy, chemistry, and physiology of bark. *International Review of Forestry Research* 1:203–77.

## Wood Anatomy

**Dale, A.**

1968 *Comparative wood anatomy of some shrubs native to the Northern Rocky Mountains.* Research paper INT. 45. Ogden, Utah: U.S. Department of Agriculture Forest Service. Intermountain Forest and Range Experiment Station.

**Kribbs, D.A.**

1968 *Commercial foreign woods on the American market.* New York: Dover Publications.

**Kukachka, F.**

1960 Identification of coniferous woods. *Technical Association of the Pulp and Paper Industry* 43(11):837–46.

# 3 Technology of Plant Materials Used in Artifacts

*Ruth E. Norton*

Knowing the composition and properties of materials that are used in artifacts, how these materials are processed, and the manner in which they are manipulated and combined in constructing and decorating artifacts is essential to understanding the present condition of an artifact as well as predicting how it will respond to its environment and to conservation treatment. It is equally important to be familiar with the cultural context and use of an artifact in order to be aware of both the alterations that may have taken place through its use and also the intangible properties with which it may have been invested.

A great deal of anthropological literature is available on the processing, construction, decoration, and use of artifacts, based on first-hand observation, informants, and actual examination of artifacts. This invaluable source of information forms the basis of much of our understanding of the artifacts. Until recently, though, there has been very little detailed analysis of the artifacts themselves to find what they can tell us. Canada has led the way through programs like the Native Materials Project of the Canadian Conservation Institute and Florian's work on the examination of materials used in Native American artifacts for identification and evidence of alteration through processing. Work in other cultural areas has been prompted by the need to identify specific conservation problems: for example, the examination of fatty residue on African wood figures (Pearlstein 1986) and the research on *Phormium* species in New Zealand (Christensen 1985).

There is a need to continue this type of examination to gain direct evidence of materials identification, processing, and use. In turn, this is necessary to gain information on artifacts not covered in detail by the anthropological literature, to confirm or question the literature, and to be able to identify the extent of processing and use of specific artifacts. For example, retting and extraction of monocot fibers removes pithy parenchymous tissue. Therefore, microscopic examination of fibers for the presence and quantity of parenchymous tissue may yield information on the extent of processing in the production of particular pieces of cordage. Comparison of the presence of oils and grime, of salt and food residue, and of amorphous plant tissue in unused and used cordage may yield information on how and how much it was used. While it is important to know the literature, it is wise to see what the artifact itself has to say.

It is particularly important to initiate artifact analysis, because conservation treatments may alter, remove, or camouflage that evidence. In this respect, the application of conservation treatment should be considered in the light of whether it is absolutely necessary despite the potential alteration of evidence, or whether no treatment or a purely mechanical treatment would suffice.

Alterations to plant materials are incurred during processing and artifact construction. The effects of these alterations should be considered both from the point of view of the artifact manufacturer—how the process achieves the desired working, functional, and visual properties—and from the point of view of the people now responsible for the preservation of the artifact—how the process may ultimately affect the structural, chemical, and mechanical characteristics and stability of the material. This chapter should be studied while bearing in mind the structure and composition of plant materials detailed in Chapters 1 and 2, and the processes of deterioration discussed in Chapter 4.

Because the composition and structure of different parts of plants are generally distinct and determine both how parts are processed and what artifact types they are used for, it is important to look not only at general processing, construction, and decoration techniques, but also at their application to particular plant organs and tissues. Since the procedures for processing and constructing materials differ regionally, examples are used to illustrate procedures where generalizations would be meaningless or misleading. (The emphasis on Pacific and southeast Asian material reflects the experience of this author.)

As so many plants are utilized, it is not possible to mention—let alone discuss—them all. Therefore, the processing and manufacture of some materials and artifacts that have already received much attention in the literature, like beaten inner barkcloth, are only superficially considered, while other materials and artifacts are looked at in a bit more detail. (Hardwood, softwood and plant extractives, such as resin, latex, and wax, have not been included because of time restrictions in the preparation of these notes.)

# General Processing Procedures

It is difficult to speak generally about the processing of plant materials and their manipulation to construct artifacts, because processing and construction often take place concurrently. Some plant organs also require considerably more processing than others. However, it is useful to look at some of the basic processes in light of their purpose and effect on the materials.

## Cultivation and Harvesting

Cultivation may affect the strength, fiber length, and composition of plant tissue. Some materials, like gourds and bamboo, are purposefully modified in shape during growth.

In some cases the harvesting or collection of the raw material is determined by the environment. In tropical areas, collection may be limited in the wet season when access to the plants and drying are difficult. Some materials are most easily

harvested at particular times of the year. For example, bark is most easily stripped from a tree when the sap is running and the vascular cambium is moist and active. On the other hand, for some materials that exhibit continual year-round growth, harvesting may be done as the need for a particular artifact arises.

Harvesting may also be determined by the maturity of the plant or plant part. Gourds are harvested when fully mature so that the shell will dry hard and durable; immature bamboo splits and collapses severely upon drying, making it unsuitable for many uses. Other plant parts are harvested when immature. Leaf strands for baskets and textiles are collected from the immature leaf shoots of the *Livistonia* and nipa palms, as the strands are then easily stripped from the leaves and are soft and flexible.

The composition, working properties, and durability of the plant material are affected by the harvest time and the maturity of the plant. Drying during wet seasons can result in mold and fungal degradation and staining. The season may affect starch and sugar concentrations in the material. Maturation often involves deposition of lignin, extractives, suberin, and cutin, and thickening of cell walls.

## Drying

Drying plant materials consists of reducing their moisture content in the green state to that at equilibrium with the ambient relative humidity. The effect of lowering the moisture content below the fiber saturation point on the cell wall and on the material as a whole, in terms of shrinkage, cell collapse, and precipitation of starch, sugar, and plant extractives is covered in the literature and in other chapters of this book.

The manufacturer of an artifact must consider how drying is likely to affect the flexibility and density of the material. Rate of drying and position during drying influence cracking, shrinkage, and distortion. Because many plant materials are stored between processing stages, thorough drying is necessary to help prevent growth of mold and mildew.

## Retting and Cooking

Retting (soaking the plant material in water) and cooking (soaking in heated water or alkaline solutions) degrades and/or extracts components of the material. The process involves the extraction of material by solution and leaching, and the degradation of material assisted by bacterial and fungal action. Soaking may be done in running fresh and salt water, stagnant fresh and salt water, and mud. A side effect may be the deposition of metallic and mineral salts from the water and mud into the plant material. Cooking in water or alkaline (usually wood ash) baths augments the degradation of material and increases the amount and type of material extracted—for example, waxes, oils, and pectin may also be extracted.

Retting and cooking are done for a variety of reasons. The degradation and extraction of components may increase pliability and suppleness, and aid the extraction and separation of fibers. Materials may be made more durable; for example, the removal of starch from green bamboo is thought to make it less attractive to wood borers. Retting aids the removal of unwanted soft tissue and components, as, for

example, in the processing of gourds where the inner pulp and bitter extractives are removed. Brief cooking in water lightens the color of some leaves.

## Fiber Extraction

Fiber extraction from monocot stems, leaves, and fruits is the process of separating the unwanted substances and epidermal and parenchymal tissue from the fiber and fibrovascular bundles—referred to collectively as fibers. Extraction is usually done mechanically by stripping, scraping, or shredding. This is sometimes preceded or followed by retting or cooking and usually followed by washing and drying in the sun. Some fibers, such as coconut husk fibers and some agave fibers, are extracted by retting and beating to remove unwanted tissue. The harshness of the mechanical stripping and the presence and amount of retting and cooking affect the extracted fiber. The fiber bundles generally remain intact, but the more strenuous the extraction, the cleaner the fiber—that is, the fiber will contain less extractives, and less parenchymal and vascular tissue will adhere to the fibers. Very mechanically and chemically harsh treatment may cause fraying, fracturing, and weakening of the fiber. Plant fibers differ in the degree of treatment they can withstand without significant weakening.

Inner bark fiber extraction after harvesting involves removing the outer bark. This is usually preceded or followed by retting and/or cooking to remove plant sap, pectin, and gums, making the inner bark more supple, whiter, and cleaner when dried, and aiding the separation of individual fibers. Sometimes, as in the processing of *Touchardia latifolia*, no retting or cooking is involved; the outer bark and sap are removed by scraping.

## Wetting and Heating

Wetting and heating may be done immediately prior to or during manipulation to attain or maintain the suppleness of the plant material. Inner bark fibers are wetted during beating in the production of barkcloth; leaf strands are wetted to keep them pliable during weaving. Given the extended periods of wetting to which many plant materials and artifacts are subjected during processing and use, this brief wetting probably has comparatively little long-term effect on the material, except perhaps the unintentional introduction of any metallic or mineral salts present in the water.

Bark sheets are steamed before bending by placing the green bark over a fire. Changes in the cellular structure and components may result from the internal steam and pressure created; often, charring of exterior material occurs.

## Bleaching

Leaves, fibers, and stems are often laid in the sun for several days to lighten the color. The time of exposure is fairly short, so there may be little degradation of material. (The artifact, furthermore, may spend much of the rest of its useful life in the sun.)

## Dyeing

Dyeing with natural dyes extracted from flowers, fruits, wood, and bark, using wood ash and metallic salts as mordants and color modifiers, and dyeing with all classes of synthetic dyes are practiced on most plant materials. The dyeing process itself may involve cooking in acidic and alkaline solutions. The residual acids, alkalis, and metallic salts are known to affect plant material to varying degrees. Dye-related damage of textile fibers and artifact materials with natural and synthetic dyes is well documented in conservation and industrial literature. Much of the brittleness, fragmentation, and loss of tensile strength that may occur appears to be related to metallic catalysis of oxidation breakage of the cellulose molecule.

# General Construction Techniques

Construction involves the manipulation of materials to build or create a form. This manipulation may consist of removing, reshaping, joining, and interworking materials.

Familiarity with construction methods is important to accurately document artifact construction and to understand the mechanical strengths and weaknesses of artifacts. The latter is essential in determining causes of deterioration, safe mounts and supports in storage and display, and appropriate repair and restoration procedures. For example, examining the corner joints of a painted wood box may lead to an understanding of the cracking and cupping that has occurred to the paint layer in those areas. Some interworked fiber constructions are strong along the horizontal axis while others are weak in that direction and require different support systems. Accurate repositioning of loose threads in the damaged area of a woven bag requires a detailed understanding of the original weave.

Evidence of the type and shape of tools used to remove material may be noticeable on the artifact in the form of characteristic tool marks. Microscopic particles of cutting and abrasive substances may still remain on an artifact's surface. Artifacts that are themselves cutting, incising, drilling, and abrasive tools may also retain particles or fragments of materials that are important in understanding their cultural use.

## Removal of Material

Material can be removed using various tools, each of which may remove different quantities and leave different marks on the material.

### Cutting

The removal of material takes place using flat or shaped blades or a series of fine blades to carve, chisel, engrave, saw, rasp, or scrape. If not removed by further sanding, polishing, or finishing, characteristic tool marks can be seen on the surface: flat or slightly concave facets from knife, adze, or chisel; curved or flat faces depending on the shape of the chisel; rough, nearly parallel or concentric lines of saw teeth as the saw passes through the material. Rasps generally remove material by cutting, but

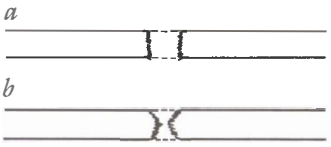



*Figure 3.1. (a) A strip drilled by pressure and abrasion from one side. (b) A strip drilled by the same method but from both sides.*

fibrous material is often left somewhat rough and furry as a rasp both cuts and incises. In removing large quantities of material, cutting may be preceded by burning. in some dugout canoe constructions, for example, the wood of the interior may be charred, then the charred wood removed with an adze.

### Incising

Incising involves using a sharp point to push away material, such as a pointed knife, awl, or stylus to incise writing or decoration on palm leaf manuscripts, bamboo containers, and gourds. Incised lines are generally fine and have rough edges.

### Drilling

Drilling removes material using a rotating bit with a cutting edge or surface. Drills with cutting edges slice away the material. Drills with cutting surfaces use abrasion under pressure to remove the material. These may be dull metal bits that abrade rather than slice; rough bits like coral that have abrasive surfaces; or hard, smooth bits that push and move an abrasive powder, made of added grit or grit removed from the material, which does the actual abrading.

Drilling tools are usually pointed, and the shape of the drilled hole reflects the profile of the point. Holes drilled completely through a material may be drilled from one or both sides. For example, a dense strip of material drilled by pressure and abrasion from one side will be of the same diameter throughout, although the cut fibers may be pushed slightly in the downward direction and the underside fibers may be frayed or splintered. The same strip drilled by pressure and abrasion from both sides will have two clean surfaces, and the hole may be hourglass-shaped, reflecting the shape of the drill point (Figure 3.1).

### Sanding

Fine bits of material are removed by rubbing with an abrasive. Generally, sanding is characterized by coarse to extremely fine parallel or concentric grooves whose size and configuration depend on the rubbing motion, the pressure applied, and the size and shape of the abrasive.

## Reshaping

Reshaping involves moving a solid material into a new shape by molding or modeling rather than removing material to create a new shape.

### Molding

Molding material like wood and bark involves first heating, steaming, or boiling to make the material pliable enough to be bent without breaking. The material must be held or secured in its new position until cool and dry. This is only a semipermanent reshaping, as the material often has a tendency to return somewhat to its original shape. It is usually necessary to secure or restrain the material to maintain the new shape.

### Modeling

Modeling consists of forming or building up a shape with a plastic material. To move a solid material into a new shape, the material must be plastic (malleable) enough to move without fracture or must be made more plastic by the application of heat. Thermoplastic plant exudates, like resins and some waxes, are warmed with the hands or fire, and pushed or built up to make figures and fill areas. Papier mâché, strictly speaking, is not modeling because it involves the use of adhesives to laminate layers of paper, but it is modeling in the sense that the form is built up from material that is malleable in its wet state.

## Joining

Parts may be joined during construction in three general ways. Usually, combinations of these techniques are used.

### Worked Joins

Parts are cut so that they physically interlock. Examples of worked joins include dovetail, scarf, lap, and tongue-and-groove joins. (See Hoadley 1980 and Hayward 1979a, for further information on worked joins.)

### Reinforced Joins

Parts are mechanically secured together with an additional element. Reinforcement may be internal, using pins, dowels, nails, screws, and rivets, or may be external, using strands or cords to lash, wrap, or otherwise bind the parts together.

### Adhered Joins

Adhesives, such as pastes, glues, waxes, gums, and resins, are used to hold the parts together.

## Interworking of Fibers and Elements

In interworked constructions, fibers and elements are combined to create structures. Fibers are interworked to make sheets, thread, and cordage. Elements are interworked in various ways to create structures, such as nets, baskets, mats, and textiles, and are used with similar techniques to join, bind, and decorate structures.

This section is not intended to present an exhaustive catalog of interworking techniques. It is intended only as an introductory guide to their classification. Refer to Emery (1966) and Seiler-Baldinger (1979) for detailed discussions and classifications of interworking techniques.

### Sheet Formation

Sheet formation refers to the production of sheets of felted fibers. Generally, they are produced by laminating thin sections of plant tissue (such as papyrus) by beating intact sections of plant fiber (such as barkcloth and barkpaper), or by casting from a slurry of dissociated fibers (such as paper).

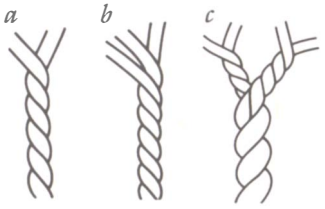



*Figure 3.2. (a) Two-ply thread. (b) Three-ply thread. (c) Re-plied thread: two two-ply threads are spun together, with the direction of twist of the final thread opposite the direction of the two original threads.*

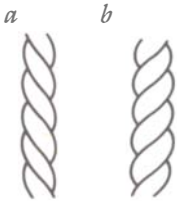



*Figure 3.3. Direction of twist: (a) S-twist, (b) Z-twist.*

*Figure 3.4. Angle of twist.*

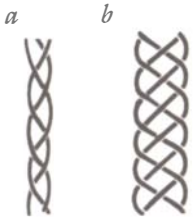



*Figure 3.5. Examples of plaited cordage: (a)three-ply and (b) four-ply.*

Lamination relies on the adhesion of starches and gums present in the tissue and, to some extent, on the interlocking of adjacent tissue crushed during burnishing or light beating.

Beating inner bark fibers spreads and separates the fibers, causing them to intermesh at different angles. The coherence of the final sheet lies primarily in the felting of the fibers, but may be aided by the presence of size naturally occurring in the material and not removed during processing, or by size added during processing (see section on processing inner bark).

Cast paper generally has shorter, highly intermeshed fibers. Sizes may be added to the slurry or to the cast sheet.

## Thread and Cordage

The production of thread and cordage involves the uniting of short, discontinuous fibers to create a long, continuous thread. This is usually done by spinning, plaiting, or knotting.

### Spun Thread and Cordage

Fibers are joined by twisting together in a uniform direction. Spinning may be done by rolling on the thigh, with a drop spindle, or with a spindle turned with a wheel-and-pulley system. Short threads may simply be twisted with the fingers.

Plied thread is made by spinning two or more spun threads together. The plied thread is usually twisted in the direction opposite to that in which the individual threads are spun. Heavy cordage such as heavy-duty rope may be made of threads plied and re-plied a number of times (Figure 3.2).

In describing a spun thread, the number of plies, the direction of twist, the tightness of the twist, and the diameter of the thread are noted. The direction of twist is the direction in which the spun fibers slant as seen when the thread is held vertically, and is designated by slanted lines, \ or /, or by the letters S or Z respectively (Figure 3.3). The tightness of the twist is determined by the angle that the slant of the twist makes with the vertical axis of the thread. Angles up to 10 degrees are considered loose, angles of 10 to 25 degrees are considered medium, and angles greater than 25 degrees are considered tight (Figure 3.4). The diameter is measured at the widest point of the thread. If the thread/cordage varies considerably in diameter, it may be more useful to note the maximum and minimum diameters.

### Plaited Thread and Cordage

Three or more threads or bundles of threads are crossed over one another in the patterns illustrated in Figure 3.5 to make a single thread/cord. A plaited cord is described by the number of plies, the tightness, and the width. The number of plies is the number of threads used. The tightness may be determined by the angle of crossing (in a manner similar to that used for spun thread) or by the closeness of packing of the crossed threads. The diameter or width is described in the same way as spun thread.

### Knotted Thread and Cordage

Fibers or bundles of fibers are knotted end-to-end to make a continuous thread. This technique is typically used with long fibers, such as the monocot leaf fibers, which may be up to 2 m long. Knotted threads are sometimes spun after knotting (see, for example, the discussion of Okinawan banana fiber cloth in this chapter).

## Interworking Elements

The following is only an attempt to present the basic techniques of interworking elements used in constructing artifacts. The variations and embellishments of these techniques are endless. The basic interworking methods are linking, looping, wrapping, and crossing elements. Most constructions involve variations and combinations of these, and using them with different numbers of elements. For example, knots are various combinations of linking, looping, and wrapping.

In constructions like binding, basketry, and weaving, the basic units of fibers used in construction are called elements. Elements may consist of a strand of plant material, a bundle of plant fibers, a spun thread/cord, a plaited thread/cord, or a knotted thread/cord. A strand of plant material is an intact section of plant material, such as a grass leaf, an epidermal split of bamboo or rattan, a strip of leaf, or a strip of inner bark. A bundle of plant fibers is two or more strands or fibers used as a single element, but that have not been spun, plaited, or knotted together. Spun, plaited, and knotted thread/cords are described in the previous section.

Elements are either active or passive based on whether they are moving or are worked around or over during construction. For example, in coiled basket construction, a passive foundation element is bound by an active element that links, loops, or wraps. In macramé, all the elements are active at one time or another, although for particular knots one element may be active and another passive.

Elements may be used singly or in small groups, such as in three-ply twining. A large group of elements that are generally parallel and function identically are called a set of elements. For example, the passive elements in twining are a set of elements.

Interworked element construction may be open or tight. In open constructions, the elements have space between them. In tight constructions (also called close constructions), the elements are drawn tightly together (packed) to create a denser construction.

When examining an artifact to determine its construction, close inspection of the configuration of elements is important, as the general visual appearance of the faces of different constructions can be very similar. For example, the obverse face of horizontal wrapping around a set of vertical elements looks exactly like the obverse face of horizontal three-ply twining around a set of vertical elements, yet the two are quite different in construction. Similarly, the obverse face of a form of wrapping, commonly called wrapped twined weaving, can be identical in appearance to the obverse face of a supplementary element decoration used on twining, commonly called false embroidery.

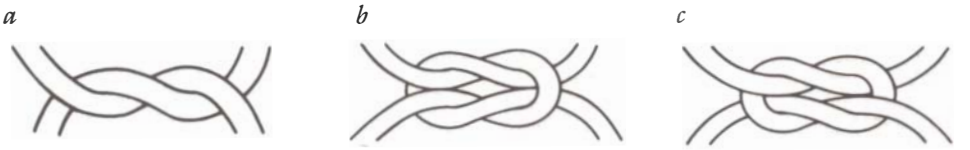



*Figure 3.6. Examples of overhand knots: (a) simple overhand knot, (b) reef or square knot, (c) granny knot.*

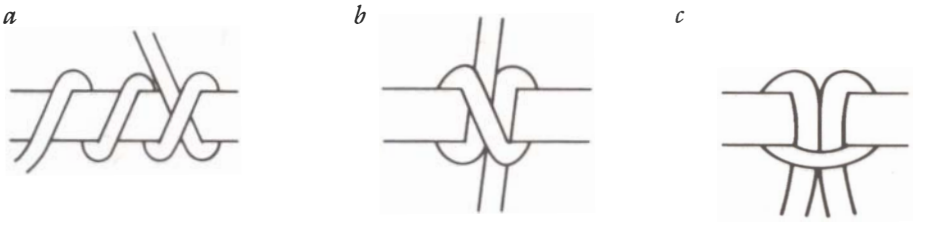



*Figure 3.7. Examples of half hitches: (a) single half hitch used to secure end of binding thread, (b) paired half hitches used in binding, and (c) facing half hitches used to secure tassels and fringes. Facing half hitches may also be used in series with a continuous thread to make netting.*

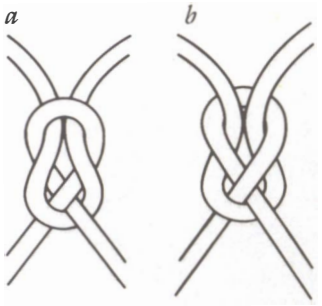



*Figure 3.8. Examples of netting or fishnet knot: (a) and (b) represent opposite faces of the same knot.*

Major interworking techniques for constructing, joining, and binding artifacts include:

- knotting (overhand, half hitch, netting)
- linking
- looping
- wrapping
- coiling (wrapped, looped, linked)
- twining
- weaving (plain, twill, hexagonal, octagonal)
- plaiting

**Knotting**

Knots are used to join fibers and elements, to bind and secure materials, to make nets, and to construct decorative and utilitarian structures. Many knots are used; each may have one or more names. Refer to references such as Ashley (1947) for further information on knot construction and function.

Three of the more common basic knots are:

- overhand knot (simple overhand, reef or square, granny)
- half hitch knot
- netting or fishnet knot

Overhand knots require two active elements (Figure 3.6). Half hitch knots are made with a single active element around a passive element or core (Figure 3.7). The netting or fishnet knot usually uses a single, active element that passes back and forth (or around) to build the net row by row (Figure 3.8).

**Linking**

Linking consists of passing an element over adjacent element(s). Usually, a single active element that passes back and forth (or around) to build the form row by row is used (Figure 3.9). Linked constructions may be very open and stretchy if they are constructed of flexible elements and are loosely constructed. Open, stretchy linking is used for clothing, like gloves and shirts, and for utilitarian artifacts, like carrying bags and hammocks, where a fabric with stretch and give is necessary or desired.

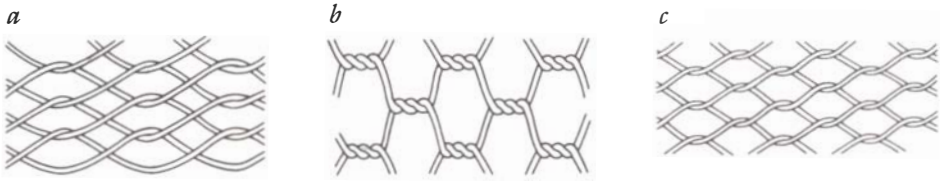



*Figure 3.9. Examples of linking: (a) simple linking, (b) twisted simple linking, (c) interlocked linking—in this example, each row passes over three other rows.*

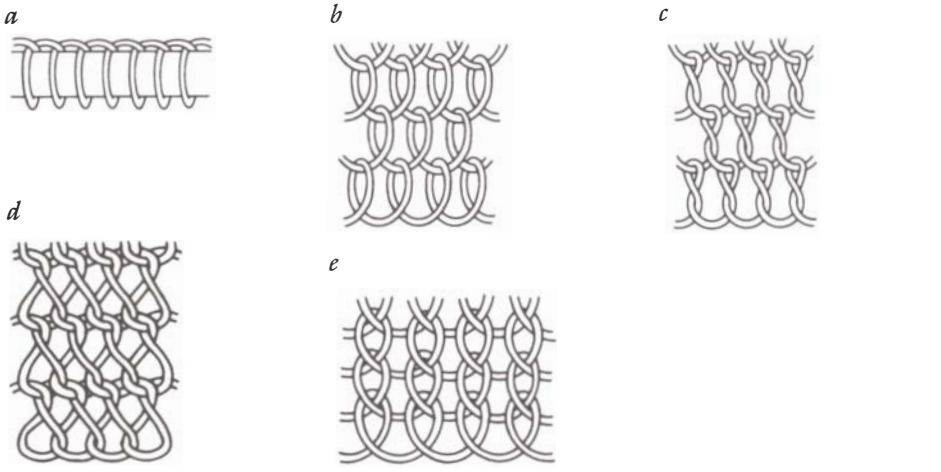



*Figure 3.10. Examples of looping: (a) series of loops around a passive core; (b) simple looping; (c) twisted simple looping, (d) hourglass or figure-of-eight looping, (e) pseudoknit looping (also called crossknit looping or needle knitting).*

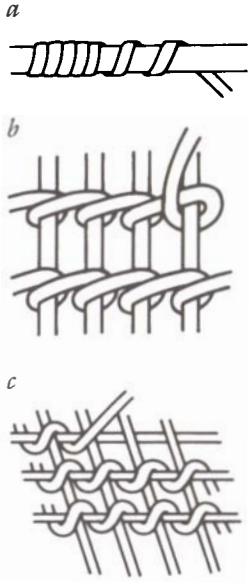



*Figure 3.11. Examples of wrapping: (a) simple wrapping, (b) horizontal wrapping around members of a vertical set of passive elements, (c) horizontal wrapping around two crossed sets of vertical and horizontal passive elements. This construction is often called wrapped twined weaving (for example, see Mason 1904), but it is not true twining or weaving.*

Linked constructions may be dense, and flexible or rigid, if they are constructed of stiff elements and/or are tightly constructed. Tightly constructed, flexible fabrics of spun threads are used for clothing and containers. Tight construction using stiff elements results in a dense, rigid sheet, such as found in some spear grips and guards.

### Looping

Looping consists of passing an element over itself to create a loop. A single active element is usually used. The element may form a series of tight loops around a passive element or core (Figure 3.10a). This construction is found, for example, in button holes and basket rims, and is used to bind edges to prevent unraveling. In the construction of textiles, nets, and basketry, interconnected rows of looping are used (Figures 3.10b to e). Looping in these cases is usually fairly open; however, tight construction, and all degrees between open and tight, are found. Usually, interconnected rows of looping are interconnected, with the loop passing over the thread between the loops of the previous row. In pseudoknit looping (Figure 3.10e), the rows are interconnected with the looping thread passing around the loops of the previous row. Pseudoknit looping is usually fairly tightly constructed.

### Wrapping

A single element may wrap around a passive element or core (Figure 3.11a). This may be functional—to bind and secure material as in basket rims—or may be decorative—to cover structural elements with materials of a particular color or texture.

An active element may wrap around members of a set of elements (Figure 3.11b) or around two or more crossing sets of elements (Figure 3.11c) to join the members and sets. These techniques are used in constructing clothing, basketry, and utilitarian artifacts.

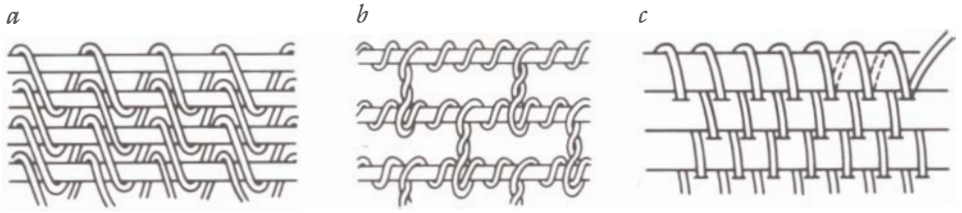



*Figure 3.12. Examples of wrapped coiling: (a) wrapped coiling, (b) wrapped coiling with a twist introduced where wrapping element connects two foundation elements, (c) wrapped coiling with split foundation element.*

## Coiling

In coiling, an active element secures a passive foundation element in position. The foundation is continuous and is coiled to develop the object shape. Coiling is frequently used in basketry constructions, usually with the foundation horizontal. It is also used in constructing many diverse artifacts such as masks, figures, and utensils.

As the active element must be fairly fine and supple, and the foundation elements are usually fairly sturdy and stiff, coiled constructions tend to be weakest between foundation rows, and this is where damage in the form of splitting and breaking of the artifact usually occurs.

There are three basic types of coiling:

- Wrapped coiling. The active element wraps around two or more foundation elements; alternatively, the active element wraps around one foundation and a portion of the adjacent foundation, splitting the foundation (Figure 3.12).
- Looped coiling. The active element loops around the foundation element; the rows of loops are interconnected (Figure 3.13).
- Linked coiling. The active element is linked between or around the foundation element(s) (Figure 3.14).

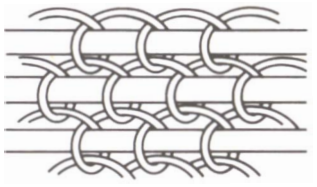


*Figure 3.13. Example of looped coiling.*

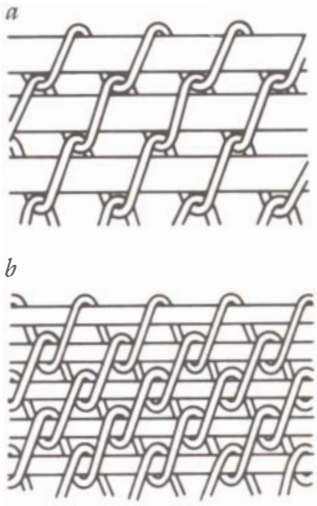



*Figure 3.14. Examples of linked coiling: (a) linked between foundation elements, (b) linked around foundation elements.*

## Twining

In twining, a pair of active elements connect members of a set of passive elements. Two active elements work together as a pair, one going in front of and one going behind each member of the set of passive elements. The pair twists between each passive element, so that, on the next passive element, the one formerly in front goes behind and the one formerly behind goes in front.

Within each row, the twining pair usually twists in the same direction. Successive rows may twist in the same direction (even or regular twist) or alternate rows may twist in opposite directions (alternating or countered twist) creating a different surface texture (see Figure 3.15). The rows of twining pairs may be tightly packed (close twining) or spaced (open twining).

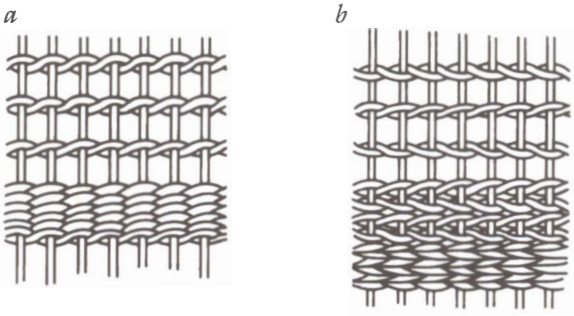



*Figure 3.15. Examples of simple twining: (a) even or regular twist, open and close, (b) alternating or countered twist, open and close.*

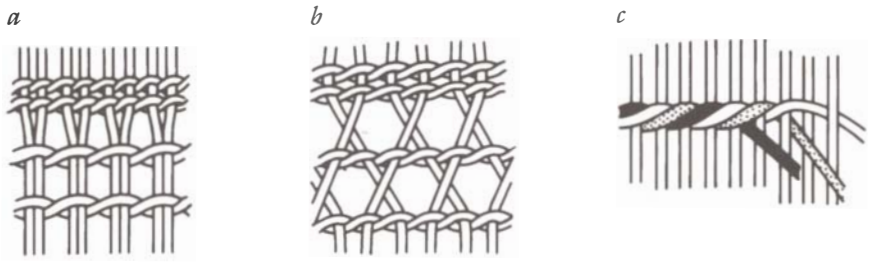



*Figure 3.16. Examples of variations in twining: (a) paired and split passive elements, (b) crossed passive elements, (c) three-ply twining, an example of multiple-ply twining.*

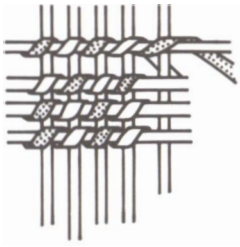


*Figure 3.17. Twining incorporating horizontal and vertical sets of passive elements.*

In basketry and textiles, the set of passive elements is usually vertical and is sometimes called the warp, while the active elements are usually horizontal and are sometimes called the weft (hence the term weft twining).

Variations on simple twining may occur in the passive set of elements (paired and split elements, crossed elements) and in the active twining elements (multiple-ply twining; see Figure 3.16). Another variation involves incorporating an additional set of passive elements horizontally within each twining pair (see Figure 3.17).

As the active elements must be fairly fine and supple, twined constructions tend to be weakest across the twining elements, and damage in the form of splitting and breaking often occurs between the passive vertical elements.

**Weaving**

Weaving comprises sets of elements interwoven parallel and perpendicular to the edge (rim or selvedge) of the artifact. The following examples illustrate weaving techniques used to construct nontextile artifacts. The use of the terms warp and weft have been avoided here as their functional meaning in weaving does not always apply to nontextile weaving. (For information on textile weaving techniques, refer to Emery 1966, Seiler-Baldinger 1979, or to any of the many books available on textile technology.)

Most nontextile weaving is done with two sets of elements crossed at 90 degrees. However, the use of three and four sets of crossed elements is not uncommon in basketry:

- two sets of elements (plain weave, twill weave)
- three sets of elements (hexagonal weave)
- four sets of elements (octagonal weave)

In plain weave (Figure 3.18), elements cross each other in a regular over-one, under-one pattern. Variations include pairing elements, making one set of elements more tightly packed than the other, and using sets of elements of different diameter or width.

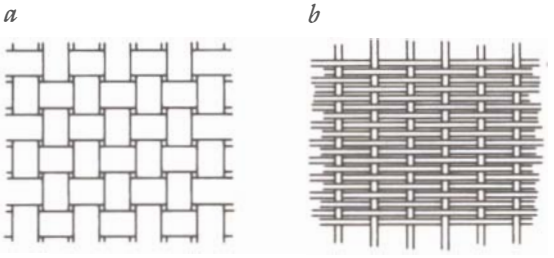



*Figure 3.18. Examples of plain weave: (a) simple plain weave, (b) plain weave with horizontal elements more closely packed than vertical elements.*

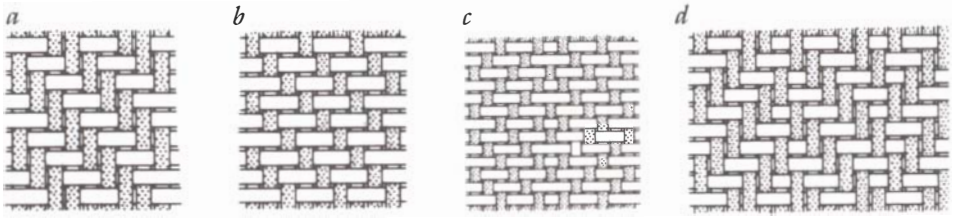



*Figure 3.19. Examples of twill weave (vertical elements are stippled to make the weave patterns clearer): (a) even 2–2 twill, (b) even 2–1 twill, (c) 2–1 diamond twill, (d) 2–2 herringbone twill.*

In twill weave (Figure 3.19), elements of one set cross over two or more elements of the second set. The crossings of successive rows are offset, creating a diagonal pattern (compare Figure 3.19a with Figure 3.18a). Twills may be described by numbers that indicate the number of elements over which and under which a single element runs—for example, even 2–2 twill (over two, under two), or even 4–1 twill (over four, under one). Twills in which the number of elements crossed and the number of elements offset are consistent throughout the weaving are referred to as even twills. Twills in which these are not consistent are referred to as broken or uneven twills. Some broken twills create geometric patterns such as the diamond and herringbone twills illustrated in Figures 3.19c and 3.19d. In many baskets and mats, intricate patterns are created by combining many variations of uneven twills.

Hexagonal and octagonal weaves are illustrated in Figure 3.20.

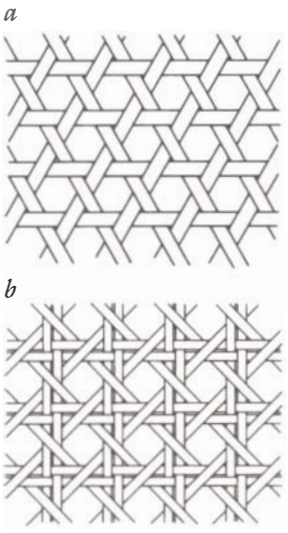



*Figure 3.20. Examples of weaving using more than two sets of elements: (a) hexagonal weave, (b) octagonal weave.*

### Plaiting

In appearance, plaiting looks like weaving with two sets of elements—the only visual difference being that the elements are interwoven diagonally (at 45 degrees) to the edge (rim or selvedge) of the artifact (compare Figure 3.21 to Figure 3.18a). The descriptive terminology used is the same as for weaving.

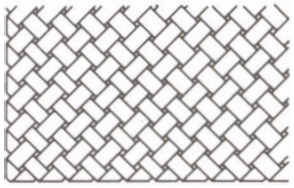


*Figure 3.21. Plain-weave plaiting.*

### Decoration

Decoration may consist of patterns developed by variations in the interworking technique. Examples include variations in twill weaves to develop geometrical patterns, alternation of twist and number of plies in twining to create variations in texture and relief, and crossing, twisting, or splitting passive elements to create open-work.

Decoration may be appendages, such as tassels, feathers, shells, and so on, incorporated during construction. Decoration in the form of different colors and textures may be achieved by using various structural elements or by incorporating supplementary elements (that is, elements incorporated into or added to the structure, but that are not structurally important).

Structural elements introducing different colors and textures may be single or multiple. Discontinuous single elements of different colors are used to create stripes and blocks of colors, as seen, for example, in the New Guinean *billum* (a carrying bag usually constructed by looping). A single flat element may also be of different color and texture on either side; this can be found in elements of split stems and some barks where the epidermal side is smooth and shiny and the interior side is fibrous and matte and of a different natural or dyed shade. If an element such as this is twisted 180 degrees when twining or wrapping, for example, the different sides are exposed. The same effect can be achieved by pairing flat elements of different colors and twisting them.

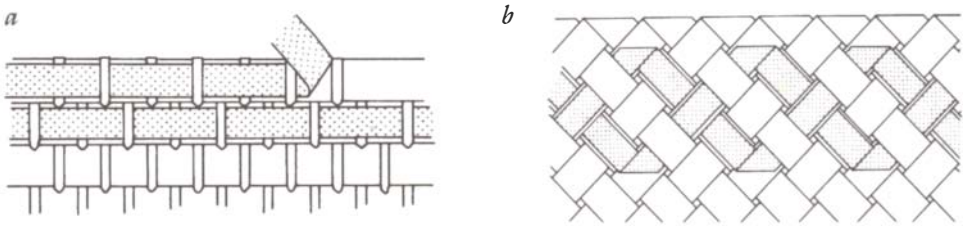



*Figure 3.22. Examples of overlaid supplementary element decoration (supplementary elements are stippled): (a) supplementary element overlaid on split foundation wrapped coiled construction, (b) supplementary element overlaid on plain-weave plaited construction.*

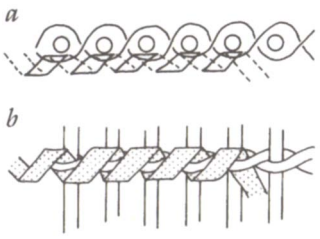



*Figure 3.23. Example of wrapped overlaid supplementary element decoration. Supplementary element wraps around obverse element of twining pair (supplementary elements are stippled): (a) cross section of (b) obverse face.*

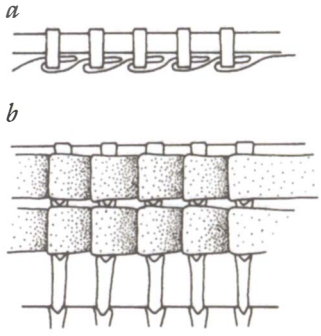



*Figure 3.24. Example of imbrication. Supplementary element folds around obverse portion of wrapping element in wrapped coiled construction (supplementary elements are stippled): (a) cross section of (b) obverse face.*

Supplementary elements incorporated into coiling, twining, weaving, and plaiting techniques are common. Three of the frequently used incorporation techniques are overlay, wrapped overlay, and imbrication. Overlaid supplementary elements lie on top of structural elements and are held in place by going under some structural elements. Figure 3.22 illustrates examples of overlaid decoration in coiled and plaited constructions. Wrapped overlay supplementary elements are those that wrap around the obverse face portions of structural elements. Figure 3.23 illustrates an example of this, which is sometimes called false embroidery. Imbrication, illustrated in Figure 3.24, is found in coiled constructions. The supplementary element completely covers all structural elements on the obverse face.

### Edges

Edges may be finished in a variety of ways. Some result from the natural turning of elements during the course of construction, such as edges in knotting, coiling, and looping, and some of the edges in plaiting and weaving.

Other edges consist of the cut ends of elements and must be finished in some way to prevent unraveling. Finished edges vary from very simple to extremely complex construction, but all are based on the basic construction techniques previously described:

- introducing one or more rows of multiple-ply twining below cut ends
- folding element ends back and working them into the construction
- looping around element ends or around top rows of construction; or looping with the element ends
- wrapping the element ends; top rows of construction may be included in the wrapping
- plaiting with or around element ends; top rows of construction may be included in the plaiting

## Decoration and Finishes

Decoration may be structural—that is, incorporated into the structure of the artifact during basic fabrication—or may be applied—that is, added to the structure after basic fabrication. Finishes are used to modify the surface texture, sheen, color, and permeability of the artifact. Finishes may be either worked or applied.

### Structural Decoration

Structural decoration is added to the basic structure at the time of construction and is incorporated into the structure. (Refer to discussion in previous section.)

Decoration may consist of supplementary elements (bundles, strands, or cordage used to create color patterns or differences in texture) interworked in the structure. Some examples are imbrication in coiled basketry, overlaid elements in plaited or woven work, and doubled elements of different colors in twined work. Other decorative elements such as feathers and tassels may be knotted or woven into the structure at the time of construction. Structural decoration may also include patterns impressed or embossed into the surface.

### Applied Decoration

This consists of decoration applied to, rather than incorporated into, the basic structure. Applied decoration includes: material (like feathers, tassels, fringes, quillwork, beading, and shells) that is attached with thread or cordage (see Seiler-Baldinger 1979 and Buck 1927,1950,1957 for examples of specific techniques used); thread, cordage, and fibrous strands that are stitched to or around the artifact in embroidery-like fashion; and decorative elements (such as metal foils, paint, shells, feathers, and other plant materials) that are adhered to the surface.

Dyeing has been included in general processing procedures because, more often than not, it is done before or during construction. However, dyes may also be applied after construction—either by soaking the material in a dye bath or by rubbing dye over its surface. Some dyeing techniques, such as those using wax, folding, and sewing resists, are done after construction.

### Applied Finishes

Applied finishes include added materials that sit on and/or penetrate into the surface, like oils, varnishes, resins, lacquers, wax, and paint. (Note: Resins and waxes may be applied to artifacts to seal joints or to waterproof. In such cases they should be viewed as a functional part of the artifact construction, not just as a decoration or finish.)

### Worked Finishes

Worked finishes result from techniques, like polishing and burnishing, which actually move the structural material to create a particular texture and sheen.

## Cultural Modification of Artifacts

Cultural modification of an artifact is as important as its initial fabrication. Artifacts are inevitably modified during use. Smoke, dirt, and oils are deposited on and absorbed into the surface; handling can further burnish these to a hard, smooth patina. Clothes absorb body oils and dirt and develop creases and folds when worn. Abrasion, nicks, and scratches occur during use. Food residue is deposited on and in containers, utensils, and cooking vessels. Tool surfaces may contain minute deposits of the plant, animal, and mineral materials which they worked. Artifacts associated with religion and ritual may be anointed, buried, and repainted.

Broken and damaged artifacts may be discarded or repaired. Repair may consist of alteration using different materials—as in the use of resin to mend cracked wood vessels—or may consist of reconstruction using the same or similar materials—as in the reweaving of damaged areas in a mat.

Artifacts may be modified in form as their ownership or use changes. For example, a food-collecting basket strap originally used as a tumpline may be replaced with a hand-held one as food sources change from those gathered to those purchased at market.

Some artifacts are not only physical documents of a culture, but have inherent or invested powers and properties within their cultural context. These intangible properties of an artifact, although not cultural modifications of the physical fabric of the artifact, are important properties related to cultural use and context and must be considered in the handling, treatment, and accessibility of the artifact.

# Plant Materials Used in Artifact Construction

Parts of a great number of plants are utilized in the manufacture of artifacts. The morphology, anatomy, and composition of organs of major plant groups are fairly distinctive and determine the physical properties of those organs. It is therefore most useful to consider the processing and use of plant material according to the major organs used (stems, trunks, roots, leaves, seeds, fruits) and, within those organ types, according to major plant groups (dicot, monocot, gymnosperm, and lower plants). Because processing and use within these groups vary culturally and with the particular plants utilized, specific examples illustrate processing, construction, and use where generalizations would be of little value. (Refer to comments on the organization and content of this section in the introduction to this chapter.)

## Stems, Trunks, and Roots

The seasoning, conversion, and working of woody tissue is well covered elsewhere and will not be discussed here. (Refer to introductory texts on wood technology and finishing for the decorative arts, such as Hoadley 1980 and Hayward 1978, 1979a, 1979b, and to monographs on the material culture of specific cultural groups.) The whole bark is used extensively in artifact production by some cultural groups. Its use is discussed through examples: the use of birch bark in the northern hemisphere and the use of stringybark and paperbark in Australia. The processing and use of the inner bark for cordage and sheet production is discussed in general terms; the reader is referred to the literature on the material culture of specific cultural groups for further information on plant sources, processing, and use. Monocot stems are important sources of material for domestic and commercial products. Their processing and utilization are illustrated using bamboos, rattans, and sedges. The stem and adventitious root system comprising the trunk of the tree fern are given as examples of the use of lower plants in artifact production.

## Bark

Bark is used relatively intact in the production of artifacts and is also an important source of fiber. The use of inner bark fibers alone will be discussed in the next section; here the use of the whole bark or of the outer bark only will be discussed. The form of the layers in the rhytidome (outer bark) is the most distinguishing characteristic of bark utilization. Also of importance is the bark's stripability along phellogerms or along the vascular cambium. Barks used in artifacts are usually those with very thin, broad sheets, like birch, cherry, and paperbark, and those that are very fibrous, like cedar and stringybark.

### Birch Bark

The bark of the paper birch (*Betula papyrifera*) was extensively used by some Native North American groups for utilitarian and religious artifacts. After the arrival of the Europeans, artifacts in European styles and incorporating trade materials were also made. Gilberg (1986:68) describes birch bark scrolls made by a religious fraternity of the Ojibway people. The outer bark was stripped around the circumference or, occasionally, down the length of the tree. Sheets of bark were sewn together with split spruce root or bast fiber cord through holes punched in the overlapping edges to achieve scrolls of the desired length. Ends of the scrolls were often bound with endsticks. Pictographs were impressed or incised on both sides of the bark, though usually on the cambium side, using sharp implements. Occasionally, scrolls were rubbed with red ocher or vermillion, or particular images were painted on them.

In India, birch bark has been used for manuscripts for over two thousand years. Agrawal (1984:13,16–17) writes that the inner bark (probably referring to the inner surface of the bark) was used for writing. First, the bark was peeled off the tree and dried. The surface was then oiled and polished to produce a smooth writing surface. Finally, the sheets were cut to the desired size. Most sheets were kept loose between wooden boards; sometimes the sheets were folded and bound or were pierced and threaded like palm leaf manuscripts. Smaller sheets were folded and worn in amulets. The usual writing material was carbon black ink prepared by boiling carbon from burned almond shells with cow's urine.

Rymar (1978:1–3) reports that the use of birch bark in Russia in buildings, kitchen utensils, and household objects predates its use as manuscript material in the ninth century. The manuscripts are found as scrolls. Processing of the bark as described by Rymar is not altogether clear. The bark was stripped off "an ungnarled part of a birch of medium thickness growing on solid rising ground" and was scoured (boiling in hot water for one hour is recommended). In the eighteenth century only the innermost layer was used to make thin manuscripts; earlier manuscripts from the Novgorod area are thicker. Writing was done by impressing or incising the inner surface with pointed bone, wood, or metal tools.

### Stringybark

The Australian Aborigines utilized whole sections of bark for dwellings, canoes, containers, paintings, and religious figures, and bark strands for binding, cordage, costumes, and containers.

Stringybark (*Eucalyptus* sp.; *E. tetradonta* is the most frequently cited) is thick and fibrous. (Refer to Chattaway 1955 for a detailed discussion of the anatomy and composition of Eucalyptus bark.) It is stripped from the tree by cutting the desired section at the top and bottom with a sharp tool, slitting down the sides with a pointed stick, and levering off the sheet. The whole bark, from the vascular cambium outward, is removed and is fairly pliable when green. It is often placed over a fire to aid in flattening and shaping it for use in artifacts such as canoes and bark-paintings; the heat and steam generated in the green bark make it more pliable.

Canoes of stringybark vary in design from simple, large (3 m to 5 m) sheets of bark with pointed ends to those with bound and shaped ends and thwarts. Sandale and Peterson (1969) document a canoe made in Arnhem Land in Northern Australia for use in marshlands that was 2 m to 3 m long and about 1 m wide. A large stringybark tree with a long straight trunk was used. The lower cut in the bark was made about shoulder height and the upper cut was made by standing on a forked tree ladder. One longitudinal split was made with a long pointed pole by inserting the end under the bark of the lower cut and pushing it up the length of the tree to the upper cut. The whole bark was peeled off around the circumference of the tree using the pole as a lever. The sheet of bark was trimmed to the desired length at the tree site and carried to the edge of the marsh. A hearth was made on the wet ground with material from an old termite mound, and a small fire was started. One third of the bark was placed inner side down over the fire; after a while, the bark was turned placing the outer side down. When considered sufficiently pliable, the end was lifted from the fire, folded in half lengthwise, and wedged between two stakes placed upright in the ground a couple of inches apart. The tops of the stakes were bound together to pull the two halves of the bark end tightly together. Binding strands were stripped from the inner bark side of stringybark and trimmed to the desired size—several millimeters thick and about a centimeter wide. Slits were pierced through both layers of bark, and the binding strand was sewn through them with back stitches. The stern complete, the process was repeated to form the bow. However, for the bow, grass was placed between the bark halves to make a tighter join, and the top corner of bark was trimmed before the end was sewn. The bark was then trimmed further to make the bow pointed. A thwart was made by tying a stringybark strip across the middle of the canoe and inserting a stick under it. When in use, the canoe rides very high in the water; the spread of the middle bows the canoe so the bound ends ride above the water line (see also Thomson 1939).

Altman (1982:14) describes contemporary painting on bark by the Gunminggu men in the Northern Territory, Australia. Sheets of stringybark are collected in the dry season; they are flattened by briefly heating them over a fire and by weighting them on a flat surface for several days. The inner bark surface is smoothed with sandpaper. Top and bottom ends may be bound between two sticks to help prevent warping. Figures are sketched in with white paint using a thick brush made from stringybark. Red ocher, yellow ocher, and charcoal black paint are applied with a very fine brush made of trimmed grass. The paint binder used is either a poly(vinyl acetate) emulsion or acacia gum. Contemporary artists' painting methods vary with regional and individual styles. Older barks were painted with

pigments bound with a variety of media, such as natural gums, orchid tuber juice, or egg yolk, which yielded generally very lean, matte paints.

Dawson (1881:14) describes the water bucket made by Aborigines in Victoria, Australia, "formed of a sheet of fresh acacia bark, about twenty inches long by twelve broad, bent double and sewed up at each side with kangaroo tail sinews, and the seams made water-tight with an excellent cement, composed of wattle gum and wood ashes, mixed in hot water. After the bucket is made it is hung up to dry, and the contraction of the inner bark causes the vessel to assume a circular shape which it retains ever after. It is carried by means of a band of twisted wattle bark fixed across its mouth." Similar buckets made from stringybark on Bathurst and Melville Islands are painted with red and yellow ocher, white, and carbon black pigments (McCarthy 1974:49).

### Paperbark

The Australian paperbark (*Melaleuca* sp.; *M. leucadendron* is the most frequently cited) has thick bark, the rhytidome of which consists of many layers of thin, broad sheets. The bark is used to make sandals, containers, knife sheaths, religious figures, canoes, and so on. Knife sheaths were made by Western Australian Aborigines by wrapping wide strips of the paperbark around blades and securing them by tightly wrapping with spun cords made of human hair. White pigment was applied over much of the wrapped areas. Sorcery figures about a meter long were made of strips of paperbark folded and wrapped to shape. Final bindings to secure the paperbark were done with sturdier, more fibrous bark. Appendages of wrapped paperbark were secured with wool yarn.

## Inner Bark

The inner bark of some plants contains considerable quantities of thick-walled sclerenchyma fibers. These are extracted and utilized universally. Fiber length, composition, strength, and overall color and texture differ considerably according to the fiber source and processing.

Inner bark fibers are primarily (1) used intact or separated into strands that are used as is for decoration or binding or are spun into cordage, (2) beaten into sheets (barkcloth, barkpaper), or (3) soaked and beaten to produce pulp for casting sheets (paper).

Inner bark fibers are collected from both cultivated and noncultivated plants. If the plants are cultivated, it may be because they are an introduced species, because a ready supply is desirable, or because cultivation is necessary to produce particular qualities. Depending on regional tradition, the bark is harvested either by stripping it from the living plant or by cutting the plant and removing the bark. Preliminary processing generally involves removal from woody tissue, removal of outer bark, and retting or cooking. The order in which these things are done varies considerably, depending on tradition, fiber source, and end use.

### Decoration, Binding, or Cordage

Unbeaten inner bark strips from the *sachi* tree (*Aguilaria agallocha*) are used for manuscripts in India. Processing varies regionally, but involves soaking or boiling, removal of outer bark (in one area it is lightly beaten), drying, dyeing with sulphide

of arsenic, and polishing (sometimes with a paste or oil size) or sanding (Kathpalia 1966:57–58).

The inner bark of *Hibiscus* sp. and members of the nettle family (Urticaceae) are used for decoration, binding, and cordage. After retting and drying, hibiscus inner bark readily separates into thin sheets that are used for decorative tassels and applied decoration and are spun into cordage. The inner bark fibers take dyes readily. The inner bark of some nettle species (for example, *Touchardia latifolia, Pipturus* sp., and *Boehmeria* sp.) is cleaned immediately after stripping from the plant by scraping both sides to remove the outer bark and push out sap. When dry, narrow strands are torn off and spun.

**Barkcloth and Barkpaper**

Beaten inner bark sheets are/were made in the Pacific area, Central and South America, Asia, and Africa. Although the inner bark of many plants has been used to some extent for beaten barkcloth or paper, those most commonly used appear to be paper mulberry (*Broussonetia papyrifera*), fig (*Ficus* sp.), breadfruit (*Artocarpus* sp.), and, to a lesser extent, members of the nettle family (Urticaceae).

*Steps in Processing Barkcloth and Barkpaper*

1. Removal of outer bark. This is usually done when the bark is fresh and may be preceded by soaking or retting.
2. Processing of inner bark. There may be no special processing or it may consist of soaking, retting, cooking, or preliminary beating.
3. Beating. Pounding between hard surfaces separates and spreads and, to varying extent, breaks fibers. Beater and anvil materials vary; they usually consist of wood and/or stone. Patterns on the surfaces of the beater vary depending on the stage of beating and desired texture. Degree of beating varies considerably, ranging from very stiff, thick sheets with little fiber reorientation, to very thin, gossamer sheets with fine, short, very reoriented fibers. Final beating of flat or rolled sheets is important to the texture of finished sheet.
4. Joining of beaten strips. Strips may be joined in a number of ways:
    - felting: beating strips together, may be parallel or crossed
    - pasting: using paste (usually a starch, sometimes a gum) to join sheets edge over edge
    - sewing: joining strips by stitching
    - combined techniques: for example, several sheets may be stacked and felted together to make a thicker sheet that is joined to others by pasting or sewing; sewing is also used to reinforce sheets
5. Decoration. Some of the techniques used for finishing and decorating the sheets include:
    - dyeing of the whole sheet, localized areas (rubbing over pattern board), or surface only (rubbed on, dyed layer felted on)
    - application of paints: freehand, stencilled, stamped, lined
    - collage: pasting cut design onto sheet

- oiling: saturating with drying or semidrying oil
- sizing: applying plant starch or gum
- perfuming: applying essential oils
- polishing: burnishing with stone or shell
- applying decorative elements: feathers, shells, coconut shell disc, cloth and beaten bark tassels, etc.
- joining layers of full sheets by sewing

*Uses*

Barkcloth sheets are used for bedding, clothing, ceremonial presentations, burial, manuscripts, paintings, and so on. Barkcloth is also used in the construction of three-dimensional artifacts in which it may be molded around wood, used in basketry or figures, or folded and bound for containers and wrapping. Finally, strips of barkcloth sheet are spun for binding and cordage.

A great deal of detailed literature is available on beaten inner bark sheets, including crosscultural and local anthropological studies as well as publications of national museums and crafts councils in countries producing barkcloth and barkpaper, to which one can refer for information on manufacture in specific areas. For examples of such sources, refer to Koojiman (1963,1972), Kennedy (1972), Mosuwadoga (1978), Bell (1983), and Wilcox (1985).

### Paper Cast from Pulp

The process of pulping and casting fiber to make paper is mentioned here because it is an important use of inner bark fibers—and of monocot stem and leaf fibers such as those from bamboo, banana, and palms. Cast paper has been made and utilized for centuries for manuscripts, clothing, and modeling. For further information, refer to the history and technology of papermaking literature.

## Monocot Stems

The stems of monocots utilized for artifacts range from fine wisps to large rigid poles. Anatomically, they are most readily characterized by long, dense longitudinal fibers and fibrovascular bundles, often closely packed toward the epidermis of the stem. The resulting physical properties of longitudinal strength and suppleness, ease of splitting longitudinally, and smooth dense exterior have made them an invaluable resource for the production of artifacts. The value of some, like bamboo and rattan, is readily evident not only in the quantities utilized, but in the variety of construction techniques used and the variety of end uses to which they are put—from major buildings to intricate jewelry. The processing and manufacture of artifacts from bamboo, rattan, and sedge are discussed as examples of the utilization of monocot stems.

### Bamboo

Bamboos are members of the Poaceae or grass family, growing singly or in clumps and ranging in size from very short and thin species to species with heights of up to 23 m and culm diameters of up to 23 cm. Like most monocots, they exhibit only primary growth. Culms reach full size in a matter of months, but take several years to mature. Maturation consists of hardening and strengthening through thickening

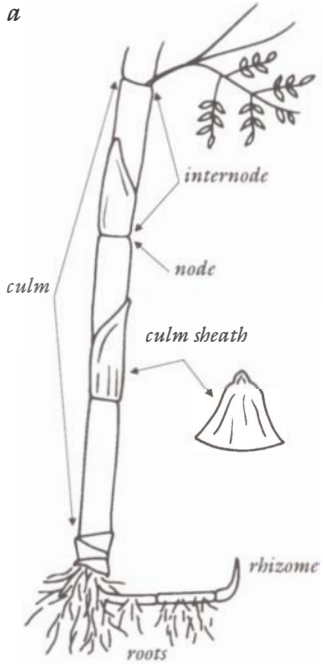



*Figure 3.25. The anatomy of bamboo: (a) major organs, (b) longitudinal section of culm at node, (c) cross section of culm wall showing outer area with very dense, small, undeveloped fibers and fibro-vascular bundles.*

of cell walls, increasing crystalline orientation of cellulose, lignification, and deposition of silica.

The major organs of bamboo (Figure 3.25a,b) are the culm or stem of usually hollow internodes and solid nodes from which grow the culm sheaths, branches and leaves, and flowering organs. The root system comprises a dense tangle of fine rootlets and thick rhizomes. Although most parts of the bamboo are used, the culm is the most widely utilized part for the construction of artifacts.

The culm consists of longitudinally oriented fibrovascular bundles in a matrix of parenchyma tissue (about 50% parenchyma, 40% fibers, and 10% vascular cells; Liese 1980a:161). The fibrovascular bundles at the outer surface are small, closely packed, and primarily fibrous (Figure 3.25c). The fibrovascular bundles of the major part of the stem are fairly regularly spaced, and the vascular tissue is fully developed. The arrangement of the fiber sheaths surrounding the vascular tissue differs between genera and can be used to identify individual bamboo genera (Liese 1980a:162–163). The exterior surface is usually a single layer of epidermal cells covered with a thick waxy coating; the inner surface is a layer of sclerenchyma fibers.

Most movement of material through the culm is longitudinal, with radial conducting tissue occurring only to a minor degree at the nodes, a feature that greatly affects seasoning and penetration of preservatives. In some cases, the high silica content on and within bamboo tissue makes the material difficult to work. Because bamboo is an important commercial crop for the construction, handcraft, and paper industries in many countries—especially in Asia—the composition and properties of bamboo have received considerable attention (see Lessard and Chouinard 1980 text and bibliography for composition, extractives, fiber structure, moisture content, strength, and so on).

### *Modification During Growth*

The shape, color, and sheen of bamboos vary widely from species to species and are exploited in artifact creation (for examples, see Marden 1980:516–521). The shape and color of bamboo may be modified during growth and immediately after harvesting. Sharma (1980:118) reports: "Japan has successfully grown artificially shaped bamboos ... A wooden frame (mould) is made in the desired shape, and it is installed on the young bamboo shoot. After about six months the frame (mould) is removed from the bamboo, which has taken on the desired shape. The culm is cut when it matures ... In Japan and Taiwan ... a mixture of sulfuric, nitric and hydrochloric acids with water and clay is prepared and painted over the green culm with a brush; this produces ornamental patches on the culm."

### *Harvesting*

As immature culms are very prone to cracking on drying and have not attained full strength, the harvesting of mature culms seems preferable. In most areas, bamboo grows year round and can be harvested at any time. Recommended harvest time appears to be related more to drying and seasoning factors than to bamboo growth. In Japan, the best season for harvesting is late fall, thus avoiding insect damage (especially *Dinoderus minutus*); insect attack is most severe from April to June (Lessard and Chouinard 1980:49). For commercial harvesting in the Philippines, *bolos* (large heavy iron knives) and hatchets are used. "Culms, three or more years

old, are ready for harvesting, those of unarmed bamboos usually being cut close to the ground and those of bamboos such as *Bambusa blumeana* being cut 2-3 m. above the ground (just above the dense growth of spiny branches ... the very thick-walled portion of the culms being left in the clump). Harvesting is usually done during the dry season, from November to May" (Lessard and Chouinard 1980:78–79). Harvesting practices for noncommercial, home use of bamboo may differ.

*Seasoning: Drying, Traditional Seasoning, Commercial Seasoning*

Seasoning involves not just drying of the culm, but processing to improve its durability. Seasoning is generally concerned with reduction of splitting upon drying and with improving the culm's resistance to insects and fungi.

Drying is usually done in the open air by laying the bamboo on the ground or by stacking in well-ventilated areas. Care must be taken against too-rapid drying, which can lead to splitting, cracking, and collapse, or too-slow drying, which can lead to fungal and bacterial attack with resulting staining and loss of cohesion and strength. Successful drying appears to be species- and age-related and presumably is dependent on the density and moisture content of the green culm. Studies by the Indian Forestry Research Institute (Lessard and Chouinard 1980:42) on air drying of nine species indicate that drying was complete in three months of clear weather. The mature culms of four species dried with little cracking; other species and all immature culms suffered severe cracking and collapse. Accelerated drying over open fires is also reported, and the use of kilns has been investigated for large-scale commercial interests.

Tamolang et al. (1980:198) report that care must be taken in placing or stacking drying bamboo to prevent the development of bends. Bent green culms can be straightened by weighting them during drying, either by placing them horizontally under weights or by hanging them vertically with weights tied to the bottom end; this takes two to four months. A faster method is to "hold the curved portion over a charcoal fire or to apply a blowtorch to it. Care must be taken to prevent the culm from being scorched. Cooling is best accomplished by the application of a cold wet cloth."

The most common (or at least the most frequently mentioned) traditional seasoning is aimed at making the bamboo less attractive to insects, particularly the powder-post beetle, *Dinoderus minutus,* by reducing the starch and sugar content of the bamboo. Liese (1980b:166) mentions an investigation on bamboo harvested during the dry season and after flowering when the starch contents were depleted, which claimed that the extent of beetle damage was related to starch content. However, he felt that further investigation is necessary.

Tamolang et al. (1980:197) recall that: "It is the common belief of carpenters that flies swarming over green and newly worked bamboo are a sign that the particular bamboo is not durable. Soaking bamboo in seawater or running water for two to three months [several weeks was reported elsewhere], as practiced in the rural areas, reduces its starch content and, consequently, lessens its attractiveness to the beetles." Of the soaking method, Liese (1980a:169) warns that, though commonly practiced, it "does not increase the durability against termites and fungi and that the submergence in water may lead to staining of the bamboo." He relates another method of reducing the culm starch content by cutting the culm at the base

but leaving the branches and leaves intact for some time (1980a:168). The leaves continue to assimilate starch stored in the stem, thereby reducing its content.

Traditional seasoning methods in Malaysia are reported to be either immersion in water to remove food substances by fermentation or smoking over a fire (Lessard and Chouinard 1980:94). Liese (1980b:168) also notes that culms are sometimes stored above fireplaces and become black with smoke deposit. He suggests that toxic agents in the smoke may inhibit insect attack or that the heat may break down the starch.

Commercial seasoning is directed toward increasing the bamboo's resistance to cracking and to insect and fungal attack. Studies were done in India to reduce cracking of bamboo culms used for handcrafts (Lessard and Chouinard 1980:42). Whole green culms of *Dendrocalamus giganteus* were soaked in 50% solutions (presumably aqueous) of polyethylene glycol-1000. No times were related, but after treatment, no cracking occurred with air drying.

From the moment of harvesting, bamboo is very susceptible to attack by termites and the powder-post beetle, and by brown rot, white rot, and soft rot fungi. Commercial processing at the time of harvesting aims to inhibit biological attack by the application of residual inhibitors and biocides. The application of chemicals, such as creosote, boric acid, zinc chloride, copper sulfate, mercurials, Chlorden, Dieldren, and DDT, has been reported. The main difficulty encountered is in developing practical and economically feasible methods of achieving effective penetration of the preservative into the green bamboo tissue. Surface treatment is inadequate because of the dense and waxy outer layer of the culm. Penetration by soaking and by forcing the preservative through the vascular tissue with gravity or pump pressure has proved effective and feasible in the field. The consequences of treatment of bamboo to be used for handcrafts and for cooking and food handling do not appear to have been considered.

*Uses*

All parts of the bamboo are used: the leaves for thatching, fodder, and paper pulp; the culm sheath in lining hats and sandals; the shoots for food; the sap for medicinal purposes; and the culm for anything and everything. Even the rhizome is utilized: "The rhizome of *D. hamiltoni* with slight trimming and dressing, is an exact replica of a rhinoceros horn, which fetches a fabulous price as an aphrodisiac. Only an expert can differentiate between the imitation rhino horn and the real; this nefarious use, however, needs to be discouraged" (Lessard and Chouinard 1980:34).

Bamboos are among the most versatile plant materials in existence. Table 3.1 indicates some of the ways in which humans have taken advantage of bamboo's remarkable adaptability.

*Table 3.1. Species of bamboos and their uses in Indonesia (excerpted from Lessard and Chouinard 1980:66).*

| Species | Building Material | Tobacco Smokehouses | Baskets | Furniture | Handicraft | Fishing Tool | Firewood | Water Pipe | Traditional Customs | Edible Shoot | Musical Instrument | Paper Industry | Medicine | Ornamental Plant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Arundinaria japonica* | | | | | | | ■ | | | ■ | | | | ■ |
| *Bambusa arundinacea* | ■ | | | | | | ■ | | | ■ | | ■ | | |
| *B. atra* | ■ | | ■ | | | | ■ | | | | | | | ■ |
| *B. blumeana* | ■ | | ■ | | | ■ | ■ | | | ■ | | | | |
| *B. glaucescens* | | | | | ■ | | ■ | | | | | | | ■ |
| *B. polymorpha* | ■ | | | | | | ■ | | | ■ | | | | |
| *B. vulgaris* | ■ | | | ■ | ■ | | ■ | | | ■ | | | ■ | ■ |
| *Dendrocalamus asper* | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | | | |
| *Dinochloa scandens* | | | | | ■ | | ■ | | | | | | | |
| *Gigantochloa apus* | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | | | |
| *G. atter* | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | | | |
| *G.* aff. *atter* | ■ | | ■ | ■ | ■ | | ■ | ■ | | ■ | ■ | | | |
| *G. verticillata* | ■ | | ■ | ■ | ■ | | ■ | ■ | | ■ | ■ | | | |
| *Nastus elegantissimus* | ■ | ■ | | | | | | | | | | | | |
| *Phyllostachys aurea* | | | | | ■ | | | | | | | | | ■ |
| *P. nigra* | | | | | | | | | | | | | | ■ |
| *Schizostachyum blumei* | ■ | ■ | | | ■ | ■ | ■ | | | ■ | ■ | | | |
| *S. brachycladum* | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | ■ | ■ | | | |
| *S. caudatum* | ■ | | | | | | | | ■ | | | | | |
| *S. lima* | ■ | | | | ■ | ■ | ■ | | | ■ | ■ | | | |
| *S. zollingeri* | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | | | | |
| *Thyrsostachys siamensis* | | | | | | | ■ | | | | | | | |

Whole sections (usually an internode plus one or both of its adjacent nodes) and radially split sections of bamboo are used as is; they may be cut, carved, incised, dyed, polished, lacquered, or painted. To take dyes, oils, and many applied surfaces, it is necessary to remove the cuticle and sometimes the very dense exterior. Normally whole sections are taken from the culm. Exceptions to this practice include, for example, fine net undershirts made in China in which very small tubes, probably taken from branch internodes, are used. During construction of the net with fine thread, short lengths of very thin internodes are strung onto the thread between each knot as shown in Figure 3.26 (Lubke 1969:21).

Tangentially split strips, usually including the epidermis or the layer just below it, are used in binding, weaving, and basketry construction techniques. The split strips are strong and flexible. Sometimes they are soaked, steamed, and heated just prior to using to make them even more flexible. Subepidermal splits receive dyes well. Bark, wood, leaf, and tuber extracts, burial in black mud (resulting in an iron

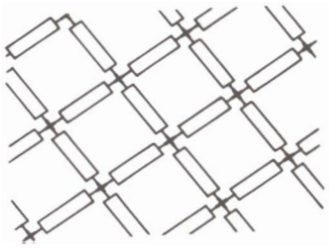
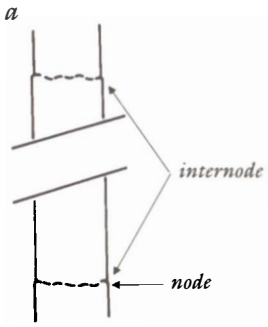


*Figure 3.26. Detail of Chinese net undershirts with bamboo internode tubes.*



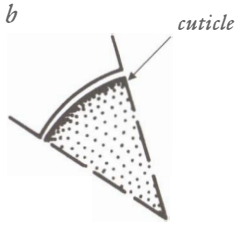




*Figure 3.27. The anatomy of rattan: (a) rattan stem with leaf sheaths removed, (b) segment of cross section of stem showing evenly spaced fibrovascular bumdles.*

tannate black), commercial dyes, soot with vegetable gum and resin, and natural resins have been used to dye and varnish the splits.

Bamboo culm fibers are used for textiles in some areas (Lubke 1969:21). Young culms are split, soaked, and peeled to expose the fibrous inner tissue. This is chewed, dried, and scraped to extract the fibers. The fibers are tied end to end to make continuous thread.

**Rattan**

Rattan is the collective name for climbing members of palms in the tribe Lepidocaryoideae. Rattans occur in tropical forests and vary in habitat and size from small undergrowth species to large climbing species with stems well over 100 m in length. The stems consist of solid nodes and internodes and are covered with several layers of spiny leaf sheaths (the spreading base of the leaf petiole that wraps around the stem), each sheath covering several internodes. Leaves vary considerably in size, shape, and length of petiole. Flowering organs consist of flowers on branches emerging from at least one major bract (modified leaf that envelops the developing flowering organ and often a series of smaller bracts). Refer to Dransfield (1979:7–16) for discussion of the general morphology of organs.

The rattan stem consists of solid internodes and nodes. Except for the base and tip, it is fairly consistent throughout its full length in diameter, internode length, and density. The internodes consist of vertical fibrovascular bundles surrounded by parenchyma tissue. The fibrovascular bundles are more densely packed near the epidermis (see Figure 3.27).

The epidermis is dense, heavily sclerified and cutinised, may have a very high silica content, and is covered with a waxy cuticle. The vascular tissue and epidermis are somewhat disarranged at the nodes to accommodate growth of the leaf, climbing organs, and flowering organs. The evenness of distribution of fibrovascular bundles in the core, the density and lignin content of the core and epidermis, and the degree of sclerification and silica deposition in the epidermis vary from species to species, resulting in differences in flexibility, strength, and brittleness.

*Uses*

Most of the organs of rattan are utilized to some extent. Dransfield (1979:27) comments that stem uses are so legion that any catalog other than the broad categories of matting, furniture, cordage, basketry, and utilitarian objects would be incomplete. The spiny leaves, petioles, and climbing organs are variously used for graters and traps. Dragon's blood—a deep maroon resin exuded by the fruit scales of a few rattan species—is used as a dye and varnish. Refer to Dransfield (1979) and Menon (1980) for further details on regional utilization of rattan.

*Collection and Initial On-Site Processing*

Most rattan is collected in the forest. The base of the stem is cut, the stem pulled down from the forest canopy, and the upper, immature portion discarded. The spiny leaf petioles are loosened and removed by twisting or bending the stem and scraping. During this process, the brittle outermost layer of heavily sclerified and silicified epidermis may also be removed. If this cleaning cannot be done immediately after harvesting, the canes are soaked to keep them moist until they can be

cleaned. The cane is cut into uniform lengths of up to several meters and dried quickly in the air or over a fire to prevent staining by fungal growth.

*Processing*

Rattan for commercial use may undergo further processing to make it cleaner and to give it greater durability. Menon (1980:25–30) reports that, in Indonesia, rattan may be washed, or washed and fumigated with sulfur dioxide, or washed, fumigated, and boiled in mud or mixtures of diesel and coconut oil. The canes are then polished and air dried to a moisture content of 5% to 10%. In Singapore and Hong Kong, rattan imported from Indonesia is further treated with aqueous sodium hypochlorite and hydrogen peroxide solutions and gaseous sulfur dioxide to alter and even its color. In Malaysia, canes are boiled in mixtures of coconut, diesel, and palm oil and in India they are rubbed with linseed oil. Boiling in oil is believed to reduce the canes' moisture content and to make them more durable by removing the natural gums and resins. Washing, fumigation, and bleaching are done to improve the canes' appearance.

Rattan is sold whole or is split to separate strips of the outer layer of the stem from the core and sold as split and core rattan. Refer to Dransfield (1979:20–30) and Menon (1980:41–42) for more information on splitting and grading rattan and on preferred rattan species for commercial use.

In villages, basket weavers would collect their own rattan, or purchase it from a local collector, and no further processing other than cutting, splitting, and trimming to prepare elements of the desired size appears to have been done.

In preparing rattan to weave a *bango*, a woven backpack made by men of the Ifugao Province, Philippines, lengths of bamboo about 3 m long and 5 cm in diameter were purchased locally. These were cut to 1 m lengths. The exterior portions were split off and trimmed to the desired size by shaving with a knife. The core of the rattan was cut into thicker strips for the base and external ribs of the *bango* (Ng 1978:37–38). The rattan strips (epidermal splits) of baskets of this type are generally about 5 mm wide and 1 mm thick, and all those examined were thinned by shaving off the core side of the strips and were woven with the epidermal surface on the exterior of the basket. The only epidermal areas removed were the slight bulges just below the nodes.

Designs in woven work are created by the weaving pattern and the use of dyed strips contrasting with the natural color. Courtenay and Chadwick (1983) report that, unlike bamboo, the rattan cuticle is said to dye well. The Punan of Borneo dye rattan red with the extract of boiled rattan seeds and black with the boiled roots and leaves of tarum. Courtenay and Chadwick further report that rattan basketry and mats are highly valued and damaged ones are mended with great care and skill.

### Sedges

Sedges are herbaceous monocot perennials in the family Cyperaceae. The sedge stem is three-sided or cylindrical with a shiny epidermis and a pithy interior. The stem diameter is fairly constant over most of its length.

The stems of sedges are used primarily for making mats and baskets and sometimes for coarse nets and binding. Buck (1957:131–134) records the use in

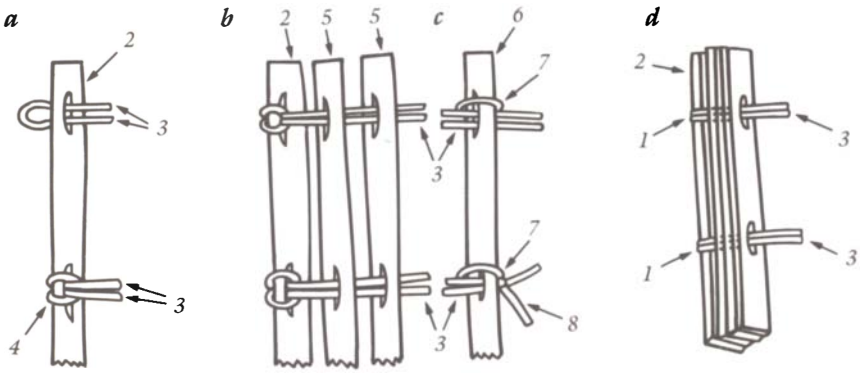



*Figure 3.28. Technique of rush mats: "(a) doubled end (1) of* hau *(*Hibiscus *sp.) string was pushed through a slit made in first strip (2) forming the commencement edge, and the free ends (3) were drawn through the loop as in (4) to fix the string; (b) double string (3) was passed through slits made in each succeeding strip (5) until the required width of the mat was attained; (c) one of the two strips (3), after passing through the slit on the last strip (6) made a complete turn (7) around the strip and the two ends were knotted together (8); (d) in the completed mat, the strips were drawn close together so that the surface was formed of the edges of the opened out rushes and the connecting weft strings (3) were concealed except for the loops (1) on the first strip (2) and the knotted ends on the last strip" (Métraux 1940:211).*

Hawaii of *'aka'akai* (*Scirpus validus*) to make coarse floor and bedding mats (which are reported to be not very durable) and the use of *makaloa* (*Cyperus laevigatus*) to make very fine flexible sleeping and clothing mats. The stem was usually cut to length and flattened, making a flat weaving element with both faces a smooth epidermal surface. The width of the element produced by simply flattening the stem varied from stem to stem and from species to species. Flattened elements were also split lengthwise to make narrower elements. Mats were plaited in plain and twill weave and decorated with colored supplementary elements overlaying the foundation elements. Buck was not certain whether young or old stems were used and whether they were used fresh or dry.

Métraux (1940:210–211) reports that sedges (*Scirpus riparius*) were used on Easter Island to make baskets, headdresses, fishing floats, sleeping mats, cloaks, and thatching. Sedge for weaving was split and dried, then split into strips with the thumbnail. Sedge for heavy mats was split open with the thumbnail and allowed to dry for a few days; then the pith was scraped out with the thumbnail. Heavy mats were constructed in a manner similar to Venetian blinds or palm leaf manuscript bundles (see Figure 3.28).

## Other Trunks

Tree ferns are large arborescent ferns such as *Dicksonia* and *Cyathea* ferns, with a thick trunk consisting of an inverted cone of woody vascular tissue surrounded by leaf petioles and a close, intermeshed network of fine (up to 2 mm diameter) but dense adventitious roots (Figure 3.29).

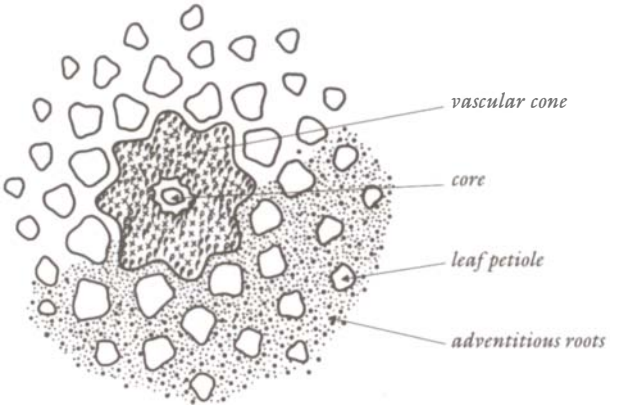



*Figure 3.29. Cross section of a tree fern trunk. The vascular cone is a convoluted ring of xylem (x) surrounded by phloem (p).*

The trunk is used in Southeast Asia and Melanesia for carved figures; some figures include appendages, paint, and costume. A sorcery figure believed to be from the Kainantu area, Eastern Highlands, Papua New Guinea, was 50 cm in height and 24 cm maximum diameter. The torso and head were deeply carved from the tree fern trunk. The woody core of 7.5 cm diameter was visible at the base; no core was visible at the top and no leaf petioles were visible. The arms and legs were formed of monocot leaves and barkcloth wrapped around wood sticks, and secured by inserting the pointed end of the sticks 3 cm to 5 cm into the torso. The diameter of the sticks was about 1.5 cm; it was not clear whether a hole was carved to seat them or whether they were just pushed into the mass of adventitious roots. The figure wore a barkcloth and spun-cordage loincloth and a spun-cordage-and-feather headdress.

The tree fern trunk torso and head of a Temes Malu dance mask from Malekula, Vanuatu, was 122 cm long by 32 cm maximum diameter. The lower two-thirds of the back were removed and the torso and most of the head hollowed out, leaving the front and sides of a thick (6 cm) wall. The woody core was visible only at the crown of the head and no leaf petioles were visible in the walls. Appendages—legs, arms, genitalia, nose, and forehead protrusion—were constructed of a very open-network monocot material wrapped around split bamboo sticks about 1.5 cm in diameter, and were secured by inserting the pointed end of the stick 4 cm to 5 cm into the tree fern trunk. The entire exterior of torso, head (excluding crown, which was covered with a conical hat), and appendages was covered with a very coarse fibrous putty about 3 mm thick. This putty was also used to model facial features and a navel. The putty surface was then painted with very matte red, white, and black paint.

From these figures, it appears that, although the tree fern trunk is not very dense, it is strong enough to support itself and its appendages even when deeply carved, and the mesh of adventitious roots is compact enough to be able to be cut into fairly distinct features. (See consolidation section of the chapter on conservation for observations on the long-term durability of the cut adventitious roots.) Because leaf petioles were not visible in these figures, it might be surmised that the dead leaf petiole is lost quite close to the woody core and that the larger, older sections of trunks used for figures are composed primarily of a thick mass of intermeshed adventitious roots around a woody core.

## Leaves

Although gymnosperm, dicot, and monocot leaves are all used in artifact construction, the monocot leaves are the most versatile and heavily utilized. Reasons for this may lie in their generally greater size and durability, but probably more importantly in the strength, suppleness, and ease of splitting imparted by their long, parallel fiber and fibrovascular bundles. Whole leaves as well as particular sections of monocot leaves, such as the midrib, sheathing base, and fiber, are used. Modified leaves, such as the culm and branch sheaths of bamboo, are also used to some extent. Examples of material from some of the more important plant groups are used to illustrate processing and construction techniques employed in artifact manufacture using leaves.

## Gymnosperm Leaves

Gymnosperm needles, especially pine needles, may be found intact or processed to loosen fibrous tissue. Intact needles are bundled to form elements in interworked basketry constructions. Needles are also retted and/or beaten to break up nonfibrous tissue that may be slightly or wholly removed from fibers. These fibers are spun and plaited for use in interworked element constructions.

## Dicot Leaves

Dicot leaves occur infrequently in artifacts. Generally they are small and have low tensile strength and folding endurance; many are brittle when green, and most are very brittle when dry.

In the few cases where this author has seen dicot leaves in artifacts (a Fijian skirt in which brightly colored croton leaves were incorporated by binding the petiole into the plaited waist band, and an Indian leaf plate in which fig leaves were pinned together with bamboo pins), the leaves were used when green and at their most supple, and the artifacts were intended to be ephemeral. No processing of the leaves was apparent in these cases.

## Monocot Leaves

So many monocot leaves are used for so many purposes that it would be impossible to mention them all. They are used whole, and without processing, for thatch and some baskets and mats; the leaf blades are cut and folded for ornaments, cut and seasoned for manuscripts, and soaked, flexed, dyed, and split for weaving. Although almost any monocot leaf has probably been used by someone at some place and time for some purpose, most processing techniques and uses can be illustrated with two of the monocot groups most widely used: *Pandanus* sp. and palms.

### *Pandanus*

Leaves of different type and quality are selected for specific purposes. For mats, the best, unblemished leaves are selected, while older leaves are left for thatching or for coarse mats. The leaves used for fine mats may be of a species with particularly fine supple leaves, or may be selected for their natural color tones of beige and brown.

Initial processing involves drying (usually in the sun), sometimes boiling or soaking, and softening before and/or after drying by various means, including passing the green leaves over a low fire, winding around the fingers, and rubbing with hard tools. If not to be used immediately, leaves are stored dry (in the Pacific, usually wound into rolls and tied).

Color is achieved by overlaying other colored plant material during weaving, overlaying or weaving with brown pandanus, or dyeing the pandanus. Natural dyes are extracted from various fruits, barks, and tubers; mineral mordants and dyes are used. Dyeing often involves heating, boiling, and steaming of the leaves. Synthetic dyes are also used.

Leaves for weaving are usually split into narrow strips with fingernails, points, or blades. Splitting between the epidermal surfaces provides thinner strips and allows the strips to curl for round basket elements. Not all pandanus is found

on basketry and mats; it is a versatile wrapper and binder. As variations in the uses of these general processes depend on the cultural group and the type of object, it is more useful to examine a few specific examples than it is to generalize further.

In 1981, Ewins (1982:2–6) observed and described the processing of leaves for fine sleeping mats on the Fijian island of Gau. *Voivoi* (*Pandanus caricosus*) is planted in small, semishaded gardens in wet but well drained sandy soil. Harvesting can begin three years after planting. A plant, with proper care, can be harvested for about twenty years, after which it becomes tall and the leaves are shorter and not desirable for weaving. The lower leaves—almost two meters in length—are cut off close to their base and carried to the village. Most preparation of the leaves for weaving—trimming, drying, bleaching, dyeing, and softening—is done immediately after harvesting. The leaves are trimmed to remove the sharp thorns along the leaf edges and the underside of the midrib. A sharp blade (a knife, a shaped piece of tin can, or a shaped black mussel shell) is inserted at the base under the unwanted parts and pulled the length of the leaf. At this stage leaves that are to remain light brown are dried; leaves to be lighter in tone are boiled vigorously for five minutes before drying. (Longer boiling would brown the leaves, not whiten them.) Leaves are hung or laid on the ground in the sun until dry. Some leaves are dyed black to be used for overlaid supplementary weft decoration. The leaves are buried in swamp mud (in taro paddies, for example) for two nights, washed in fresh water, and boiled with the dye plants. Several recipes were observed using different leaves requiring different boiling times (from one to six hours). After boiling, the leaves are rinsed in fresh water and dried in the shade. Finally the leaves are softened and made more supple by rubbing with a hard tool, usually the edge of a large shell. Softening by coiling leaves and beating on the circumference of the coil with a wood beater on a stone anvil is sometimes done. The leaves may be used immediately or rolled into large coils for storage or sale. Prior to weaving, the leaves are split into strips 2.5 cm to 4 cm wide. Each of these strips is further split into narrower strips (usually, four) leaving them joined at the base at about 15 cm. Mats are plaited or woven, and decoration finally worked, usually at the sides and edges, with black pandanus and colored wool. Designs and techniques are described (Ewins 1982:6–21).

Pandanus preparation and dyeing for mats, baskets, and fans in the Cook Islands has been described by Buck (1927:106–107,121–123). Leaves are chosen from species of pandanus with smooth edges and midrib, cultivated especially for mats, baskets, and fans. The cut leaves are hung in the sun to dry. The leaves curl as they dry; to flatten them, they are rolled and also rubbed with a shell. They are stored in a large roll until needed. Before plaiting, the leaves are rubbed again, making them softer and more flexible. They are split longitudinally into six or eight strips with a sharp pointed tool. The midrib and edges are discarded. Decorative borders are made with overlaid black and red strips. One type of black strip is obtained from plantain leaves. The black outer skin of the leaves is peeled off, and pithy material on the underside is scraped off. The leaves are dried and split to the desired width. The other type of black strip, as well as the red strips, are dyed pandanus strips. Pandanus leaves are prepared for dyeing by splitting the leaf between the upper and lower epidermal surfaces by ripping. The leaves are first softened for splitting by drawing them through a fire. The lower half is discarded. The upper half is

soaked for several days in sea water and then in fresh water, and dried. The strips are finally soaked in a coral lime solution for three days or until they take on a yellow tone. They are then washed and dried to await dyeing. The red dye is obtained from *nono* (*Morinda* sp.) roots. The roots are scraped and the juice is mixed with water and coral lime. The pandanus leaf strips are soaked in the solution until the desired color is reached. After drying, the strips are heated in an oven to fix the dye. The black dye is obtained from the inner bark of the candlenut tree. The leaves are soaked for three days in the liquid expressed from the scraped and pounded bark, dried, and heated in an oven to fix the dye. The leaves are finally immersed for several days in taro paddy mud.

### Palms

Palm leaves are extensively used in construction and for clothing and utilitarian artifacts. Leaves vary in shape: single long broad lanceolate, fan shaped, and lanceolate leaflets on a thick petiole. The leaf may be used whole, or the midrib and edges may be removed and the blade only used, or the undersurface of immature or young leaves may be stripped off to produce a fine thin strand. Leaves are woven, sewn, and bound; undersurface strands are woven into cloth and baskets and spun into cordage; leaf blades are folded and intricately cut for ornaments.

*Species*

A few examples of palms are presented to illustrate some of their uses.

**Nipa Palm (*Nipa* sp.).** Nipa palms are short palms (they appear trunkless) that grow in wet tidal stream areas in the Indo-Pacific region. Their leaves are long and broad. Mature leaves are used extensively for thatching. Immature leaves, collected from the unopened leaf spike, are soft and flexible and woven into utilitarian baskets and mats. The immature unopened leaf is about 1 cm wide and is double, the two halves of the blade lying side by side with the midrib at one edge. They are used green as-is, or split along the midrib.

**Coconut Palm (*Cocos nucifera*).** The coconut palm leaf consists of leaflets on a thick petiole. Many containers, hats, mats, and thatch are made by splitting the petiole in half and weaving the attached leaflets.

**Raffia Palm (*Raphia* sp.).** The underpart of young raffia palm leaves is stripped off and dried upon harvesting the leaf. Cross sections of raffia strands show the lower epidermis and some of the lower parenchyma with young fibers, the lower edges of lacunae giving the inner surface a serrated appearance. The strands are about a centimeter wide, very thin and strong, with a tendency to curl longitudinally.

In Africa, raffia is used to lash and bind artifacts and to produce cloth, costumes, and mats. Sieber (1972:159) briefly describes cloth manufacture by the Kuba of the Republic of Zaïre: "Palm-leaf fibres, stripped, rubbed, and scraped, are woven into mats by men working on vertical looms. The finished mat may be placed in a mortar with cold water and beaten with a smooth ivory pestle to soften it. The mats, hemmed and stitched together, serve at times as a base for applique." The cloth is also decorated with embroidery and cut-pile work; dyeing may be done before or after weaving. Sieber (1972:159) includes an early twentieth century description of traditional mending: "holes and worn places ... were skillfully covered by pieces appliqued on in different designs with palm fibre dyed black."

**Fan Palm (*Livistonia* sp.).** The underpart of the young leaf is stripped off the blade segments of the immature leaf spike, yielding strands similar to raffia but larger and stiffer.

Strands from the cabbage fan palm (*Livistonia australis*) are used by Australian Aborigines in the northeastern coastal areas of the continent for cordage and fiber for baskets. Strands up to 1.5 m long and 5 cm wide are obtained. The natural color of the dried strand is light beige; strands are dyed yellow, red-orange, and purple using natural dyes. For yellow, the bark of *Morinda reticulata* is scraped off and layered in a bucket with the palm strands. Water is added and the material is boiled for about five minutes, after which it is rinsed and dried. Red is obtained by adding wood ash to the boiling dye bath. Purple is obtained by using this same technique with scraped root bark of *pa'aamp* (botanical name not identified). The strands are spun on the thigh to make two-ply cordage. Cordage is used to make twined, knotted, and looped bags.

*Palm Leaf Manuscripts*

Palm leaves are used to make manuscripts in South and Southeast Asia. Several palm leaves are used (Agrawal 1984:25–27):

- *Borassus flabellifer* (the palmyra palm): leaves thick, initially flexible, but lose flexibility with age; more prone to insect attack than the *talipot* leaf
- *Corypha umbraculifera* (talipot or fan palm): leaves soft, light in color, flexible
- *Corypha taliera*: leaves slightly brown, thick, stiff; more prone to insect attack than the *talipot* leaf

The palm leaves are variously processed by retting, boiling, smoking, oiling, and air, sun, and kiln drying. Agrawal (1984:27–31) describes methods used in different areas. In Indian states, leaves are dried in the shade and rubbed with *gingili* oil to make them smooth; or hung in smoke for several days, then surface smoke deposit is wiped off, sometimes followed by rubbing with turmeric paste; or dried in the sun, buried in pond mud for 10 to 15 days, cleaned, dried, and rubbed with turmeric paste; or boiled in water and dried, sometimes followed by rubbing with turmeric paste. In Sri Lanka, fresh young leaves are boiled in water or lime water for a few hours and dried in the shade. In Thailand, the golden leaf from the Lopburi region is preferred. Leaves are dried in the shade, the midrib is removed, and the blades cut to uniform size. Bundles of leaves are placed in a kiln for twenty-four hours, causing a black oil to exude from the leaf edges. The oil is wiped off; the leaf is held over a fire for a few minutes, and finally polished. The removal of the oil is believed to make the leaves more durable.

Writing and decoration of palm leaf manuscripts vary considerably. The most common form found is inscribed characters or drawings darkened with black, but many elaborate styles exist.

A display at the National Library, Bangkok, includes manuscripts of different styles and periods on palm leaf, paper, cloth, ivory, and copper. Palm leaf manuscripts included those with inscribed and blackened characters, black ink, gamboge ink on blue-painted leaf, black ink on gilt leaf, gilt leaf with illuminated margins, gold ink on vermillion-lacquered leaf, and gilt on black-lacquered leaf. The display

also includes the tools used to write and to inscribe and blacken characters on plain palm leaf: strings covered with fine black ink that are held tautly over the leaf and snapped to make black lines to guide the writing, the wood *sanab* on which the leaf is placed while being inscribed, the pens for writing and the styli for inscribing, the cloth pads used to smear on and wipe off the black soot mixed with wood oil that fills the inscribed characters, fine sand used hot to wipe off the soot, and the resin used to remove the black ink line marking.

Individual manuscript leaves are usually bundled between hard cover boards. Holes are pierced in the center or at the ends of the leaves and the boards, and cords pass through these and wrap around the closed bundle. The cover boards are usually of wood or bamboo and may be elaborately finished and decorated. Closed bundles are traditionally wrapped in several layers of cloth and stored in chests. Palm leaves may also be joined by tying at the edges so that they can be folded and unfolded accordion fashion.

## Monocot Leaf Midrib

The midvein of some monocots, especially the palms, is highly developed, forming a stiff dense rod with considerable vascular and fiber tissue. When developed in this fashion, it is referred to as the midrib. The midrib of monocot leaves is often discarded. However, in some woven constructions, especially if they are stiff ones, like fans and some baskets, the entire leaf with its midrib is used, and sometimes the midrib alone is an important weaving element. The midribs of some palms are also used in utilitarian artifacts and construction.

Brigham (1906:5–15) describes and illustrates Micronesian and Polynesian baskets and fans made with the coconut palm leaf used with the leaflets attached to half the petiole, with the leaflets used whole, and with the midrib and leaflet blade used separately. Coconut leaflet midribs are reported by Handy and Handy (1972:173) to have been used in Hawaii to make shrimp snares and brooms (midribs bundled and tied together with sennit), as rods to hold *kukui* nuts burned for light and heat, and as *kapu* markers. Nipa palm leaves are used in the Philippines to thatch buildings. The leaves are folded over a one-and-a-half meter stick; a midrib is run through both layers of leaf just below the stick to secure them in place.

## Monocot Sheathing Leaves and Petioles and Sheaths

The lower section of leaves and petioles of some plants thicken and broaden to enclose the stem. These sheathing sections are fairly strong and stiff and are used in building construction and in artifacts. The fibrous degraded remains of the sheathing sections of some leaves are also occasionally used.

Sheaths are modified leaves that enclose and protect developing branches, leaves, and flowers. Some, such as those of some bamboos, are used in artifacts.

### Banana (*Musa* sp.)

The banana leaf has two sections of distinctly different appearance and function. The lower part of the leaf is broad and sheathing. The sheaths closely overlay each other (like the stalks in a bunch of celery) forming a compact cylinder that functions as a trunk supporting the upper part of the leaves and the fruit. The leaf above the

*Figure 3.30. Technique used by the Tiwi to fold and bind the ends of containers made from palm sheath sheets.*

sheathing portion narrows into a thick midrib from which extend two large, flat, thin blades. The sheathing portion is large—up to 2 m long, 15 cm to 20 cm wide and, when fresh, up to 1 cm thick—and crescent shape in cross section. The fiber bundles are mostly situated in the outer portion of the sheath. The fibers are strong, but the rest of the sheath is mostly air and water in large lacunae and parenchyma cells between thin, not very dense epidermal layers.

The thin leaf blades are primarily used in cooking and as ephemeral food covers and plates, but are also found as wrappings on composite constructions. The sheathing stalk is used for thatching and artifact construction, but is most important for its long, strong fibers. (See monocot leaf fibers section of this chapter.)

The sheaths were used whole in building construction. Kamakau (1869:99) describes the laying of the first layer of roof thatch in Hawaiian houses: sheaths from "large banana trunks were scraped until the sap was out, then set up in the sun and dried. They become as shiny as dress silk. Two or three thicknesses of sheathing were set up against the purlins and held in place with a cord on the back of the thicknesses of the dried sheaths."

Radially split sections of the sheath are used in constructing baskets, mats, personal ornaments, and utensils. A pair of Micronesian wristlets in the Bishop Museum collection are constructed by securing small shells to a narrow strand of banana sheath with spun cordage. Split strands of banana sheath were one of the two most important materials for baskets on Easter Island. The sheath was dried then split to the desired width to make plaited baskets. Colored patterns were created by using strands "from the natural dark-colored parts of the banana material" (Métraux 1940:211–212). Strips of banana sheath formed the foundation band of Easter Island feather headdresses (Métraux 1940:223).

### Palm Leaf Sheaths

The sheathing bases of some palm leaves or leaf petioles are large, forming long broad sheets which are quite rigid upon drying. The epidermal surfaces may be smooth or softly ridged longitudinally and may be very dense and hard.

The Tiwi of Bathurst Island in northern Australia use palm sheath sheets to make containers. In two containers examined, sheets 50 cm to 60 cm long and 35 cm to 40 cm wide were used. The ends of the sheets were folded up and bound at the top edge to create rectangular containers of 10 cm to 13 cm in height (See Figure 3.30). One container had a strap handle sewn to the container at either end. The sheath surfaces were ridged; the surface of the inside of the container was more deeply ridged and slightly rougher in texture than the exterior surface.

Painted panels from a Haus Tambaran in the Sepik Wosera-Abelam area of Papua New Guinea are reportedly made from the lower part of the sago palm leaf painted with carbon, mineral, and plant dye pigments (Lee 1980).

### Palm Leaf Sheath Remains

Around the trunks of some palms, particularly the coconut palm, are found fibrous mats which are the remains of the sheathing bases of leaf petioles. The remains consist of two layers of fibrovascular bundles, the fibers in each layer are parallel 1 mm to 3 mm apart, and those in one layer lie crosswise to the other layer. The fibers and layers are connected only by the dry, fragmented remains of pithy tissue.

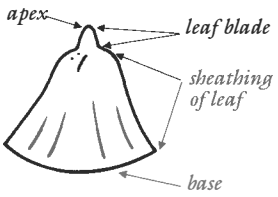



*Figure 3.31. Bamboo culm and branch sheath.*

Sections of sheath about 15 cm by 20 cm were used in a mask from the Purari Delta, Papua New Guinea. The sheath pieces completely covered the crown and face framework of the mask. It was secured by stitching through the sheath and around the framework with a stiff strand of plant material. The face area was further covered with barkcloth and painted. Handy and Handy (1972:173) record that the fibrous sheath at the base of the leaf stalk of the coconut palm was used in Hawaii to wrap the earth ball of seedlings when transplanting and to wrap deep-sea fishing bait. The sheath can also be seen on contemporary objects for the tourist market—for example, as costume material for native dolls.

**Bamboo Culm and Branch Sheaths**

The culm and branch sheath is a modified leaf attached at the node and surrounding the internode above it. When removed from the plant, the sheath is roughly triangular, with vascular bundles and fibers running from the base to the apex (McClure 1966:62–69). The surfaces may be smooth or may be covered with fine hair and spines. They are reported to be used in India for lining hats and sandals and in dried flower arrangements (Lessard and Chouinard 1980:34).

Satow (1899:18–19) reports on the use of the culm and branch sheaths in Japan: "The sheaths of the madake are of a light yellow color, with black spots. In size they range up to 1 foot 5 or 6 sun in width, and over two feet in length. Their use is manifold, for making hats, sandals, sandal-thongs, burnishers [f]or the block-printer, as wrappers for meat, poultry, fish, cakes, vegetables and fruit. There are some thirty or forty dealers in bamboo sheaths in Tokio alone, and the quantity annually dealt in may be estimated by tens of thousands. For the soles of the best class of bamboo-sheath sandals and of wooden clogs the smaller sheath of bamboo branches, commonly known as eda-gawa, is preferred. Its color is pure white. It was used for the class of sandals formerly known as setla and the soles of what are now called geta (wooden clogs)."

## Monocot Leaf Fibers

Monocot leaf fibers are those that comprise the vascular bundles (xylem, phloem, sclerenchyma fibers) and fiber bundles (sclerenchyma fibers) of monocot leaves. They are often referred to as hard fibers, as distinguished from the soft fibers obtained from the inner bark of herbaceous and woody plants. They may in fact be harder as they tend to be more heavily sclerified and lignified, but they are also mechanically stiffer. As the fibers grow in discrete fiber bundles, leaves are usually processed to extract the whole bundle which is a compact complex of many cells.

The strength, color, and abrasion resistance of monocot leaf fibers vary greatly depending on inherent characteristics and on processing methods. Generally they tend to be smooth fibers with a surface sheen (which can be beautifully exploited by burnishing). In some families, individual cells have great tensile strength and have smooth surfaces, but the whole fiber bundle tensile strength is low, because the smooth surfaces of the cells allow the cells to slip under tension (for example, cayenne fibers; Collins 1960:256). Table 3.2, excerpted from Collins (1960:256), shows the tensile strength of various plant fibers.

*Table 3.2. Tensile strength of some fibers (Collins 1960:256, adapted partially from Matthews 1947:300).*

| Fiber | Relative Tensile Strength | Fiber | Relative Tensile Strength |
|---|---|---|---|
| Manila | 100 | *Phormium tenax* | 67 |
| Pitafloja (*Aechmea magdalenae*) | 104 | Hemp | 56 |
| Palmaixtle | 78 | Jute | 55 |
| Cotton | 75 | Philippine fiber | 31 |
| Sisal | 71 | Smooth cayenne | 29 |

The extraction of fibers involves harvesting, stripping (decortication), retting or cooking, and separation from nonfibrous tissue. The fibers may be further processed by bleaching and dyeing. Fibers are spun, plaited, or knotted to make continuous thread. Some leaf fibers may be further separated and fragmented for paper pulp. Fibers from a number of plants are used. Some of the more commonly used plant groups include:

- *Musa* species: banana, abaca, Manila hemp, plantain, *basho*
- Agavaceae, *Agave* species: agave, sisal, maquey, henequen
- *Phormium* species: New Zealand flax
- Bromeliaceae, *Ananas comosus*: pineapple, *piña*

### Banana (*Musa* sp.)

Banana fibers are taken from the sheathing portion of the banana leaf which forms the stalk or trunk of the plant. (See previous section on monocot leaves.)

Harvesting consists of cutting off the leaf midrib and blades, and cutting off the stalk at ground level. The sheaths are separated by prying each sheath loose from the stalk. Fiber extraction, cleaning, and dyeing methods differ among cultural groups. Methods used in the Philippines and Okinawa are presented as examples.

*Philippines (*Musa textilis*: Manila hemp, abaca)*

In the Philippines, fibers are extracted by stripping. The sheath is pulled between a smooth or toothed blade and a smooth drum. This process mechanically removes the epidermal and most of the parenchymal tissue, leaving coarse fibers about two meters in length. With increasing commercial demand for the fibers, the stripping process is made easier and faster by the use of stripping machines (Huke 1963:336–337). The sheath is mechanically pulled through a very fine toothed blade which is held with considerable pressure against the drum. The more pressure between the blade and the drum and the closer the teeth of serrated blades, the cleaner and finer the fibers. In fully mechanized stripping, the sheath is fed through rotating drums fitted with fine teeth. Fibers stripped by this method are cleaner and finer than hand-stripped fibers, but the fibers extracted include both the larger and stronger bundles associated with vascular tissue and the much weaker fiber bundles in the hypodermis, which are not extracted in the hand-stripping methods. After stripping, the fibers are dried and bleached by hanging them in the sun before they are used locally or sent to market.

Most fibers are now used for the commercial production of rope and paper. Traditionally, the fibers were used primarily for textiles and cordage. For textiles, small bundles of fibers are knotted end to end to make continuous thread, which is

usually dyed before weaving. Cole (1913:79) describes dyes used by the Bagobo of Mindanao: "If a red color is desired the root of the *sikarig* palm (*Morinda bracteata)* is scraped and the scrapings placed in bark vats filled with cold water. The thread is first washed in, and is later boiled with, the dye, for a half hour, after which it is placed in a basket to drain and dry. The process is repeated daily for about two weeks, or until the thread assumes a brick red color. If a purple hue is desired a little lime is added to the dye. Black is obtained by a slightly different method. The leaves, root, and bark of the *pinarrem* tree are crushed in water. This yields a black liquor which is poured into a jar containing the thread and the whole is placed over a slow fire where it remains until the liquid is near the boiling point. When this is reached the thread is removed and placed in a gourd, the open end of which fits over the jar so as to catch the steam coming from the dye. After a time the thread is removed and dried, and the process is repeated until at last a permanent black is obtained."

After weaving, *abaca* cloth is often burnished. The cloth is dampened, placed on a smooth board, and rubbed with a smooth shell. Light burnishing produces a soft sheen to the cloth. Heavy burnishing flattens and polishes the fibers so that they develop the appearance of shiny scales.

*Okinawa* (Musa basjoo-basho)

Banana fiber is one of the oldest fibers used for textiles in the Ryukyu Islands and was the major fiber used until the sixteenth century, when cotton and silk became available (Niho Sen'i Isho Senta 1980:4–5). Banana-fiber cloth (*basho-fu*) continued to be important for local use and export, and its manufacture continues to this day on the island of Okinawa.

At the plantation, after cutting the trunk and separating the sheaths, the outer layer containing the strong fibers is peeled off in strips. Strips about 1.5 m in length are obtained.

In the village of Kijoka, fiber extraction is done by cooking and hand cleaning. The sheath strips are rolled up and tied to prevent tangling, and boiled in water and wood ash to degrade and loosen the nonfibrous tissue. After rinsing and drying, the strips are cleaned to remove this unwanted tissue. The strips are split into narrower strips and these are pulled at an angle through flat bamboo tweezers. This procedure is repeated until the fibers are clean. The clean strips are further separated into fine threads which are knotted end-to-end to make a continuous thread. Plain, warp *kasuri* (ikat), and warp and weft *kasuri* cloth is made. For plain warp *kasuri,* only the warp is spun; for warp and weft *kasuri,* both warp and weft are spun. For *kasuri,* wrapping of the threads prior to dyeing is done with sections of banana leaf blade tied with banana fiber, or with flat nylon packaging cord. Both a brown dye and indigo are used. After weaving, the cloth is refined by boiling in wood ash, rinsing, soaking in fermented rice for 2 to 3 hours, and finally rinsing. The cloth is stretched on bamboo slats and dried in the open. (Information from Kijoka Basho-fu Workshop, Kijoka, Okinawa.)

In Okinawa, a special decoration technique, *bingata,* is applied to *basho-fu. Bingata* is a stenciled paste resist design that is dyed with hand-painted dyes, often followed by an overall indigo dye. The stencil is made from thick paper saturated with *basho-shibu* (juice from the banana fiber plant). When dry and hard it is laid on

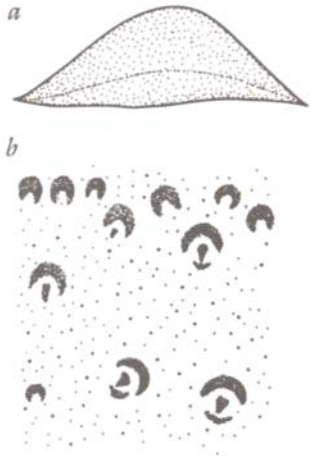



*Figure 3.32. (a) Transverse section of an* Agave sisalana *leaf showing location of fibers. (b) Microscopic section of a portion of* A. sisalana *leaf showing peripheral "horseshoe" fibers and median "ribbon" fibers.*

a block of dried tofu (soy bean curd) and the design cut with a sharp, pointed blade. Heavily cut areas are reinforced with a hair or silk fiber net. The stencil is laid on the stretched cloth and the rice starch paste resist brushed on. When dry, natural dyes made to a thick consistency are painted on (for dye sources see Niho Sen'i Isho Senta 1980:5–6). The colors are finely worked and blended to achieve soft shading and color blends. (The washing and indigo dyeing that follow the dye painting were not observed, and the only texts found that appear to describe the process in detail are in Okinawan and Japanese.)

**Agavaceae**

Fibers from many members of the family Agavaceae are used. Besides *Agave*, important genera include *Yucca* and *Phormium*. *Agave* is indigenous to tropical and subtropical America, but is now cultivated in appropriate climates world-wide. *Phormium* is used extensively by the Maori of New Zealand.

*Species*

Following are some of the more important *Agave* species (Lock 1962):

***Agave sisalana* (sisal).** Sisal is cultivated for its fibers in America, Asia, and Africa where it was introduced in 1892. Its leaves are about 120 cm long. Sisal is the most easily cultivated and economically important species of *Agave*.

***Agave cantala* (maquey, cantula fiber).** This species is cultivated in Indonesia and the Philippines. Its leaves are 130 cm to 160 cm long. Although maquey is the finest of the *Agave* fibers, it is both hard to cultivate (it is disease prone) and difficult to work with. The leaves are hard to decorticate, and the spiny leaf margins make it awkward to harvest and process.

***Agave fourcroydes* (henequen, Mexican sisal).** This species is cultivated in Mexico, particularly in the Yucatan Peninsula. The leaves are 100 cm to 130 cm long. Its fibers are coarser than sisal and have some reputation for durability.

***Agave lechuguilla* and *Agave heteracantha*.** These two species of *Agave* are utilized and possibly cultivated in Central America. The fibers are coarse and stiff.

*Harvesting*

Leaves are individually cut from the plant several centimeters above the leaf base. The plants can be continually harvested after they are one to one and a half years old. Fibers from young plants are generally finer than those from older plants.

*Fiber Extraction (Decortication)*

Traditionally, the leaves are heavily beaten to break up the nonfibrous tissue and scraped to remove it. Along the Philippine coast, the maquey leaves are retted and beaten in sea water. In the 1830s, the first mechanical decorticators were developed in Mexico based on blades on rotating drums to crush and scrape away nonfibrous tissue. The fibers are rinsed in water and dried.

*Fiber Characteristics*

Fibers are distributed throughout the spongy parenchyma, which comprises most of the interior of the leaf. The average mature sisal leaf contains about 1,100 fibers of two types in a ratio of 1 to 3: the flattish crescent shaped fiber bundles that protect the vascular tissue and the finer, round-to-horseshoe-shaped fiber bundles (see Figure 3.32). The composition of sisal fibers is detailed in Table 3.3.

The extracted fibers are compact bundles of sclerenchyma fiber cells, polygonal in cross section. The length, diameter, and cell wall thickness vary with species. Growing conditions, harvesting, and extraction influence fiber strength; and age and position in the leaf influence size and coarseness. The dry fiber is stiff and somewhat harsh; white upon extraction, it yellows with exposure to sunlight due to UV action on lignin.

*Table 3.3. Composition of sisal fiber (excerpted from Locke 1962:279).*

| Sisal Composition | | % by Weight of Oven-Dried Material |
|---|---|---|
| Cellulose: | "True" cellulose | 62 |
| | Pentosan | 16 |
| | Total cellulose | 78 |
| Lignin | | 8 |
| Waxes, etc., extractables with organic solvents | | 2 |
| Other carbohydrates, hemicelluloses, pectins, etc. | | 10 |
| Ash (calcium carbonate, potassium and magnesium salts, and silica) | | 1 |
| Loss during analysis | | 1 |
| Total | | 100 |

*Uses*

*Agave* fibers were used in Central America to make strong cordage for rope, sandals, bags and containers, and so on. Von Hagen (1977:42) writes that *Agave* "furnished the peoples of Mexico with drink, food, spines, gutters for thatching, fibers for shoes and clothing, ... its importance to native economy was unmatched by that of any other plant." *Agave* fibers are now commercially utilized primarily for rope and twine, and to some extent for mats. The fine tow is used in packing and upholstery.

### *Phormium* species (New Zealand flax fibers)

The leaf blade and the leaf fibers of *Phormium* species are extensively used by the Maori of New Zealand. The leaves are long and smooth, with a central midvein and two smooth blades that are joined for some distance above the base. The fibers lie in a plane under the upper epidermis.

For fine weaving fibers, undamaged mature leaves one to one-and-a-half years old are cut about 15 cm below the point where the blades divide. The fibers are extracted from the fresh leaves. Mead (1969:151–152) relates that the midrib and leaf edges are slit off and each blade slit in two, making four strips per leaf, each about 2 cm wide. With the dull (lower epidermis) surface facing upward, the leaf is scored across the strip to, but not through, the fibers. A dull blade, traditionally a mussel shell, is held underneath, on the shiny side, below the score. The leaf blade is bent and the shell run along the length of the leaf. The stiff nonfibrous portion of the leaf above the fiber layer lifts from the fibers and is discarded. The bruised epidermal tissue on the shiny (upper epidermis) side of the leaf is scraped off with the shell. The fibers are washed in fresh water and scraped to remove all remaining nonfibrous tissue. The fiber may be used as is or may be further refined by soaking in running water for about four days, and then being beaten with a stone on a stone anvil. This process is repeated until the desired texture is achieved. The fiber is dried

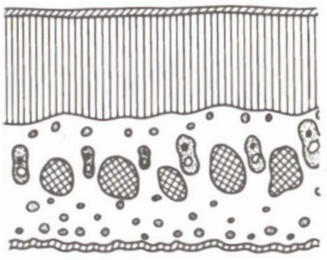



*Figure 3.33. Schematic diagram of cross section of pineapple leaf (after Collins 1960:47).*

in the sun and may either be used immediately or stored for future use. Storing is said to improve its color and texture.

Single and two-ply threads are spun on the thigh. They are used in their natural color and are also dyed red, black, and in some areas yellow. Mead (1969: 152–155) describes some of the dyes used. One red dye is obtained by scraping off and pounding the bark of *Phyllocladus trichomanoides* and boiling it to extract the dye. The fiber is added to the dye bath and boiled. Next, the fiber is removed, rolled in hot white ashes, and returned to the boiling bath for ten minutes. The fibers are then hung up to dry. A black dye based on the formation of black iron tannates is used. The bark of *Elaeocarpus dentatus* or *Wenmannia racemosa* is pounded and layered with the fibers in a wooden container. The mixture is covered with water and allowed to soak twelve to sixteen hours. The fibers are then removed, buried in black mud for twenty-four hours, rinsed, and dried. Yellow is probably obtained from the bark of *Coprosma* sp.

Cloaks are made using the flax thread primarily by twining. Applied decoration of many types—feathers, flax tassels, leaves, strips of dog skin—are usually woven in during the cloak construction. Colored borders (*taaniko*) are done with tight wrapping of the colored threads around the warps and each other.

**Bromeliaceae (particularly *Ananas* sp.—pineapple fibers)**

Pineapples are the best-known members of the family Bromeliaceae, but other genera in the family are locally important fiber sources. Collins (1960) mentions some: *Pitafloja*, from *Aechmea magdalenae*, is very strong and said to be scarcely affected by salt water; smooth Cayenne fiber is soft and silky but very low in tensile strength; fiber from *Bromelia sylvestris* is known as silk grass in British Honduras, *istle* or *lechugilla* in Mexico, and *pita* or *pinuella* in Central America. However, Von Hagen (1977:45) reports that *pita* is the Spanish word used in Central America for maquey, an agave, and that *icxotl*, (the possible source of the anglicized istle) is a yucca. Both are members of the family Agavaceae. Collins recommends Kopp (1929) for descriptions of fibers from bromeliads.

The fibers of the pineapple leaf occur in a layer in the under-half of the leaf as shown in Figure 3.33. The extracted fiber comprises either the whole vascular bundle or the two fiber sheaths alone (see Figure 3.34). In pineapple fiber cloth from the Philippines, fiber bundles varied in thickness, but were generally very fine and flattish. The individual fiber cells of each fiber bundle remained tightly packed with only minor loosening of outer fiber cells, and parenchyma tissue cell fragments remained on the surface of the fiber bundles.

*Cultivation, Harvesting, Fiber Extraction*

Fibers can be extracted from the leaves of many bromeliads. In the case of pineapples, the fibers are usually extracted from plants grown specifically for that purpose. The fibers of pineapples grown for the fruit are shorter and harder to extract. Collins (1960:255) describes the cultivation, harvesting, and extraction of fibers from pineapple:

> The cultivation of pineapple plants for fibres in the Philippines and in Formosa is biased toward the production of a high-quality fibre. A variety of pineapple plant is grown which has leaves yielding a high-quality fibre


X *xylem cells*

P *phloem cells*

:::: *endodermis sheath*

/// *fiber sheath*

▭ *parenchymatous sheath*

*Figure 3.34. Schematic diagram of cross section of vascular bundle (based on material in Collins 1960:51–53).*

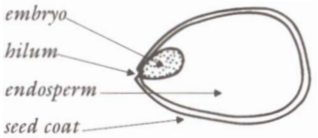



*Figure 3.35. Schematic diagram of longitudinal section of a seed.*

although the fruit is insipid. The plants are grown in the shade if possible, and the fruit buds are pinched off as they appear so that all the nourishment is forced into the leaves. When the leaves are at their prime they are pulled from the plants, graded, and processed by individual families … Such an agricultural operation would be difficult to mechanize while retaining the present high quality of Philippine and Formosa fibres.

Preparing pineapple fibres is a tedious job. Workers in the Philippines, in Formosa, and in the Congo bruise the leaves to loosen the cuticle and then extract the fibres by hand stripping. After washing and bleaching the fibres in the sun, they glue together the 3 to 4 ft. long fibres to form a thread. Such labor-saving devices as raspidors, which have been used so successfully on sisal leaves, damage the fibres and fail to remove all the adhering tissue from the pineapple fibres. Retting, another method of reducing the work of preparing fibres, lowered the tensile strength and discolored the fibres in the tests which have been made.

*Uses*

Pineapple fibers are used to make a fine cloth (*piña*) in the Philippines and are said to have once been used for cloth on the Indonesian island of Lombok. *Piña* cloth production probably developed in the Philippines with Spanish colonization, as pineapples are a Central and South American plant and no mention of the use of pineapple fibers is found in the literature on traditional material culture of Filipino groups.

*Piña* cloth is very light and is usually loosely woven, with colored motifs woven in with discontinuous supplementary wefts. The threads are fine, and comprise one to several pineapple fibers knotted end to end to form a continuous thread. The threads do not appear to have been spun before or after knotting.

## Seeds and Fruit

Seeds and the fleshy or fibrous fruit that encloses them are important sources of dye and fiber, and are used as decorative elements and in the construction of a variety of utilitarian, religious, and decorative artifacts.

### Seeds

The bulk of the seed consists of the endosperm and parenchyma cells heavily filled with starch, which is the source of nutriment for the embryo upon germination. The embryo and endosperm are enclosed in the protective seed coat comprising dense layers of parenchyma cells that are often heavily sclerified, lignified, and pigmented. The seed coat is perforated by the hilum, the placental scar (Figure 3.35). (Note: The starchy endosperm is an attractive food source for boring insects and the hilum is an easy route to it, avoiding the unattractive seed coat. As an insect hole in the hilum is not particularly obvious, considerable damage to a seed may occur before one is aware of the insect problem.)

Small seeds such as Job's Tears (*Coix lacryma-jobi*), *Abrus,* apple, and legume seeds are often found used like beads in personal ornament. They are pierced or drilled, then sewn onto the support or strung. They are also applied as

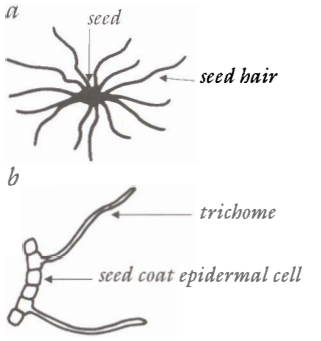



*Figure 3.36. (a) Seed with seed hairs. (b) Cross section of seed coat epidermis showing seed hairs (trichomes) as outgrowths of seed coat epidermal cells.*

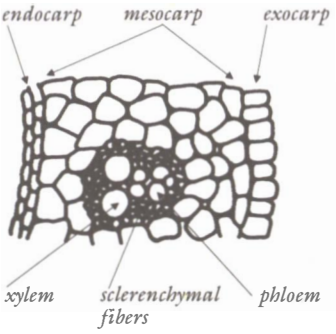



*Figure 3.37. Cross section of pericarp tissue.*

decoration on a variety of artifacts by adhering or embedding them into wax, resin, and clay. Larger seeds such as candle nut seeds and some legume seeds may be carved, strung, or hung in fine nets.

## Seed Hairs

A seed hair is a trichome, an outgrowth of an epidermal cell of the seed coat (Figure 3.36). It is usually unicellular, although sometimes multicellular, and develops a thickened secondary wall. The size of the lumen varies: that of cotton is small compared to the thickness of the cell wall, while that of kapok is very large. When the seed matures and dries, the trichome may collapse, giving cotton fiber, for example, its flat, twisted appearance.

Intact seeds with seed hairs, such as kapok and milkweed, are used for stuffing and as applied or adhered decoration. The seed hairs alone (such as cotton fiber) are used for stuffing and applied decoration, and are spun into thread. Seed hairs are removed from the seed by hand separation, by feeding the seed through a pair of rollers (the fibers are pulled through the rollers, stripping them from the seeds, which are too large to go through), or with an industrial gin.

## Fruit

The fleshy fruit surrounding the seed(s), called the pericarp, comprises three major tissues as shown schematically in Figure 3.37. The endocarp, closest to the seed, is a hard layer that may be thin and transparent as in apples, or may be thick, dark, and fibrous as in stone fruits like peaches, nuts, and coconut. The exocarp, the epidermis of the fruit, is usually thin and covered with cutin. The mesocarp, between these two areas, makes up the bulk of most fruits. It comprises vascular, fiber, and parenchyma tissue, and may be fibrous or fleshy.

The amount and hardness of each part vary considerably from species to species. The fibrous component of the mesocarp also varies considerably. It may be soft and minimal, as in edible fruits, or may be coarse and extensive in fruits like the coconut. Although most fruit is readily perishable, some fruit and fruit parts are quite durable and are used to construct and decorate a variety of artifacts. Coconut and gourds are discussed here as they are some of the most extensively utilized fruits.

### Coconut *(Cocos nucifera)*

The coconut is a palm bearing a large fruit with an edible seed and fibrous pericarp. The thick, hard endocarp and the coarse fibers of the mesocarp are utilized extensively (Figure 3.38).

#### *Coconut Shell*

The endocarp and inner mesocarp of the coconut (known as the coconut shell) are very hard and dense. It has been used to make utensils like spoons and ladles, drinking vessels, percussion instruments, ornaments, and decorative elements.

The inner surface is naturally covered with a very thin tissue, which appears opaque and light brown. The outer surface is naturally rough and fibrous. Both surfaces can be scraped, sanded, and polished to a smooth, brown surface. With

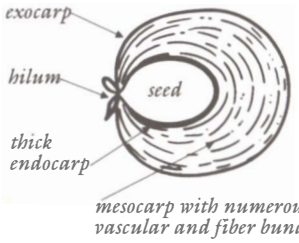



*Figure 3.38. Longitudinal section of coconut fruit.*

use and handling, many of the utilitarian artifacts develop a satiny, deep brown-black patina.

The coconut shell is shaped by cutting, grinding, and drilling. Because of its great density, coconut shell can be very intricately carved and filigreed. Decorative elements are often pierced by drilling and attached to the artifact with cordage. Coconut shell utensils may have attachments secured by lashing, pinning, and adhering.

*Coconut Fiber (Coir)*

The fiber and fibrovascular bundles—which, for the sake of convenience, will both be referred to as fibers—of the mesocarp are traditionally used for cordage (sennit) and weaving, and commercially used in the manufacture of brushes, mats, and ropes. Cordage from coconut fibers is woven or knotted for clothing, armor, baskets, and nets; it is also used for binding and lashing anything from fine ornaments to canoes and large buildings. The fibers vary considerably in diameter and length and, if well cleaned, have a deep sheen. They vary in natural color from light to dark red-brown and can be dyed to a deep red-black. The fibers are dense and resistant to abrasion, rot, and sea water. Although initially very supple, coconut fibers become very stiff and brittle with age.

In the intact mesocarp, the fibers run roughly parallel to the long axis of the fruit, and are intermeshed in a ground of pithy parenchyma tissue. To extract the fibers, the husk is retted in sea and/or fresh water, dried, and beaten and teased to loosen and remove the degraded parenchyma tissue. The processed fibers are plaited and spun to produce cordage. Three-ply plaits are common, but higher plies are also made. Spinning is done on the thigh, spinning two single-ply threads with one rolling stroke and plying the two on the return stroke.

Although coconut fiber cordage has been extensively used in the Pacific, surprisingly few references can be found on its manufacture. Handy and Handy (1972:176) merely state that the fibers were pulled off and cleaned. It was spun on the thigh to make a cord. Heavy cordage for lashing house timber, canoes, and tools was made by plaiting the spun cord. Stokes (1906:105) states that "the preparation of coir was simple, merely requiring the separation of the fibers of the husk" and spinning and plaiting into cord. However, Kamakau (1869:118) gives an indication of the effort and time involved in making sennit when he states that the making of a canoe "was a laborious task … half the task was in making the coconut cordage."

The processing of coconut fiber for cordage by the Polynesian inhabitants of the Micronesian island group of Kapingamarangi was observed and described by Buck (1950:123–124). Green husks were chosen as the fiber source—in contrast to the use of the mature, brown husk in much of Polynesia. Husk sections were soaked in sea water for at least a month, after which the shorter inner fibers and the outer skin of the husk were pulled off and the remaining material beaten with a wooden beater on a stone anvil. Nonfibrous tissue was pushed out by the beating process and was washed out in intermediate and final rinsing, leaving the section of intermeshed fibers. These were dried in the sun and stored until needed. Right- and left-hand two-ply cordage was made by spinning on the thigh. Fibers were pulled from the cleaned sections. First, short sections of single-ply cord were made, then these were joined and plied to make the final cord.

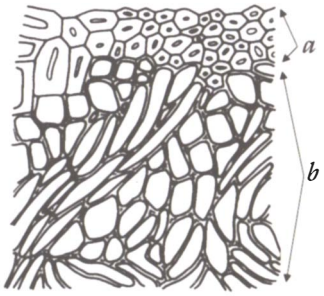



*Figure 3.39. Cross section of outer section of* ipu nui *(a) hypodermal layer of stone cells and (b) thick layer of fiberlike parenchyma cells.*

**Gourds**

Gourds are the fruit of a vining plant (*Lagenaria siceraria*) in the family Cucurbitaceae. *Lagenaria siceraria* grows and is utilized worldwide. Its early distribution and use is evidenced by artifacts made from the fruit found at South American and African sites from around 5000 B.C. and by references from early Sanskrit and Italian texts (Whitaker and Davis 1962:6–7).

The fruit of the gourd or calabash tree (*Crescentia cujete*) in the family Bignoniaceae is similar in appearance to gourds and is utilized for similar purposes. *Crescentia cujete* is native to Central and South America and is cultivated and widely used there and in Africa. It is a small to medium-sized tree. The fruit is spherical or ovoid and varies in size from several inches in length and diameter to lengths of 18 inches and diameters of 12 inches (Heiser 1979:15).

The terms gourd and calabash are confusing as they are used interchangeably and "calabash" is sometimes used to refer to any large spherical container, including those made of wood. The fruits are similar in appearance and are decorated and used similarly. Heiser (1979:24) explains that the cellular structure of the tree gourd is different from that of the vine gourd and would be the only definite means of distinguishing between the two. Gross differences may be apparent: the tree gourd rind rarely exceeds 3 mm and the interior has a smoother finish. To avoid confusion in this text, the term gourd will be used to refer to the fruit of *Lagenaria siceraria*, and the term tree gourd to refer to the fruit of *Crescentia cujete*.

*Lagenaria siceraria*

The gourd wall consists of a hard fleshy mesocarp of "thick-walled elongate parenchyma cells which, in poorly defined, strand-like clusters, run in all directions, forming an interlocking fibrous mesh" (Eames and St. John 1943:257). The hypodermal exocarp consists of a thin layer of very thick-walled stony cells. Between the exocarp and the thin epidermis is a layer of cells that breaks down as the fruit ripens, causing the epidermis to be easily peeled or rubbed off.

Figure 3.39a shows a cross section of an outer portion of the wall of *ipu nui* (Bishop Museum specimen 1141), a large variety of *L. siceraria* developed in Hawaii. Only 1/200 of the wall is shown; the remainder is uniformly like (b), the inner part. The hypodermal layer of stone cells (a) is of irregular thickness; the thick layer constituting the bulk of the wall (b) consists of soft-woody, fiberlike parenchyma cells in poorly limited, interwoven strands; the epidermis is lacking (Eames and St. John 1943:257).

Gourds vary in size and shape depending on growth and variety, with diameters of large varieties reaching 50 cm and wall thicknesses of large varieties up to 3 cm, with natural shapes from squat to very elongate, and with or without a neck. The gourd shape can be modified during growth by hanging, confining, or binding. Shape modification may result in a simple narrowing of neck or waist, or in complex configurations such as that illustrated in Figure 3.40. Small gourds used to house pet crickets in China were decorated in molded relief. Earth molds of the design in negative were secured around the young fruit. As the gourd grew within the restraining mold it grew into the relief design. When of correct size, the mold was broken off revealing the design in raised relief in the gourd surface (Heiser 1979:137–138).

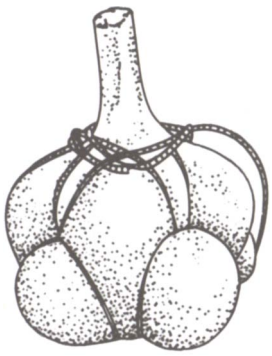


*Figure 3.40. Hawaiian water bottle made from a gourd bound during growth.*

**Cultivation and Harvesting.** Pacific gourds used for artifacts are varieties of *Lagenaria siceraria* (out-dated synonym, *L. vulgaris)*. Varieties are generally divided into three groups: the sweet gourds, the bitter gourds, and the large gourds such as the *ipu nui*. The last two were preferred for artifacts because they had harder shells and were more durable.

The fruit to be used for artifacts was harvested when the stem had withered (Dodge 1943:12 and Kamakau 1869:46), that is, when the fruit had fully matured. Handy and Handy (1972:216) add that, if the fruit is harvested when immature, the rind will crack when dried. They also record a 1922 report that the fruit was "put in a good place for a few days" before processing.

**Cleaning.** The process of removing the seeds and inner pulp differed among Pacific island groups and with the type of artifact to be made. Dodge (1943:15) states that for open-mouthed containers and other objects, the gourds were cut open around the stem and the pulp and seeds scraped out. Handy and Handy's (1972:215) 1922 Hawaiian source stated that, after initial cleaning, the gourd was filled with water and allowed to stand only long enough to soften the pulp, but not so long as to rot the gourd; the softened pulp was completely rinsed out and the interior cleaning finished by rubbing with coarse beach sand.

As the gourds used were usually of the bitter variety, the extraction of the bitterness (identified by Whitaker and Davis [1962:207] as cucurbitacins—crystalline bitter substances apparently related to tetracyclic triterpenes and occurring in plants as either monoglycosides or aglycones) was necessary if the artifact was to be a food or water container. Dodge (1943:15) describes two processes used in Hawaii. In one process, the pulp and seeds were scraped out and the shell was dried until thoroughly hardened. Then the remaining soft material was scraped out with pumice or coral, and the gourd was filled with water and allowed to stand until the bitterness was leached out. In the other process, after initial cleaning, the gourd was filled with ten daily changes of sea water, followed by final scraping and drying. Handy and Handy (1972:217) add that the final scraping was done with pumice.

For narrow-necked containers like water bottles, the seeds, pulp, and bitterness were removed by soaking, rotting, drying, and tumbling. According to Dodge (1943:16) the gourd was filled with water until the pulp was "well rotted." The water and loose rotted pulp and seeds were poured out, stones and sand poured in, and the gourd shaken until all soft parts were loosened. After rinsing, it was filled with water until the bitterness was leached out. The method used in New Zealand as reported by Dodge (1943:16) was: "After the gourds were picked they were either dried before a fire, by the sun, or buried in sandy or gravelly soil. This assisted the pulp to decay and the inside was then cleaned with gravel. After cleaning, the gourd was hung in the smoke of a fire to harden."

No mention was found of the removal of the epidermis except in descriptions of decoration techniques. However, given the weak attachment of the epidermis and the processing involved in cleaning gourds, one might expect to find no epidermis remaining.

Cleaning techniques used on gourds in Africa and the Americas appear to be similar to those used in the Pacific.

**Artifact Construction**. Gourds have been used for a wide variety of artifacts. Eames and St. John (1943:256) cite the use in Japan of the *hyotan* gourds as battle standards, ornaments, face masks, liquid containers, and general receptacles. The *hyotan* is said to be fairly thin walled and will shatter easily. Chen (1968:125) states that all groups of Formosan aborigines used gourds, primarily as liquid containers and ladles. Specialized decoration and uses included: the Puyuma and Ami tribes constructed protective covers and slings around gourds using leather and rattan splints; on Botel Tobago Island, small gourds were used for holding lime to be chewed with the betelnut; southern tribal groups used incised gourds in religious ceremonies. In Oceania, gourds are used as liquid and food containers; storage containers for clothing, equipment and valuables; musical instruments like drums, rattles, and whistles; toys; fishing equipment; helmets; and various household items like lamps, strainers, rat guards, and toilet spatulas (Dodge 1943:Table I).

In many artifacts, construction involves cutting or carving the rim, cutting the shape from the gourd wall, and drilling or piercing holes. Many containers had lids of another gourd or a coconut shell inverted over the top. Narrow-necked water containers were closed with stoppers or plugs of wood, shell, tooth, and folded palm or pandanus leaf. Blown whistles were made by drilling and cutting a larger hole for blowing with the mouth or nose, and smaller holes of different diameters for changing tone. Swung whistles had tone holes plus small holes for attaching the swinging cord.

Some artifacts involve more elaborate construction. In musical instruments worldwide, gourds serve as rattles and as resonating boxes for drums and stringed instruments. Drums and resonating boxes are made by lashing or adhering skin over the open mouth of the gourd. The skins, cordage, lashing technique, and adhesive vary with the instrument size and the cultural group. Other drum types are made. In constructing a double-gourd Hawaiian drum, the *ipu hula,* a smaller gourd with a wide mouth is inverted into the mouth of a larger oblong gourd and the two adhered with gum (Buck 1957:405--407). Rattles may be simply constructed of a cleaned gourd with hard seeds placed inside and handle lashed on through small holes. A more elaborate Hawaiian rattle, the *ʻuliʻuli,* consists of a small spherical to ovoid gourd with an elaborately decorated handle. The gourd is pierced with four holes just below the stalk end through which the gourd is cleaned, and through which small hard seeds are fed. Plant strands pass through opposite holes and are bound together above the stem end of the gourd to form a handle. Buck (1957: 411) records the use of *ti* leaves (*Cordyline terminalis*) and the leaves of the climbing screw pine, *ʻieʻie* (*Freycinetia* sp.), for this purpose. Handles are elaborated with an ornamental disc of tapa, birdskin, feathers, and, after European contact, trade cloth. In one disc construction, Buck (1957:412--414) explains that the leaves of the handle were bound for several inches and then radiated out perpendicular to the handle. The ends of the leaves were folded over a wire hoop four inches in diameter and secured. (In older rattles, a hoop of *ʻieʻie* was used.) Discs were variously covered with tapa, birdskin, and cloth, and bird feathers were secured around the periphery (in some cases, at least, adhered with gum to the tapa).

**Decoration.** Many gourd artifacts are undecorated. Others are simply or very elaborately decorated. Decoration of gourds in Polynesia, particularly (or

possibly exclusively—according to Dodge 1943:59) in New Zealand and Hawaii, involved incising, cutting, and staining.

Dodge's (1943:66–67) examination of New Zealand decorated gourds indicates two styles of cutting or incising: in one, the design was outlined in deeply cut grooves; in the other, the background was created with numerous shallow incisions or cuts leaving the design in slightly raised relief. Buck (1957:36–37) describes the method of staining gourds in New Zealand to create patterns of the natural gourd color against a dark background: "The technique consisted of marking out the pattern by cutting through the outer skin of the gourd. The parts between the decorative motifs were scraped to remove the outer skin, and the gourd was immersed in the black mud of swamps after soaking in an infusion of bark. On removal, the gourd was washed and the parts that were not covered by outer skin had turned black, whereas the decorative pattern that was protected by the outer skin retained the natural yellowish color of the gourd … infusions or mixtures of bruised leaves or bark supplied tannic acid and ferruginous earth or black mud supplied some iron salt with the result that tannate of iron … was formed."

Some Hawaiian gourds are decorated with simple, incised geometric designs. Dodge (1943:59–60) cites seven artifacts with dark geometric patterns, slightly lower than the natural colored surface, which may have been created by burning or by cutting and staining. Most Hawaiian decoration is done by resist staining. In appearance, the designs consist of fine, light-colored geometric patterns on a dark ground. The gourd surface is smooth, often shiny, and in specimens examined microscopically by Eames and St. John (1943), no epidermis is present. Dodge (1943:60–63) quotes five reports of the staining process, all varying considerably in detail. The resist is reported to be either the incised epidermis, or a gum applied over the hypodermis after the epidermis is removed. The stain is reported to be a solution of plant material and/or mud, applied from the interior by filling the gourd and/or from the exterior by burying the gourd in dark mud. The mud is fairly consistently reported to be that of taro paddies, which would be rich in iron and organic matter. The plant materials reported are *Arum* stalks and leaves, *pala'a* fern, *Sphenomeris chusana* fern, *alahe'e* (*Plectronia odorata*) leaves, and *holei* (*Ochrosia sandwicensis*) tree bark. In one report (Handy and Handy 1972:217), the stain was set by steaming or baking the stained gourd in a pit oven, and the gourd finished by polishing with fine pumice.

Heiser (1979:166–169) describes carved, burned, and stained decoration in Peru and Africa. The design is engraved on the surface. Design areas are blackened by charring the area with a smoldering stick or hot tool; instead of being engraved then charred, the black areas may be burned-in in a single operation. Stains used to color design elements in Peru were trade secrets, but the use of acids was reported. A Nigerian stain reported was a red obtained from a paste of sorghum stalks boiled in cottonseed oil. A Zaïrian artist, Madya, colors the engraved design with shades of black by charring with hot tools and with white from kaolin. A glossy finish is achieved by polishing with oil from a palm nut. Gourd containers and musical instruments in Africa are also decorated with metal studs and wire staples.

**Covers and Slings.** Gourd containers are frequently covered in basket and net slings for protection and ease in handling and carrying. Dodge (1943:26,68) very briefly describes basket and net covers in Hawaii and New Zealand; many of his photographs include covered gourds. Stokes (1906:105–152) describes and diagrams in detail the construction of net slings and covers found on Hawaiian containers. *Olona* (*Touchardia latifolia*) and *hau* (*Hibiscus tiliaceus*) inner bark fiber cordate, sennit, and *ʻieʻie (Freycinetia arnotti)* are reported to be the common materials used. Basket and net covers fit snuggly, and, in most cases, must have been constructed over the specific gourd vessel.

**Traditional Repair Techniques.** Buck (1957:392) describes several gourd whistles in which the maker had changed his mind about the placement of finger holes and blow holes. The unwanted holes were plugged, but Buck does not say with what.

Cracked and broken gourds appear to have been commonly repaired by piercing small holes along both sides of the crack and then stitching across the crack. Buck (1957:33,44) mentions piercing the holes with an awl and stitching in various patterns with spun *olona* cordage. Dodge (1943:69) mentions drilling the holes and sewing with *olona*. Heiser (1979:125) reports the repair of gourds by sewing in Africa and South America.

*Crescentia cujete*

Tree gourds are used in Central and South America for cups, containers, and rattles *(maracas)*. Past uses included tribute containers, ritual vessels, and gold mining pans (Heiser 1979:18).

Decoration usually takes the form of design in the natural gourd color against a dark, highly polished resinous finish. This was achieved with resist and with carving techniques. Heiser (1979:22–23) relates a resist technique recorded in San Salvador in 1910 by C.V. Hartman: "After the tree gourd is cut and the contents taken out, the epidermis is removed and the surface polished with rough leaves until it becomes nearly white. Freehand decorations are then painted on the gourd with a paint brush dipped in beeswax. Following this, a mixture of a gummy solution made from sugar or honey, soot from wood, and boiled pods of a leguminous tree is rubbed over the gourd, giving it a brilliant black color." The wax is removed by placing the gourd in hot water, revealing the design in light against the dark ground.

Designs may be carved on unlacquered tree gourds; usually, however, the gourd is given a colored, resinous coating before carving. Heiser (1979:24) reports several coatings. In Guatemala, the tree gourd is covered with a yellow wax lacquer obtained from a scale insect, *Llaveira axin*, and soot, and then polished to a shiny black. A deep red is obtained by using the red coating of *achiote* seeds, *Bixa orellana*. In Brazil, the tree gourd is covered with a powdered tree bark extract, which turns glossy black when exposed to fermenting urine fumes, or is dyed by covering with fermenting or urine-soaked manioc leaves (*Manihot* sp.).

## Conclusion

The intention of this chapter has been to introduce the processes involved in the conversion of a part of a living plant to an artifact used within a society. The topic is much too large and diverse to cover anything but a few examples in detail. The intention has been not to present an exhaustive compilation of data, but to outline the general processes that are involved in conversion and may affect the physical and chemical properties of the artifacts under the conservator's care.

For the conservator, a major aim in studying technology is to enable him/her to recognize the material he/she is working with, how it has been manipulated, and how that manipulation affects the properties and stability of the artifact under consideration. The latter has not been detailed throughout this chapter. The effects of some processes and constructions—such as the catalysis of degradation of dyed fibers by metallic ions introduced in dyeing—and the inherent planes of weakness of some interworked constructions are familiar to most conservators. Inherent weakness of some processed materials—such as the looseness of several fragments of carved tree fern trunk adventitious roots and the incohesiveness of palm leaf sheathing petiole remains—can be readily deduced. Effects of processes, such as the introduction of various oils into bamboo and rattan and the retting and cooking of plant tissues, may be deduced from the deterioration mechanisms presented elsewhere in this manual. The net effect of other processes, such as the smoking of materials and artifacts, may be surmised, but requires further examination.

## References


**Agrawal, O.P.**

1984 *Conservation of manuscripts and paintings of Southeast Asia*. London: Butterworths.

**Altman, J.**

1982 Artists and artisans in Gunwinggu society. In *Aboriginal art at the top*. P. Cooke and J. Altman, eds. Maningrida, Northern Territory: Maningrida Arts and Crafts.

**Ashley, C.W.**

1947 *The Ashley book of knots*. London: Faber and Faber.

**Beg, M.A.A. and T.H. Usamani**

1980 Utilization of Mazri leaves for fibre production. *Pakistan Journal of Scientific and Industrial Research* 28 (3):211–214.

**Bell, L.A.**

1983 *Papyrus, tapa, amate and rice paper: Paper making in Africa, the Pacific, Latin America and Southeast Asia*. McMinnville, OR: Liliaceae Press.

**Brigham, W.T.**

1906 *Mat and basket weaving of the ancient Hawaiians described and compared with the basketry of the other Pacific Islands.* Honolulu, HI: Memoirs of the Bernice P. Bishop Museum 2(1).

**Buck, P.H. (Te Rangi Hiroa)**

1927 *The material culture of the Cook Islands.* New Plymouth, New Zealand: Memoirs of the Board of Maori Ethnological Research.

1950 *Material culture of Kapingamarangi.* Bernice P. Bishop Museum Bulletin No. 200. Honolulu, HI: Bishop Museum Press.

1957 *Arts and crafts of Hawaii.* Bernice P. Bishop Museum Special Publication No. 45. Honolulu, HI: Bishop Museum Press.

**Chattaway, M.M.**

1955 The anatomy of bark V: Eucalyptus species with stringybark. *Australian Journal of Botany* 3:165–169.

**Chen, Chi-lu**

1968 *Material culture of the Formosan Aborigines.* Taipei, Taiwan: The Taiwan Museum.

**Christensen, G.**

1985 *The deterioration of New Zealand flax.* Conservation of Cultural Property No. 1. Otago University research project. Wellington: Interim Committee for the Conservation of Cultural Property.

**Clark, J.**

1983 *The aboriginal people of Tasmania.* Hobart, Tasmania: Tasmanian Museum and Art Gallery.

**Cole, F.C.**

1913 *The wild tribes of Davao District.* Field Museum of Natural History Publication No. 170. Anthropological Series, Vol. XII (2). Chicago: Field Museum of Natural History.

**Collins, J.L.**

1960 *The pineapple.* London: Leonard Hill Books.

**Courtenay, P.P. and N.J. Chadwick**

1983 Punan art and artefacts. *Arts of Asia*, November-December.

**Dawson, J.**

1881 *Australian Aborigines: The language and custom of several tribes of Aborigines in the Western District of Victoria, Australia.* Melbourne: Walker, May and Co., (Facsimile edition published 1981, Australian Institute of Aboriginal Studies, Canberra.)

**Dodge, E.S.**

1943 *Gourd growers of the South Seas.* Ethnographical Series No. 2. Boston: Gourd Society of America.

**Dransfield, J.**

1979 *A manual of the rattans of the Malay Peninsula.* Malayan Forest Records No. 29. Forest Department, Ministry of Primary Industries, West Malaysia.

**Eames, A.J. and H. St. John**

1943 The botanical identity of the Hawaiian *ipu nui* or large gourd. *American Journal of Botany* 30(3):255–259.

**Emery, I.**

1966 *The primary structures of fabrics.* Washington, D.C.: The Textile Museum.

**Ewins, R.**

1982 *Mat-weaving in Gau, Fiji.* Fiji Museum Special Publication No. 2. Suva, Fiji: Fiji Museum.

**Gilberg, M.**

1986 The care and preservation of birch bark scrolls in museum collections. *Curator* 29(1):67–80.

**Handy, E.S. Craighill and E.G. Handy**

1972 *Native planters in old Hawaii: Their life, lore and environment.* Bernice P. Bishop Museum Bulletin No. 233. Honolulu, HI: Bishop Museum Press.

**Hayward, C.I.**

1978 *Practical woodwork.* New York: Drake Publishers.

1979 *Woodwork joints.* New York: Sterling Publishing Co.

1979 *Staining and wood polishing.* New York: Sterling Publishing Co.

**Heiser, C.B.**

1979 *The gourd book.* Norman, OK: University of Oklahoma Press.

**Hoadley, R.B.**

1980 *Understanding wood: A craftsman's guide to wood technology.* Newton, CT: The Taunton Press.

**Huke, R.E.**

1963 *Shadows on the land: An economic geography of the Philippines.* Manila: The Bookmark, Inc.

**Jane, F.W.**

1970 *The structure of wood.* London: Adam and Charles Black.

**Kamakau, S.M.K.**

1869 *The words of the people of old*. (Translated by Mary Kawena Pukui from the original Hawaiian published in *Ke Au ʻokoʻa*.) Bernice P. Bishop Museum Special Publication No. 61. Honolulu, HI: Bishop Museum Press, 1976.

**Kathpalia, Y.P.**

1966 *Writing materials of the ancients in India: Bark paper*. Indian Pulp and Paper July:57–58.

**Kennedy, R.**

1972 Bark-cloth in Indonesia. *Journal of the Polynesian Society* 43, (1934):229–43.

**Koojiman, S.**

1963 *Ornamented bark cloth in Indonesia*. No. 16. Leiden: Mededelingen van het Rijksmuseum voor Volkenkunde.

1972 *Tapa in Polynesia*. Bernice P. Bishop Museum Bulletin No. 234. Honolulu: Bishop Museum Press.

**Lee, D.J.**

1980 The removal and conservation of the painted bark [sic] panels and carved figures from a Papua New Guinea Haus Tambaran. Paper presented at Symposium 86: The Care and Preservation of Ethnologic Materials. Ottawa: Canadian Conservation Institute.

**Lessard, G. and A. Chouinard, eds.**

1980 *Bamboo research in Asia*. Proceedings of a workshop held in Singapore, 28–30 May 1980. Ottawa: International Development Research Centre.

**Liese, W.**

1980a Anatomy of bamboo. In *Bamboo research in Asia*. Proceedings of a workshop held in Singapore, 28–30 May 1980. Ottawa: International Development Research Centre, 161–164.

1980b Preservation of bamboo. In *Bamboo research in Asia*. Proceedings of a workshop held in Singapore, 28–30 May 1980. Ottawa: International Development Research Centre, 165–72.

**Lock, G.W.**

1962 *Sisal*. London: Longmans, for the Tanganyika Sisal Growers' Association.

**Lubke, A.**

1969 Bamboo. *Ciba Review* 3:2–39.

**Marden, L.**

1980 Bamboo, the giant grass. *National Geographic Magazine* 158(4):502–529.

**Mason, O.T.**
1904 *Aboriginal American Indian basketry*. Government Printing Office, Washington D.C. Originally issued as annual report of the Board of Regents of the Smithsonian Institution, June 30, 1902. Reprinted in 1976, Santa Barbara, CA: Peregrine Smith.

**McCarthy, F.D.**
1974 *Australian Aboriginal decorative art*. Sydney: The Australian Museum.

**McClure, F.A.**
1966 *The bamboos*. Cambridge: Harvard University Press.

**Mead, S.M.**
1969 *Traditional Maori clothing*. Wellington: A.H. and A.W. Reed.

**Menon, K.D.**
1980 Rattan: A state-of-the-art review. In *Rattan*. A report of a workshop held in Singapore 4–6 June 1979. Background paper. Ottawa: International Development Research Centre, 11–74.

**Métraux, A.**
1940 *Ethnology of Easter Island*. Bernice P. Bishop Museum Bulletin No. 160. Honolulu, HI: Bishop Museum Press.

**Mosuwadoga, G.N.**
1978 *Traditional techniques and values in the Lower Musa River*. Port Moresby: National Museum of Art Gallery.

**Ng, M.**
1978 *Natido Binwag weaves the bango*. Manila: The Council for Living Traditions.

**Niho Sen'i Isho Senta**
1980 *Textile designs of Japan*. Japan Textile Color Design Centre. Tokyo: Kodansha International.

**Orchard, W.D.**
1971 *The technique of porcupine quill decoration among the North American Indians*. New York: Museum of the American Indian Heye Foundation.
1975 *Bead and beadwork of the American Indians*. New York: Museum of the American Indian Heye Foundation.

**Pearlstein, E.**
1986 Fatty bloom on wood sculpture from Mali. *Studies in Conservation* 31(2):83–91.

**Rymar, G.I.**
1978 Conservation and restoration of birch-bark manuscripts. *ICOM Committee for Conservation Preprints*, 5th Triennial Meeting. Zagreb, (78/14/17):1–6.

**Sandale, R. and N. Peterson**
1969 Making a bark canoe. 16 mm. color/sound film. Educational Media. Australia.

**Satow, Sir E.**
1899 *The cultivation of bamboos in Japan*. Tokyo: The Asiatic Society of Japan.

**Seiler-Baldinger, A.**
1979 *Classification of textile techniques*. Ahmedabad, India: Calico Museum of Textiles. (Translated by B.V. Iyer from German: Systematik der Textilen Techniken. Basler Beitrage zur Ethnologie, Band 14, Museum für Volkerkunde Basel. Basel, Switzerland: Pharos-Verlag Hansrudolf Schwabe, AG, 1973.)

**Sharma, Y.M.L.**
1980 Bamboos in the Asia-Pacific region. In *Bamboo research in Asia*. Proceedings of a workshop held in Singapore 28–30. Ottawa: International Development Centre, 99–120.

**Sieber, R.**
1972 *African textiles and decorative arts*. New York: The Museum of Modern Art.

**Stokes, J.F.G.**
1906 *Hawaiian nets and netting*. Honolulu, HI: Memoirs of the Bernice P. Bishop Museum 2(1):105–162.

**Tamolang, F.M., et al.**
1980 Properties and utilization of Philippine erect bamboos. In *Bamboo research in Asia*. Proceedings of a workshop held in Singapore 28–30. Ottawa: International Development Research Centre, 189–200.

**Thomson, D.F.**
1939 The tree dwellers of the Arafura swamps: A new type of bark canoe from central Arnhem Land. *Man* 39(109):121–128.

**Von Hagen, V.W.**
1977 *The Aztec and Maya papermakers*. New York: Hacker Art Books.

**Whitaker, T.W. and G.M. Davis**
1962 *Cucurbits: Botany, cultivation and utilization*. London: Leonard Hill Books.

**Wilcox, D.**
1985 The bark papermakers of San Pablito. *Fiberarts* 12(4):22–25.

# 4 Deterioration of Artifacts Made From Plant Materials

*Dale Paul Kronkright*

Studying the deterioration of plant material in artifacts is, in itself, a problematic issue. Most commonly, scientists describe deterioration mechanisms—whether chemical, physical, mechanical, or biological—using models that appear to account for observed phenomena in carefully controlled and focused experiments. Typically, the systems studied are isolated or highly homogenous and all but one or two variables are controlled. Slowly, a somewhat clearer picture of a particular deterioration mechanism begins to emerge. Models for the process are created and then tested to find the errors in the model and increase its accuracy.

Plant materials in artifacts afford us none of the luxuries of isolation, homogeneity, or control. They are incredibly variable, even within a stem or leaf. Natural materials are formed under the influence of daily changes in the environment and reflect those changes in the organization of their structures. The plant materials used in artifacts are frequently cultivated to maximize certain characteristics, then manipulated in preparation and manufacture through a variety of conditions and treatments. Next, they often go through a useful lifetime of wear, utility, native care and abuse, and other poorly documented trials and treatments. Finally, they are collected and subjected to a whole new range of ritual conditions that seek to meet the needs of the connoisseur or curator. It is indeed true that no two objects have undergone the same conditions leading to their present state of preservation.

The deterioration mechanisms also add to the complexity of our task. Seldom, if ever, do they take place in isolation or affect a single component of plant material. Instead, deterioration takes place—to greater or lesser degree—simultaneously at all levels of organization discussed in previous chapters. This diffuseness makes the study and understanding of deterioration of artifactual plant materials complex and often confusing. Each level of organization has various characteristics that may be affected by deterioration processes and the products of these processes at any one level of organization may have an effect on the rate of deterioration reactions for the same and other levels of organization. It follows that relying on commonly understood models for routes of deterioration of plant materials may result in a false sense of clarity.

The artifact itself often provides clues for how to proceed. It is possible to study the ways the artist put the artifact together. With experience, the technologies

and structures can guide our understanding of how the object was meant to behave, rest, wear, and be used. Conservators must learn to read the object, its inherent strengths and weaknesses, and the areas or materials most vulnerable to damage. We must learn to read the materials and structures for whatever signs of deterioration they might offer: color changes, accretions, efflorescences, susceptibility to abrasions, brittleness, loose structures, fractured or torn elements, distortions, and previous repairs pointing to inherently worn or weakened areas.

# Factors in Deterioration

In an important work, Florian (1981) makes several observations about deteriorated plant material and the impacts that degraded materials can have on conservation treatments. In a discussion on the deterioration of terrestrial waterlogged wood, she points out that the variability found in these materials is due to the sum total of: (1) different states of deterioration, (2) different wood species, (3) different physical descriptions of the artifact, and (4) different histories of the artifact's ethnographic use. We might add to this list a fifth variable: different conditions imposed on the artifact after collection.

Florian goes on to define the first variable as the net result of the different agents of decay and environmental conditions to which the artifact has been subjected. Identifying some of the chemical, morphological, and mechanical consequences of deterioration may help to clarify the contributions of the various mechanisms. The second variable may be taken into account by using simple methods to discover, at the very least, the kinds of cells and tissues present in the artifact. Equipped with this information, one can consult the literature and the conservation scientist to determine what processes and compounds may further contribute to the denaturation of the important remaining tissue properties. The third variable can be understood by knowing the mechanical characteristics of the various artifact structures.

The fourth variable relates to the reasons the artifact is suitable for a museum collection and worthy of conservation in the first place. The preservation of such information—disclosed in patterns of wear and distortion, as well as in deposits from materials used or processed during utility and during burial or deposit at a site—is one of the resources that has made possible the fundamental purposes of a museum.

The fifth variable may be more closely understood through museum conservation records, curators' and registrars' notations and catalog entries, correspondence with collectors, ethnographers and/or archaeologists, published accounts of earlier treatments, and through analyses. In combination, this data makes it possible to not only account for the variability in preservation of artifacts made from plant materials but also to accurately characterize their deterioration and thereby plan for their preservation.

## Conservation as Deterioration

Shortly, we will consider a definition of deterioration that will focus our attention on the consequences for planning conservation treatments. Yet, underlying the discussions concerning treating problematic aspects of deterioration is an assump-

tion of great importance to contemporary conservation practice. Material culture must be treated with respect for the great potential it has to explain and expand our awareness of the rich and uniquely human approaches to living on the planet.

Often, these objects are part of systematic anthropological collections; the potential for analytical and comparative studies of the whole collection is of greater importance than the merit of any one particular object. This fact has important implications for our attempts to identify and stabilize deteriorating conditions. All evidence of utility or origin including food residues, abrasions, discolorations, patterns from wear or handling, and so on, have the potential to significantly add to or clarify the body of knowledge embodied in the collection. Treatments must not only address the property that has failed to such an extent as to have resulted in instability—they must also avoid confusing or obscuring any potential intrinsic data or detrimentally affecting any stable properties that may remain in the plant materials.

Our concern, as conservators of these materials, is to provide for their long-term preservation, ensure their proper and complete investigation, and make possible their prudent use to instruct and inspire. Yet, because of the complex ways in which the many dimensions of determination affect the condition of an artifact, often we find our practices and materials inadequate to properly address all our responsibilities.

Deterioration of materials or structures can never be reversed. The damage has been done. The same may also be true for previous conservation treatments. This fact presents us with an ethical as well as procedural problem. A National Institute for Conservation (NIC) report (1984) notes a growing concern that the vast analytical potential of these objects in collections may easily be lost through inappropriate conservation treatments. As a profession, we have become aware of *ourselves* as a potentially dramatic dimension in deterioration processes. Clearly, our treatments can interfere with future analysis of the object and alter associated components that have not deteriorated.

As a result, we now witness a movement in conservation to encourage less intrusive approaches to treatment. These include controlling surroundings and environments in order to stabilize deteriorating materials and structures and prevent developing deterioration processes. This trend is particularly true for ethnographic and archaeological collections. In essence, we are forging a future, as yet unknown even to ourselves, through our restraint. As stated in the NIC report, "Whereas art conservation often seeks to return a work of art to its original condition, ethnographic and archaeological conservation should seek to preserve the object's life history at the time of collection" (1984:4). This may, on occasion, mean deferring treatments until a time in the future when developments in materials and methods provide us with more suitable alternatives.

Lyall (1980) makes an interesting contribution to the literature with her review of conservation approaches to Australian aboriginal artifacts made from bark. In her work, Lyall describes the morphology, heavy extractive content, and other qualities and aging characteristics of eucalyptus barks. Although she does not specifically cite the role of the heavy extractive content on resistance to biological decay, moisture and vapor permeability, and color in barks, Lyall does note that the impact of solvented treatments in flattening and other conservation treatments could cause

changes in the remaining natural properties of the bark. Lyall (1980:20) states, "The development of a satisfactory method of conservation is dependent on a thorough understanding of the composition and properties of the materials from which the object is made. Unfortunately, in the past, few conservators have used this approach in treating bark objects."

Lyall attempts to assess the probable effects of some typical conservation treatments. She also discusses the chemistry of bark and the normal extracting solvents, including reference to extraction of the saturated hydroxy fatty acid suberin by alkaline alcohol. Finally, she addresses the problems caused by treatments that use solvents with the high extractive content of bark, and questions flattening techniques that exert stresses on an object, as well as the use of hygroscopic materials that may cause molding.

## Focusing the Study of Deterioration

Before considering the deterioration of plant materials in a systematic manner, we have placed the task at hand in a number of important contexts. First, it is important to remember that no one deterioration process takes place in isolation. Plant materials undergo deterioration from a variety of sources simultaneously at rates that are partly dependent on environmental conditions, tissue types, and artifact design. These result in the physical, mechanical, and chemical changes found in the artifact. Likewise, any one deterioration process can attack artifacts made from plant materials at any number of levels of organization.

Second, studying the deterioration of plant materials, in one sense, means learning the process of "reading" the artifact. Perhaps there can be no greater insight into the conservation needs of an artifact than that provided by a truly systematic examination of its condition. The creator of the artifact made conscious decisions about the strength and utility of the object, beginning with the selection, cultivation, and preparation of the specific materials found in the artifact. Tissue types relate strongly to functional requirements for the material within the artifact. Many materials undergo deterioration in unique or specific ways that can also serve as indicators of the conditions encountered by all materials in the artifact.

Considering what manufacturing techniques were used for the various parts of an artifact's construction also allows us to learn how the maker intended the object to sit or rest, as well as how it was to be used. This knowledge may, in turn, allow us to better understand distortions, worn or damaged areas, and discolorations and abrasions, as well as suggesting parts of the structure best suited for supporting the piece in exhibition or storage.

Third, now we must also carefully consider our own actions as potential contributors to deterioration. It has become clear that much of what has been done in museums in the past has served to confuse or obscure potential information contained in artifacts. In the case of many ethnographic and archaeological objects, much of the deterioration or "damage" found in the artifact may be part of what we are trying to preserve, protect, and study.

The complexity of the deterioration process, the value of a systematic examination, and the importance of a nonintrusive approach to conservation will be strong underlying themes throughout the remainder of the chapter. They will

illuminate our understanding of the deterioration of plant materials and guide our approach to conservation practices.

For conservators and conservation scientists, it can be useful to define deterioration in a way that allows us to explore many related ideas. Questions about when deterioration begins, if it stops, when it creates unstable situations, when it may be stable, what it means to the understanding of the object, and what concerns the conservator should have about it can only be developed and answered if there is a shared and useful definition of deterioration. Although some terms must be thought of broadly when considering the breadth of cultural and artistic material, an operational definition can be adapted from that proposed by Krueger (1986:1040):

> Deterioration can be defined as those processes which individually or in combination, result in changes to the properties of an artifact material or structure, thereby reducing their ability to perform any of their intended functions, or which serve to destroy, obscure, or confuse original intrinsic information.

Perhaps the most significant use of such a definition of deterioration is that it encourages us to question *which specific properties* of an artifact have deteriorated to such a point as to make the object unstable. Properties are generally related to observed changes in the artifact that are seen to be undesirable or problematic. Typically, changes in chemical, mechanical, structural, and visual properties produce a range of consequences—from the effect on the visual or aesthetic value of the artifact to its value in documenting native utility. Common examples are color changes, distortions, and changes in the flexibility of materials and the responsiveness of structures: weaknesses; breaks; tears; fractures; separating attachments; and pigments, coatings, native food, or other deposits flaking from the artifact or being destroyed by insects.

## Properties and Levels of Organization

At the molecular level, some chemical properties may directly affect object stability. Deterioration of compounds forming chromophores whose absorbance characteristics result in a color change are a good example. Deterioration of cuticle waxes, oils, resins, and lignin can directly relate to changes in permeability, moisture regain, and subsequent susceptibility to further deterioration.

Frequently, however, changes that take place at several levels of organization result in observable changes in the plant material's mechanical or chemical properties. Brittleness, a commonly observed condition of museum artifacts made from plant materials, results from the deterioration of several properties: Not only do oxidation and hydrolysis play a significant role at the molecular level, but so do structural and material deformation, swelling and shrinkage, and possibly ethnographic deposits.

### The Retention of Properties

It is our responsibility as conservators to identify, as best we can, the extent of deterioration at all levels of organization, as well as those properties that still contribute to

the stability remaining in the object. It is important that any treatment to address deficiencies in a given property avoids altering original properties that are still intact.

Properties of plant materials are seldom completely lost. Tensile strength, bending strength, moisture regain, and other measurable mechanical properties are often measured by the portion of the original property still retained by the deteriorated material. Measurements are made to determine how much strength is left, how much elasticity remains, and how much continuity remains in the structure. Retention of properties is an important concept for the conservator; it points out that deterioration of artifacts need not be inherently unstable, nor require treatment. Although it is common for deterioration of an artifact to result in changes that render it unserviceable in its original cultural context, in a museum setting the degree of property retention required to achieve stability and ensure preservation may easily be met by a deteriorated artifact. Deterioration does not necessarily mean that the object will be unstable in a given museum setting.

## Problematic Conditions

The concept of property retention allows us to recognize that not all museum settings are the same, and that stability in storage and stability on exhibit or in transit all require different degrees of mechanical, chemical, and structural property retention in the artifact. A deteriorated artifact may, for example, be stable in dark storage but have oxidation products present that make the artifact much more light sensitive on exhibition. Problematic conditions are those that, in a specified museum setting, result in further deterioration. Perhaps the piece sheds portions of tissues when handled, leans to one side from distortion on exhibit, loses attachments and pigments, or continues to tear and fracture when handled or transported.

Using our definition of deterioration, the focus of any conservation methodology should therefore be twofold. First, it would determine which portion of the material's original properties were retained by the artifact, and which had been lost or altered to an extent that resulted in instability. Second, it would encourage us to determine the minimum degree of recovery of those specific properties needed to affect stabilization of deteriorating materials in a given museum setting.

## Deterioration and Ethnographic Evidence

Our operational definition of deterioration has some important consequences for ethnographic and archaeological artifacts. Clearly, processes that reduce the ability of the material and structures to perform their intended functions—whether aesthetic, utilitarian, or documentary—begin shortly after the fabrication of the object is completed. Deterioration, using our definition, begins almost immediately.

Evidence of deterioration while in use prior to collection is an extremely important part of what we are attempting to preserve. Evidence of wear, distortion, repairs, deposits, and stains establish the cultural context into which all other comparative materials are placed.

The possibility for future analyses of deposits on archaeological and ethnographic objects should be considered by the conservator. If complex characterizations of organic compounds are outside a museum's current instrumentation or

budget limitations, the conservator has all the more reason to advocate restraint in modifications to the artifact. These deposits are an important source of information which can potentially broaden and clarify the picture we now hold of a group of people.

The value of such a perspective often extends beyond the obvious preservation of food deposits and signs of wear. Jane Bassett, Objects Conservator at the Bishop Museum, brought an archaeological carved wood vessel into the conservation lab for examination. The object was collected from one of many cave sites containing pre- and post-contact Hawaiian materials.

The piece was collected at a time relatively void of archaeological systematics and, as a result, little documentation as to the geographic location of the cave and its associated artifacts existed. On the interior surface of the vessel, Bassett found remnants of soil and a mud nest of a species of wasp, made of a mass of iron-laden dirt, plant fibers, and insect remains.

Presented for her consideration, therefore, was a hygroscopic, insect-inviting, metal-ion-containing potential deterioration source, tenaciously adhered to the cross-sectional tissues of the plant material. Yet Bassett remained cautious about the wisdom of removing the wasp nest. If the nest was formed prior to the artifact's removal from the cave, and if the wasp was specific to a very narrow ecological area on the Hawaiian Islands, as many insects are, the value of the nest to developing the provenance of the vessel and its associated cave artifacts could be tremendous.

## The Processes of Deterioration

In this chapter, deterioration processes affecting artifacts made from plant materials are grouped into four general categories: physical, chemical, mechanical, and biological. In reality, these four groups are never discrete in their effects upon artifact materials. They interact and work together to deteriorate both object materials and structures. Physical processes involve deterioration of properties through interaction with loads and forces, stresses applied in swelling and shrinkage, and changes in dimension and molecular structure caused by thermal and light energies. Chemical processes of deterioration involve chemical reactions with compounds inherent to the material or those introduced by the environment or in conservation treatments.

Mechanical processes of deterioration also result in tears, fractures, wear and abrasion, related deformation, and applied soiling and staining. Frequently, mechanical deterioration results in damage that can be understood as interruptions in the original structural continuity intended by the maker. In these cases, specific parts of the structure are damaged and their function within the artifact to absorb and distribute stress to associated structural elements can be lost or impaired.

Biological processes are those caused by attacks of fungi, molds, bacteria, insects, and rodents. They may result in loss and weakening of original materials and structures, staining, distortion, and loss of ethnographic deposits.

Each of these types of deterioration processes will be considered in the context of their impact on museum artifacts made from plant materials and their implications in the planning of appropriate conservation treatments.

## Physical Deterioration

The action of physical phenomena such as changing relative humidities, physical forces resulting in loads and stresses, thermal energy, and radiant energy are part of the plight of artifacts made from plant materials, even before their fabrication is complete. Cooking, steaming, retting, drying, swelling, deforming, and sun bleaching are important parts of many fabrication processes, and are common sources of physical deterioration.

The processes have been studied in some detail, usually in isolation and as components of more homogeneous structures, such as papers or ultimate fibers. Plant tissues, however, seldom approach such homogeneity in their structures, at any level of organization. Thus we are reminded that each time we begin a study of a model for an isolated deterioration process, we are seeing only a part of a very complex picture.

### Swelling and Shrinkage

It is well known that if the capacity to hold water vapor decreases in the air surrounding a plant material—as a result of a decrease in temperature, for example—the material will swell. Conversely, if the capacity of the air to hold water vapor increases, the plant material will shrink. This has obvious consequences for veneered furniture or paintings on panels. But the impact on artifacts made from plant materials is more complex and deserves explanation beyond the understanding that the materials are changing volumetrically.

#### Hydrogen Bonding

We know that many organic compounds exhibit polarity in their electron attracting and repelling characteristics. As Florian has pointed out in an earlier chapter, cellulose itself is a highly polar molecule, exhibiting strong intermolecular attraction and bonding (see Chemistry and Structure of the Cell Wall, Chapter 1). A great number of organic compounds exhibit hydrogen bonding, which is weaker than ionic or covalent bonding but stronger than the intermolecular van der Waals forces (see Figure 4.1). Hydrogen bonding can take place between any slightly electron-rich atom and a somewhat acidic hydrogen atom.

The strength per mole of hydrogen bonds ranges from about 5 to 10 kcal/mol. This energy has little effect on covalent bonds, which are ten times as strong. They are strong enough, however, to provide great strength to cellulose crystalline structures (Barrow 1972:318).

Water is a good example of such a compound. Because of oxygen's electron-attracting capabilities, the electrons from the covalent bonds with hydrogen spend a greater percentage of their time near the oxygen nucleus (Figure 4.1). The hydrogens acquire a slight positive polarity and the oxygen a slight negative polarity. In ice, the water molecules arrange themselves in an orderly fashion, and the proximity of the hydrogens to two neighboring oxygens, and of the oxygen to a neighboring hydrogen, allows hydrogen bonding and increased crystalline structuring in the material. (For an illustration of this molecular arrangement, see Barrow 1972:321.)

*Figure 4.1. Hydrogen bonding between water molecules (Barrow 1972:520).*

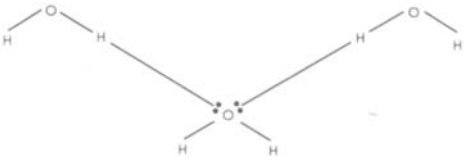
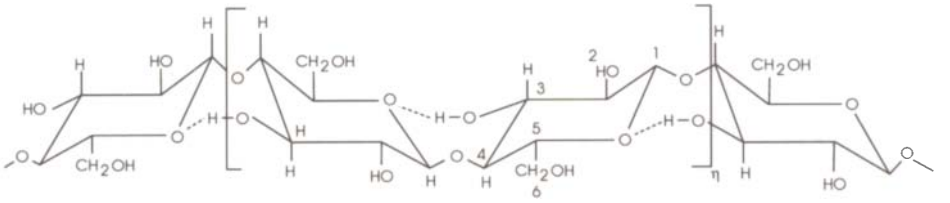


*Figure 4.2. Hydrogen bonding between anhydroglucose units within the cellulose chain (Barrow 1977:251).*



In plant materials, hydrogen bonding plays a fundamental role. Cellulose, formed by the condensation of several thousand anhydroglucose molecules through glucosidic 1-4 ether bonds, also benefits from hydrogen bonding between the hydrogen of the 3-carbon hydroxyl group and the ring oxygen atom of the neighboring glucose unit (Figure 4.2). The overall shape of this ladderlike polymer is shown in Figure 4.3.

*Figure 4.3. Overall shape of cellulose chain.*

Cellulose polymers increase in crystallinity as the three-dimensional structure becomes more orderly and tightly packed. Hydrogen bonds allow adjacent, evenly spaced cellulose polymers to form hydrogen bonds between the 6-carbon hydroxyl group hydrogen and the oxygen of an adjacent 3-carbon hydroxyl group (Figure 4.4).

*Figure 4.4. Hydrogen bonding between cellulose chains.*

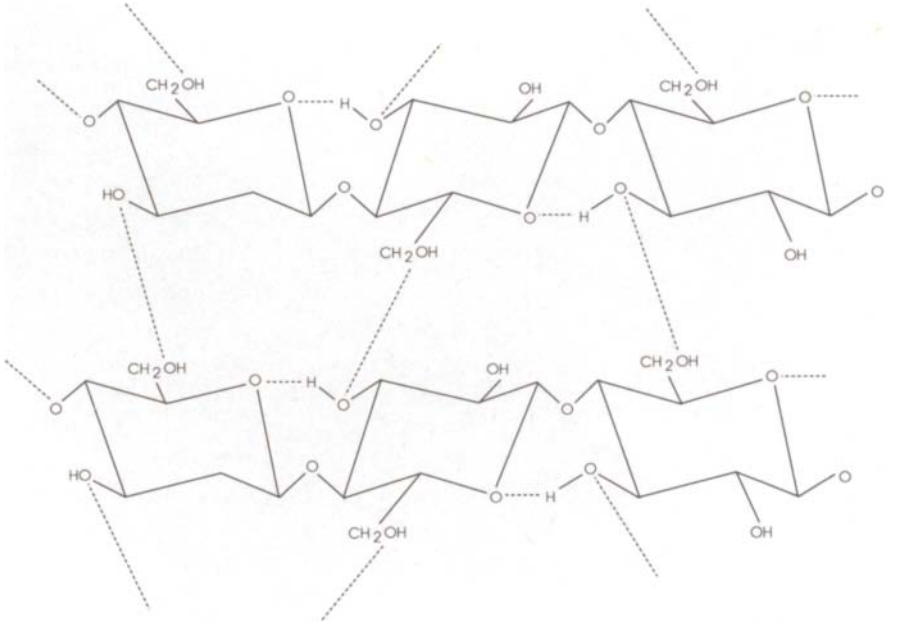


*Figure 4.5. Some configurations of anhydroglucose units in a two-dimensional model of cellulose (Atalla 1981:171).*

*Figure 4.6. Some configurations of sheets of anhydroglucose units showing the intramolecular ordering of the polymer (Atalla 1981:172).*

### Crystalline and Amorphous Regions

Plant materials, from the molecular level to the cellular, contain both highly oriented crystalline regions, where nearly all available sites are bonded, and amorphous regions, which are less tightly oriented. As Florian points out in Chapter 1, crystalline micelles have no available sites or routes for solvents or enzymes to penetrate. The only sites available to hydrogen bonding with a solvent are those along the edge of the crystalline regions where no other suitable hydrogen or oxygen atoms are close enough to form a bond.

Atalla (1981) points out that the ordering of crystalline and amorphous segments of cellulose in the native state is highly variable. If we use his illustration of a simple two-dimensional model for cellulose, we see that the rectangular blocks representing anhydroglucose units connected diagonally at alternating corners can easily take on a number of configurations (Figure 4.5). The figure illustrates highly disordered, partially disordered, and a highly ordered intramolecular ordering of the polymer. The next level of organization is aggregates or sheets of adjacent polymers. In Figure 4.6, one can see the variability possible, with differing ratios of crystalline and amorphous regions.

### Hemicellulose, Amorphous Regions, and Hydrogen Bonding

As Florian describes in Chapter 1, hemicelluloses appear to act as a protective hydrated amorphous matrix surrounding cellulose fibrils. They swell the areas between microfibrils and fibrils apart, preventing aggregation, hydrogen bonding, and crystallization. They form a flexible gel, allowing strong crystalline regions to slide, compress, and move away from each other when the cell is put under tension, compression, or other load (Figure 4.7).

Hemicelluloses can do this because they are composed of many polysaccharides, not simply the geometrically convenient glucose cyclical structure. They contain both open-linear and cyclic sugars including xylose, mannose, galactose, and glucose. This means that the hemicelluloses are not able to polymerize and orient themselves in the manner of cellulose. They bond to the available sites along the edges of the crystalline regions and in the amorphous regions between crystalline micelles. They branch in three dimensions and therefore cannot create hydrogen bonds with adjacent hemicelluloses. The matrix hydrates, performing as a gel and forming hydrogen bonds with water (or another solvent with a similar dipole moment). This is what causes volumetric swelling with increases in relative humidity (Figure 4.8).

## Mechanosorptive Creep

Artifacts fabricated from plant materials always have a specific form intended by the maker that allows the artifact to distribute the stresses and loads placed upon it in service without failing, tearing, or breaking. In tapa (barkcloth), this is accomplished by a felted network of bast fibers, aligned in specific directions. In basketry, it is accomplished through the number, size, type, and contact surface areas of the weaving elements and by the fabrication technology employed. In cordage, it is accomplished by the number, length, diameter, and twisting and/or braiding method used. In each case, however, the plant materials are restricted from, and are restricting, the

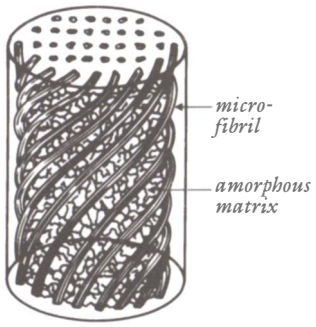



*Figure 4.7. Helical arrangement of fibrils in cellulosic fiber.*

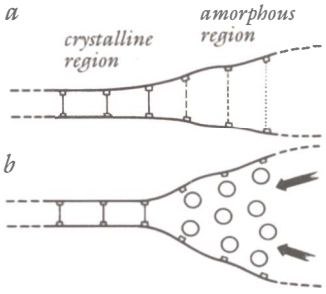



*Figure 4.8. The swelling of hemicellulose (After Cumberbirch 1984:60).*

possible movements the material might take upon swelling or shrinkage. Scientists who study the mechanics of plant materials and their response to such movement say that the material is under a stress from an applied load (Schniewind 1983).

Brommelle and Moncrieff (1969) cite Gibson's (1965) explanation of the response of wood to adsorption and desorption of water vapor under a load. Gibson notes that adjacent cellulose chains—as well as the hemicelluloses that cement and bulk apart adjacent crystalline regions—are held together by hydrogen bonds. During sorption and desorption, water molecules move quickly through the material, hopping from one available site to the next, forming and breaking hydrogen bonds many times.

Gibson points out that each break in bonding weakens the material slightly in response to an applied stress. The breaking of bonds allows adjacent regions to slip past each other, compress, or otherwise take on a new configuration. A spatial reordering of the adjacent chains thus takes place as a result of swelling. Upon desorption, tensile stresses caused by lost water molecules draw newly aligned regions closer together. Hydrogen bonding takes place between closely associated celluloses and hemicelluloses that are stronger than those made with water.

Other hemicelluloses degrade as a result of hydrolysis and oxidation (to be discussed later), and are solubilized from their positions between crystalline regions. This causes shrinkage to take place from a smaller and different deformed configuration. The material is now in a different shape, from which it cannot recover. The new shape also has an increase in newly oriented, tightly packed crystalline regions. Upon subsequent adsorption, the hydroxyl groups are not freed for bonding with water, leading to lower moisture regain.

The process of deformation in plant materials is known as creep. Two kinds of creep take place in artifact materials; Boyd (1982:171) defines them as viscoelastic and mechanosorptive creep. Viscoelastic creep is the deformation beyond the elastically recoverable deflection that occurs with loading at constant moisture content. Mechanosorptive creep, on the other hand, is defined as deformation that occurs as a consequence of changes in moisture content of the material while subjected to applied forces.

Schniewind (1983) points out that mechanosorptive creep, a form of plastic (that is, nonelastic) deformation, takes place to a greater extent during periods of swelling agent adsorption and desorption than when the moisture content is constant. This obviously has a significant impact for the conservation of these materials, both in terms of the importance of protecting artifacts from changes in moisture content and for any efforts to reduce the extent of deformation in artifacts made from plant materials.

## Decreased Moisture Regain

Changing humidities do more than change materials volumetrically and cause distortions. Each change in relative humidity results in three significant changes to the material in addition to those we have just considered. The first result is that, increasingly, sites along amorphous regions available for hydrogen bonding with water will be taken with new, more closely oriented hydrogen bonding between cellulose polymer aggregates. This takes place at many levels of organization wherever water mole-

cules could once penetrate: amorphous regions between the crystalline micelles, between cellulose aggregates in the microfibrils, between microfibrils within the fibrils, and between the fibrils within the cell wall (Figure 4.9).

The net result is that the quantity of water molecules taken into amorphous regions following a previous desorption and subsequent mechanosorptive creep is decreased. We say that the moisture regain of the material has decreased. A decrease in moisture regain means that there are fewer available sites, and consequently fewer gel amorphous regions between crystalline areas to allow flexibility, compression, tension, and elasticity.

## Increased Crystallinity

As there is a decrease in amorphous regions, there is an increase in overall orientation at many levels of organization. Contributing to this process are cleavages of cellulose and hemicellulose polymers through hydrolysis and oxidation processes (to be discussed later). Again, one must keep in mind that none of these processes are taking place in isolation. As we shall see, the oxidation of lignin not only decreases the hydrophobic properties afforded to cellulosics in the primary cell wall and middle lamella, but contributes to their oxidation as well.

The net result, however, is an increase in crystallinity of cellulose. Referring again to Atalla's discussion and two-dimensional model for cellulose in Figure 4.8, one can see that the degrees of order can again take place at many levels of organization. Increased ordering can take place at the molecular level within the cellulose polymer, between cellulose polymer aggregates within the micelles, and, as noted earlier, within all the amorphous regions from the areas between the micelles to the cell wall itself.

## Collapse of Cell Wall Microcapillaries

The third impact of repeated shrinking and swelling involves the cell wall itself, principally the secondary cell wall. Strength and elasticity in plant materials are closely dependent on homogeneous distributions of crystalline and amorphous regions within the cell wall. As explained in the previous two sections, repeated sorption and desorption of a swelling solvent, among other processes, contributes to the

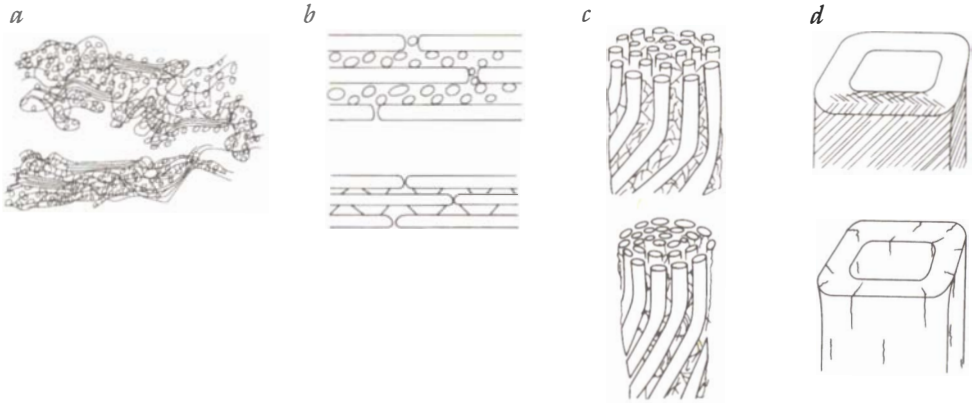



*Figure 4.9. Effects of desorption and subsequent mechanosorptive creep on amorphous regions (a) between crystalline micelles, (b) between cellulose aggregates in the microfibrils, (c) between microfibrils within the fibrils, and (d) between the fibrils within the cell wall.*

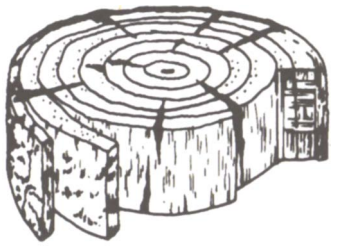


*Figure 4.10. A cross section of the trunk showing void spaces equal to the volume of water lost through drying.*

reorientation and crystalline packing of cellulose and to a decrease in the amorphous areas. We also know that in a semisolid system, a loss in volume of one part of the system—in this case, the hydrated hemicelluloses matrix—requires a compensatory increase in volume of another component—in this case void space or air.

On a larger scale, we can understand this phenomenon clearly if we think of a freshly cut log that loses much of the moisture maintained by the living tree. The cross section of the trunk develops checks, void spaces that are equal in volume to the volume of water lost through drying (Figure 4.10).

A similar phenomenon takes place within the cell wall of plant materials. In undeteriorated material, the cell wall gel of mechanical fibers is very homogeneous, with a great many evenly distributed small microcapillaries. These microcapillaries are thought to be approximately three water molecules wide. With repeated wetting and drying of the gel, the cell wall becomes increasingly less homogeneous, with fewer and larger capillaries combined with larger volumes of cell wall where microcapillaries have collapsed and the cellulose has hydrogen-bonded to form a more rigid structure. The gel is now heterogeneous and, as deterioration continues, becomes increasing so. This creates stress gradients within the cell wall. The cell wall, now having smaller regions of relatively continuous strength and larger areas having no strength at all, exhibits lower compression and tension strength values. The material is now weaker, as well as having lost much of its flexing and elastic properties.

## Qualities of Specific Plant Materials and Consequences for Conservation

Another important variable on the rate of physical deterioration from shrinkage and swelling is the particular permeability of a specific plant material. Split stems have a different permeability from leaves, leaves from roots, roots from barks, and so on. This is important for our understanding of the deterioration of an artifact because, in the great majority of cases, a material was incorporated in an artifact for the particular qualities it would bring.

In several conservation articles Florian (1977a,1977b,1978,1981) discusses (a) the makeup of cuticles on leaf surfaces, split grasses, the extractives, and other components of cedar and birch bark, (b) the differential swelling of raffia and secondary phloem of western red cedar, and (c) their role in the biology of the plant.

In these articles, Florian cites the increase in wettability and the extraction of cuticular fatty acids and waxes as undesirable effects of mechanical removal and solvented and alkaline solutions on cuticles as a result of possible conservation treatments. She discusses the role of extractives in restricting permeability and wettability in woody tissues and the resistance to biological decay afforded by tannins. She also emphasizes the inherent weaknesses present in many plant materials. Western red cedar secondary tissue is one of the prime examples she names. Because of silica bodies present in this and other plant materials such as grasses, and because the tissues undergo differential swelling and shrinkage during changes in moisture content, they work both physically and mechanically to tear themselves apart.

These materials all contain both inhibitors and contributors to deterioration. Often the contributors have resulted in the deterioration, which is seen as problematic. It is very possible that little can be done to stabilize the material, at least

with procedures presently available. The inhibitors, on the other hand, play an increasingly important role as the material continues to age. Florian has consistently pointed out that conservators should carefully consider the impact of conservation treatments that might mechanically or chemically alter these protective compounds.

## Swelling, Shrinkage, and Previous Conservation Treatments

The literature recommending various wet treatments for artifacts made from plant materials has a long history. Many of these recommend procedures taken from textile or paper treatments, where physical and chemical properties of ultimate fibers, both pulped and woven, are more completely researched and documented. Clearly, however, textile and paper fibers—although frequently of plant origin—are far from their native state and from their accompanying complex structures and materials.

Cleaning basketry with solvents, steaming, and treating with insecticides is described by Foreman (1971), and Withers (1976) also describes procedures for immersion and wet-sponge cleaning treatments, gluing with Duco cement, and treatment with glycerine and water. Baird (1976:36) also describes wet treatment for baskets that have become "quite dry and brittle" and wet cleaning with Ivory soap flakes. Gunther (1978) recommends wet cleaning with soap flakes. In an early report, Mason (1904) recommends that baskets containing remnants of food and berries be carefully scrubbed with soap and water first, and then rubbed down with oil and dryer.

Schaffer (1976), in an article on the preservation of basketry, reports that "the physical properties of bark and root deteriorate on long exposure to low relative humidities" and recommends a relative humidity of 50% or higher. She suggests that low relative humidity is damaging because it causes "the weave of the artifact to become brittle and the bark to lose its flexibility and pliability." She goes on to conclude that because relative humidities are difficult to control in exhibition halls, the "only avenue open for protection of the artifacts is chemical treatment." A polyethylene glycol and glycerol solution is reported to have yielded the best results.

Bakken and Aarmo (1981) report on the treatment of barkcloth with polyethylene glycol and alkaline buffer solutions. The authors' experiences with objects treated with PEG 400 in 1972, which have since been kept under close environmental control, indicate no deleterious effects of treatment. They comment on the material itself, describing it as beaten bast fibers glued together into sheets, pointing out that a central difference between tapa and paper is that in tapa the structure of the bast fibers is always kept intact.

They outline the conditions of the tapa in their collections: grimy, dusty, with harmful pollutants. The authors wanted to wash the cloths for grime and pollutant removal, and considered the lost adhesives as a consequence of treatment, planning to replace them.

The authors also "wanted to strengthen the fibers and make the material more pliable." They found that deacidification was necessary. There was, however, no indication that the properties of the fibers had been tested nor that swelling the structure with PEG would, in fact, increase any strength characteristics. The authors report experimenting on some sample tapa, cleaning with a detergent in water (5% lissapol N). They conclude that washing is an acceptable treatment, that the amount

of glue lost from the tapa was negligible, that PEG 400 was a good choice—although a 10% solution made the tapa feel greasy, and that sodium citrate was the best deacidification agent.

Besides the possible chemical effects of alkalis, PEG, and glycerol on lignocellulosic material (to be considered later), it now seems more probable that cycling relative humidities and rapid introduction of polar swelling agents causes more rapid and severe damage than low relative humidities. Baskets and other artifacts made from plant materials that are either recovered at dry archaeological sites or part of museum collections in arid environments are frequently found to be in better condition than their counterparts in wetter and more fluctuating conditions.

A simple but important fact worth remembering is that plant materials for the most part are dry when they are used in an artifact. They are processed to retain a surprising degree of mechanical flexibility in service. Brittleness in artifacts is not analogous to dried flowers. Physical deterioration from the introduction of a swelling agent into degraded plant material can be much more threatening than low relative humidity.

Damage to deteriorated plant materials from stresses caused by rapid swelling will be essentially the same, in the nature of the processes taking place, whether from steam, water, or polar solvents, as shown experimentally by Kronkright (1981). Conservators, therefore, should exercise control over the rate and degree of swelling through careful selection, temperature, concentration, and vapor pressure of a solvent used in the vapor phase, where the swelling of plant materials is accepted as a necessary part of treatment (see Table 4.1).

Aged artifacts made from plant materials are more brittle than similar pieces of recent manufacture. It cannot be avoided. It can be retarded, however, by controlling environmental factors contributing to physical, chemical, mechanical, and biological deterioration.

*Table 4.1. The swelling of wood in nonpolar and polar liquids relative to swelling in water (after Arganbright 1983:15).*

| Swelling Medium | Relative Swelling | Dielectric Constant |
|---|---|---|
| Toluene | 1.6 | 2.39 |
| Ethyl ether | 3.0 | 4.33 |
| Ethylene glycol monoethyl ether | 87 | — |
| n-Butyl alcohol | 13.5 | 17.8 |
| n-Propyl alcohol | 45 | 21.8 |
| Ethyl alcohol | 83 | 25.7 |
| Methyl alcohol | 95 | 31.2 |
| Acetone | 63 | 21.4 |
| Methyl acetate | 80 | 7.3 |
| Ethyl acetate | 54 | 6.4 |
| Liquid ammonia (-36 °C) | 116.5 | 22 |
| Water | 100 | 81 |

## Paraffin Wax, Oil Treatments, and Physical Deterioration

Another treatment found in the literature—of consequence to conservators as treated pieces reenter the conservation lab—is the application of waxes and oils to artifacts made from plant materials. In one case, waxes were adopted, in all probability, from their field use as consolidants in archaeological settings (Hatchfield and Koestler 1987). Waxes were expected to strengthen the materials and to prevent moisture from affecting them. Oils and waxes were also used to saturate surfaces and colors that appeared dry. There may have been a sort of "feeding of the wood" myth in popular plant material treatments.

Paraffin and other wax treatments seem to occur frequently in museum documentation of common treatments. E.L. Judah (1937) suggests soaking and sewing with raffia for repairs, followed by drying over cardboard forms and dipping in a solution of beeswax and cleaners' gasoline or benzine. The director of a small California museum wrote to a collector describing a similar treatment, which consisted of dissolving paraffin in solvent and painting it liberally over the surface of baskets that had been thoroughly washed and dried (Bates 1980). The same treatment was used on a number of Northwest Coast coiled basketry specimens at the Museum of Natural History in New York.

S.A. Reed (1966) published an article describing plant fiber artifacts, including mummy cases, a woven raincoat, basketry, carvings, masks, and a rattle, that had been dipped in a solution of mineral spirits, xylol, a "non-alkyd" resin, and phenyl mercuric succinate. Results noted by the author include a general cleaning, the clarification of design paints where none were originally suspected, moisture resistance, strengthening, the elimination of brittleness, and insecticidal effects. Today, many of those objects have darkened considerably, have become embrittled, and are covered with a tenacious coating of dust and grime. The materials are now virtually useless for analytical testing for evidence of cultural context.

Commonly, in artifacts treated with a wax—and to some extent in those treated with various oils—gradients are created between tissues that become coated with the wax, restricting moisture vapor permeability, and those less affected by the applied material, which retain more permeability. The materials can be expected to respond to subsequent changes in relative humidity quite differently.

The tissues at the margins of the gradient are placed under tension and compression and can fail, causing checking, splitting, loss of surfaces, and structural damages due to deterioration of component materials. The same can be expected with treatments with resins that either partially saturate materials before forming a film or that coat the surface fibers in a treatment procedure. This may be an inherent danger with direct resin adhesion treatments such as the experimental procedures tested by Kronkright (1981).

## Summary of Swelling and Shrinkage Processes

### Brittleness in Plant Materials

In the conservation literature (Schaffer 1976, Horton-James and Townley 1978, Foreman 1971, Bakken and Aarmo 1981), brittleness in plant materials found in museum artifacts has frequently been associated with an overly dry state. Treatments

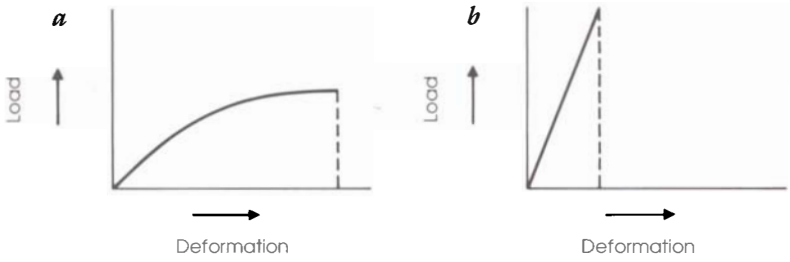



*Figure 4.11. Modulus curves for (a) elastic and (b) brittle materials.*

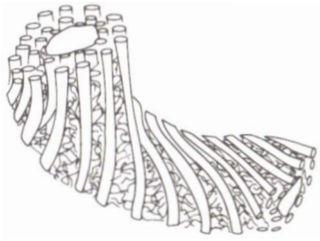


*Figure 4.12. Deformation of plant materials under stress.*

with water, steam, or humectants have been proposed. In fact, brittleness is the outcome of both physical and chemical processes that result in a loss in mechanical elasticity. Mechanical elasticity is measured in the material sciences by measuring the modulus of elasticity.

If a graph is plotted for the load or stress placed on a material, divided by the deformation of the material as the stress is being applied (Figure 4.11), the slope of the plot is the modulus of elasticity and the area underneath the plot—from the initial measurement to the breaking point of the material—is the total energy expended to failure.

Wood and other plant materials have been chosen by the makers of utilitarian and artistic objects principally because they exhibit a high degree of mechanical elasticity, even after cultivation, preparation, and fabrication. If executed properly, the structures are often expected to exhibit the elasticity of the materials placed into them by flexing and conforming to the stresses and loads of utility in the predictable ways desired by the maker.

Although swelling plant materials during a treatment procedure will swell the gel-amorphous regions within the cell walls and increase the plasticity of the material, it does not necessarily increase the elasticity. Swelling can be expected to decrease the wet strength of the material; upon drying, the shrinkage and reorienting caused by tensile forces of lost water may also result in a somewhat lower modulus of elasticity.

Two things happen to plant materials when they are swollen under stress. The first is that, upon swelling of the amorphous regions of the cell wall, the fibrils are able to flex and move in relation to each other within their helical arrangement (Figure 4.12) up to the limit of their elastic capabilities.

When the swollen material is then put under stress—as happens when a basket weaver first incorporates dampened material into a basket, or when conservators apply a swelling agent in an effort to reform distorted plant material for repair—the degree to which the elastic limit is exceeded causes the cell wall gel to slip slightly. The gel then takes on plastic deformation—that is, deformation that is not elastic and therefore does not return to its original configuration upon the release of the stress.

In a plot of stress over deformation, this slippage takes place when the slope of the line ceases to be linear; it is called the fiber stress proportional limit. It is this second process that allows deformed plant materials to take on and retain a shape in an artifact. Upon drying, shrinkage occurs with the new fibrillar and microfibrillar arrangements that, upon each successive swelling and shrinkage cycle, result in more

compacted and hydrogen-bonded cell wall arrangements. This is called mechanosorptive creep.

The cycles can be caused by ethnographic use and, over extended periods of time, in archaeological and museum settings. Many other factors contribute to the rate of this process, including temperature, the extent of oxidation and/or hydrolysis of component materials, and mechanical and biological forms of deterioration.

Three important results of mechanosorptive creep for conservators involve many levels of plant material organization. Moisture regain commonly decreases in physically degraded plant materials, indicating a decrease in available hydrogen-bonding sites in amorphous regions. This reduced availability of hydrogen-bonding sites in turn indicates that both physical and chemical actions have decreased the amount of hemicelluloses gel matrix present in a given material.

An increase in the crystallinity within the cell wall indicates that changes have taken place from the molecular level within the polymer—all the way through the previously amorphous regions between crystalline aggregates that allow close orientation and hydrogen bonding to take place. For this process to unfold, it is necessary for cellulose polymers to become shorter, soluble hemicellulosic matrix materials to be removed or broken down, forces to be applied, and polymers to be reoriented, making bonding to adjacent polymers possible.

Finally, the size and distribution of the microcapillaries, which constitute part of the amorphous matrix of the cell wall, will be radically altered. The homogeneous distribution of very small microcapillaries on which both strength and elasticity depend will change to an arrangement of fewer and much larger void gaps within the cell wall.

The larger the capillary voids, the less applied force is required to achieve failure of the cell wall. The more cell wall failures are present in a given tissue, the weaker it becomes and the more stress is transferred to those cells remaining intact. Because of the increased load placed on the remaining intact cells in the tissue, the rate of deterioration for them increases proportionately. An applied force to weak tissues causes a route of breakage to form between the weakest cell walls in the tissue, causing a fracture or tear.

### Adding the Complexity of Antiquity

What adds complexity to our understanding of physical deterioration processes is the fact that aged plant materials are not the same as new native plant materials used to conduct mechanical tests for the empirical testing of physical models. As Florian (1977b) and Grattan (1980) point out, chemically and physically altered celluloses, lignin, and extractives do not necessarily behave the way their unaltered counterparts can be expected to.

Increased crystallinity can indicate a decrease in amorphous regions. Altered lignin may lead to increased permeability and access to unprotected hemicelluloses. Oiled and waxed tissues suggest that a material has a special sensitivity to moisture changes and that surfaces may have been softened or made sensitive to photodegradation and abrasion. Conservators must think about all the levels of organization contained in the artifact and carefully consider what swelling and shrinkage stresses have done in the past and what they will do in the future to remaining components.

## Photodegradation

Baugh (1981) notes that the action of another physical phenomenon, light energy, has been the subject of fairly intense investigation for almost 100 years. In his review of research on the subject since 1970, Baugh outlines the work done on direct and sensitized photodegradation. Both of these processes are of interest to conservators.

Because artifacts made from plant materials contain both compounds that undergo direct photodegradation and compounds that inhibit direct photodegradation, this process should become familiar to us. Plant materials also contain intrinsic and extrinsic compounds that act as sensitizers in the photooxidation process. Included in this group are compounds already familiar to us, such as lignin, hemicelluloses, oils, and resins. Among the extrinsic materials are dyes, pigments, soils, dust, applied oils, polyethylene glycol, water, and biocides.

### Photon Energy

Both Hon (1981a) and Grattan (1980) point out that light, in discrete units called photons, contains energies that are proportional to their wavelengths. Grattan notes that as the wavelength of light becomes shorter, the photon energy or quantum of energy increases. The quantum energy for light, with a wavelength of approximately 275 nanometers (abbreviated nm), is approximately 102 kilocalories per einstein (abbreviated kcal/mol.) Hon points out that this energy is sufficient to break the bond energy of the oxygen–hydrogen bond. At a wavelength of 305 nm, light has a quantum energy of about 93 kcal/mol, sufficient to break the carbon–hydrogen (C–H) bond. Light at a wavelength of 280 nanometers has a quantum energy of 98 kcal/mol, sufficient to break the bond energy of the carbon–oxygen (C–O) bond. A carbon–carbon (C–C) bond can be broken by the 35 kcal/mol quantum energy produced by light at 345 nm (Hon 1981a).

### Absorbance of Light Energies

Before bonds can be broken between atoms, the first law of photochemistry must be observed: light must be absorbed discretely by a chromomorphic group in the molecule (Hon 1981a, Baugh 1981). Like thermal energy, the absorbance of light energies can be dissipated throughout the polymer at all its levels of organization. When energies are sufficient to cause the breakage of bonds, a photochemical reaction has taken place.

### Cellulose

Baugh, Grattan, and Hon each describe the absorbance characteristics of various compounds in plant materials. Each points out that pure cellulose does not appear to be a good absorber of ultraviolet light wavelengths that contain the quantum energies necessary to break fundamental bonds. Hon notes that, in the absence of oxygen, photochemical reactions of cellulose do not appear to take place at wavelengths longer than 340 nm; in the presence of oxygen, however, degradation does take place at a slow rate.

In the presence of ultraviolet radiation, C–H bonds (particularly those close to ether oxygens) undergo an occasional homolytic scission. The carbon radicals very quickly react with molecular oxygen, if it is present, to form peroxy radicals and these, through conventional autoxidation pathways, convert to carbonyl, hydroxy,

and carboxylic acid groups. The carbonyl groups tend to form chromophores. The breakdown of peroxy radicals also leads to the rupture of C–C bonds and the degradation of cellulose polymer chains. Details of this can be found in recent articles by Hon (1981a,b).

Where accessible in amorphous areas, light in the region of 260 nm is apparently absorbed by the acetal groups at the $C_1$ position of the anhydroglucose units. As Hon (1981b) points out, localization of the absorbed energy produces free radicals. These result in scissions and a lowering of the degree of polymerization, leading to other associated forms of physical deterioration, such as decreases in the amorphous regions.

Hon further reports that in the presence of oxygen, cellulose irradiated with ultraviolet light produces peroxides. Grattan points out that peroxides and hydroperoxides absorb light in the ultraviolet region quite strongly. Both functional groups undergo scission of the peroxy bond to give two free radicals which contain unpaired electrons. This reduces the resistance of cellulose to thermal oxidation (Hon 1981a) and initiates chain oxidation reactions in which the ring-backbone of the cellulose polymer is destroyed, leading to the formation of carbonyl and carboxyl groups.

**Lignin**

Lignin is an amorphous polymeric substance that together with cellulose forms the woody cell walls of plants and the cementing material between them. It is a polyphenolpropane derivative (Figure 4.13). Florian, in Chapter 1, describes the persistence of lignin and its interdependent role in combination with the hemicelluloses. In her outline of lignin characteristics, she notes the presence of functional groups and lignin's sensitivity to alkaline degradation. Since, as Florian points out, it is not yet possible to isolate lignin without some degradation, its precise nature remains a puzzle. It seems certain, however, that lignin has an absorption peak at a wavelength of 280 nm and extends slightly over 400 nm, making it an excellent ultraviolet light absorber (Figure 4.14; Hon 1981b).

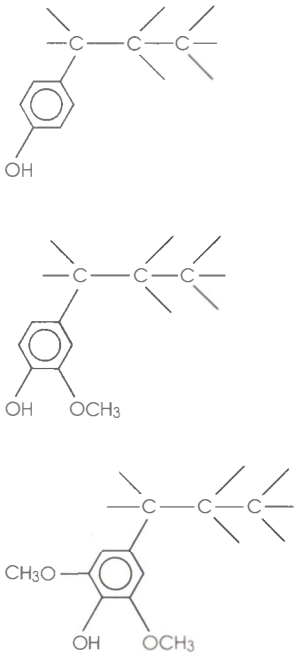



*Figure 4.13. Various lignin structures.*

Hon reports that the reactive groups available in lignin consist of ethers of various types, primary and secondary hydroxyls, carbonyls, carboxyls, and ester functions. There are aromatic and phenolic sites capable of forming phenoxy radicals. These phenoxy radicals undergo further oxidation to produce quinoid structures and methyl groups (Figure 4.15). Quinoids are colored and contribute to the yellowing and increased absorbance of light waves in the visual spectra.

Likewise, carbonyls and carboxyls in lignin are good ultraviolet light absorbers in the 300 nm to 390 nm region. According to Hon, research suggests that carbonyls play a major role as photosensitizers. Conjugated double bonds in lignin also absorb light in the UV light regions and undergo oxidation, yielding carbonyl structures. Many of these are also chromophores sensitive to visible-light spectra and are, therefore, contributors to the yellowing discoloration in lignin-containing materials.

It is critical to remember that, besides initiating many yellowing chromophoric compounds as well as free radicals capable of initiating chain oxidation

reactions with neighboring cellulosics, photooxidation of lignin results in chemically altered lignin. Its mechanical capabilities, hydrophobic properties, and solubility will all be altered through light degradation. Hon (1981b) reports that UV interacted strongly with lignin, making it increasingly water soluble. It will have yellowed the material and made the tissues even more light sensitive to the more abundant visible light spectra. It will leave areas of the amorphous hemicelluloses matrix unprotected from other forms of physical deterioration, as well as oxidation reactions.

**Hemicelluloses**

Hon points out that the photodegradation of the hemicelluloses follows generally the same pathways as cellulose. Several differences deserve our attention, however. The central difference is that, while cellulose is largely contained in crystalline regions, hemicelluloses are an important structural component in the amorphous regions in which oxidation reactions, either direct or from free radical intermediates, can get ready access. In this sense, hemicelluloses are very important to the mechanical performance of deteriorated plant material in an artifact. They play a pivotal role in the elasticity of the material. They degrade into monosaccharides, which are soluble and increase the degree of shrinkage of plant materials.

Hon (1981b) reports on research that showed that colored materials in the yellowing of paper pulp are water soluble and related to oxidative degradation of hemicelluloses. Hon also reports on research that identifies carbonyl groups, again, as compounds that are responsible for yellowing.

*Figure 4.14. Ultraviolet absorbtion spectrum of lignin.*

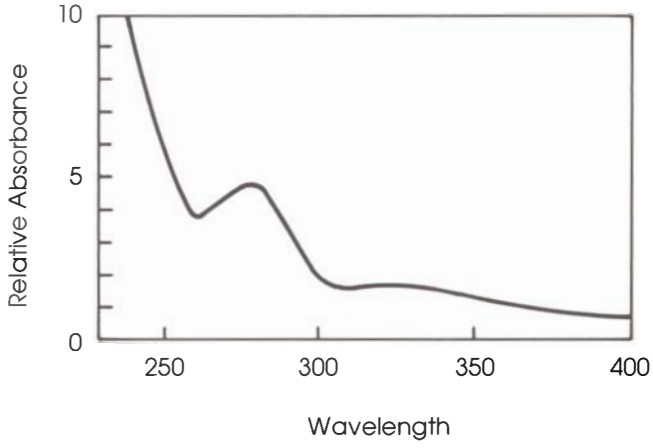
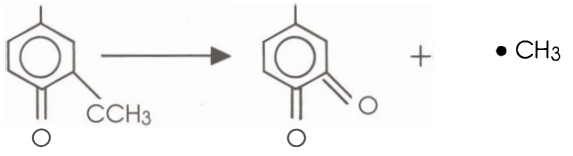



*Figure 4.15. The formation of chromophoric quinoids.*



### Photooxidation of Other Components

The photooxidation of other plant materials is somewhat outside the scope of this chapter. The oxidation of oils and resins, in particular, has been studied and reported on in the conservation literature in some detail in the study of painting materials and materials used in conservation treatments in paintings. The oxidation of these materials takes place much as the oxidation of the other plant material components: absorption of high energy light by sensitive groups, followed by the formation of largely free radicals or intermediates, leading to the production of free radicals, which begin oxidation chain reactions.

The oxidation of these materials does have important consequences for plant materials. The most commonly recognized is the yellowing and darkening discolorations that take place. The oxidation products themselves contribute to the oxidation of other adjacent components in the tissues and become selectively more sensitive to the more prevalent visual spectra radiation. Changes in the oils, gums, and resins may alter the permeability of the tissues. Their solubilities may be altered, and while their importance to degraded tissues may be important to slowing the rate of all forms of deterioration, their own susceptibility to degradation may increase.

It is also important to remind ourselves that oxidation reactions from any physical source do not degrade plant materials in isolation. In reality, they work alongside—and perhaps in combination with—chemical degradation reactions such as acid hydrolysis. Heat, plant fiber morphology, even access to structural materials via biological deterioration all play a contributing role in the final condition of the object.

### The Role of Sensitizers

A sensitizer is any material aded to an object which increases that object's sensitivity to oxidation reactions in one or more of the following ways:

1. It makes the absorption of light energies more possible.
2. It contributes either free radicals or intermediates, leading to the formation of free radicals with unpaired electrons to chain oxidation reactions to the host material.
3. It swells oxidation-accessible areas apart, making reaction sites and functional groups that were inaccessible to bond breakage newly available.

### Dyes

Baugh points out that sensitizers generally have the ability to make the material much more sensitive to photooxidation induced by longer wavelengths than are normally responsible for direct oxidation (Baugh 1981). Dyes are a complex group that fit the bill as sensitizers quite well, changing the absorption spectrum of plant materials readily and undergoing complex degradation reactions. Baugh reviews the contemporary literature on photooxidation of dyes extensively; a description of the various mechanisms is beyond the scope of this paper. Suffice it to say, however, that dyes do make plant materials more capable of absorbing light energies not previously absorbed and that they can function beyond this role, providing oxidation products, which themselves can contribute to the oxidation of the host material.

### Lignin, Hemicelluloses, Oils, Resins, and Gums

We have already considered the photooxidation of these materials and discovered that the carbonyl groups, carboxyl groups, phenoxy groups and quinoid structures —which are oxidation products of hemicelluloses and lignin—are also good sensitizers. These compounds, indicated by a generalized yellowing or browning of the material at the surface, selectively absorb radiation from the visual spectra, of which much more is present from all museum illumination sources. With increased energy absorbance, the rate of photooxidation is increased, with a resulting roughening and loss of gloss.

### Water and Polyethylene Glycol

Ultraviolet light penetrates approximately 75 microns and visible spectra radiation approximately 200 microns (Hon 1981b). By itself, this penetration is sufficient to be of concern for many artifacts made from plant materials. Objects such as baskets, cordage, and tapa have an extremely large area-to-volume ratio. The effect of all sources of deterioration is amplified because of the relatively smaller volume of solid material that is made available to heat, light, moisture, and gases. The problem is further compounded by the role of swelling agents.

Research suggests that photo-induced free radical formation is limited almost exclusively to the amorphous regions of the cell wall gel (Hon 1981b). The crystalline regions of the cell wall are impervious to light as well as to most free radicals. Increased swelling, on the other hand, can serve as a vehicle to open up the semicrystalline regions, creating new surface areas and available sites for free-radical and intermediate formation. Hon (1981b) relates that it is well known that moisture can also accelerate the rate of oxidation and yellowing in plant fibers. The production of more free radicals by itself accelerates the rate of deterioration. Likewise, it accelerates the rate of other physical and chemical deterioration reactions, such as hydrolysis.

Once again, we can see the importance of certain inherent materials to the preservation of plant materials. Cuticular waxes on the surfaces of barks and leaves are a good example. One of the functions of the waxes in the living plant is the protection of the tissues underneath the outer surfaces from harmful ultraviolet light. Waxes also control water permeability and the excessive swelling of surrounding mechanical tissues, such as fibrous sheaths around vascular bundles in palm, pandanus, grass, and other monocot leaves. Pectin is another important structural component that is protected by cuticular waxes and cutin in leaves.

Other extractives common to plant materials such as suberin and cutin play similar roles in barks. These materials help artifacts made from plant materials resist deterioration and should not be compromised by conservation procedures aimed at altering some other objectionable or problematic condition.

### Metallic Ions

In the presence of many sensitizing compounds, including metal ions, the role of visual light energies becomes even more important to the degradation of plant materials. Hon (1981b) reports that when cellulose is treated with metallic ions, complexes formed between cellulose and the ions are capable of absorbing light of long wavelengths. From a study of model compounds, Hon reports that glucose, lactose

and cellobiose—which are practically without any light absorption beyond 300 nm—interact with ferric ions to create new absorption centers between 365 nm and 370 nm. He found similar complexes formed by $Ce^{4+}$, $Cu^{2+}$, $Ag^{2+}$ and $Pb^{2+}$.

## Thermal Degradation

Thermal degradation involves the absorption of thermal energy by a plant material. Again, the impact of absorbed thermal energy is observed at many levels of organization. Excitation takes place both within the molecule and to the molecule itself. This affects cellulose, hemicelluloses, lignin, suberin, cuticular waxes, fatty acids, oils, resins, functional groups, and water. Processes involve oxidation reactions (exclusive of light), lowering viscosities, physical swelling beyond levels reached at room temperatures, and—in the absence of additional moisture vapor—desiccation and subsequent shrinkage. Other chemical deterioration reactions are typically also accelerated in the presence of additional thermal energy.

### Heat and Molecular Excitation

Grattan (1980) points out that heat energy, when absorbed by a molecule, is distributed in three modes: rotational energy (the energy stored by spinning atoms or portions of molecules), vibrational energy (the energy stored in the vibrations of the molecular framework), and translational energy (the energy of moving molecules).

In plant materials, heat energy is distributed among these three modes in a random way such that most molecules have an average amount of energy. Some molecules, however, will have large amounts of energy and others will have very little. As Grattan points out, this random distribution ensures that at any temperature a certain number of molecules will have sufficient energy to decompose. Temperature, moisture content, and bond energies, as well as other factors, influence the rate of this type of thermal degradation, known as thermal oxidation.

Oxidation reactions are not restricted to cellulose and hemicelluloses in plant materials. Lignin is known to be easily oxidized by ultraviolet light and the rate of oxidation can be accelerated by heat. Fatty acids and the oils that are composed of their esters with terminal functional groups also undergo oxidation, as do suberin, waxes, gums, and resins.

Oxidation of these materials results in commonly found changes in permeability, color, surface gloss, texture, and resistance to abrasion. Oxidation also results in less obvious changes in materials' moisture regain and swelling characteristics, in hemicelluloses, lignin, and resin solubility, and in increases in peroxides, hydroperoxides, and carbonyl and carboxyl functional groups. Each of these changes can, in turn, accelerate other rates of chemical and physical deterioration. Oxidation reactions, however, are not the only results of increases in heat energies.

### Heat and Fluid Characteristics of Thermoplastic Compounds

All thermoplastic materials in plant materials, including lignin, waxes, oils, resins, gums, and suberin, take on more fluid states as temperatures increase. This is due to increased translational energy of the molecules of the compounds. Increases in fluid characteristics in these materials permit structural components of the tissues to slide over each other more easily than they do at lower temperatures, when the tissues are under a load and undergo accelerated rates of distortion.

Harvey and Odegaard (1984) as well as Pearlstein (1986) report that cuticular and applied fatty oil ester waxes on ethnographic artifacts formed whitish and bluish glaucous bloom on the surfaces of the objects. Harvey and Odegaard used SEM photomicrographs to demonstrate the loose crystalline structures of the bloom on the surface of barks used in North American basketry.

Pearlstein presents a thorough research project in which blooms found on ritual and functional objects in Mali, West Africa, were characterized using infrared spectrography and gas chromatography. Pearlstein describes the capacity of waxes to undergo polymorphism into three crystal packings: alpha, beta, and beta prime. Crystal size and stability increase in the order presented.

Pearlstein points out that temperature conditions influence whichever polymorphic form is most stable. Under rapid cooling conditions, formation of fine alpha crystals is favored. Under slow cooling, beta crystals are produced that are large enough to create visible graininess. She also notes that modification of these waxes in treatment procedures may confuse any attempts to study or authenticate the object.

Cuticular waxes can migrate under the influence of elevated temperatures, particularly if tissues are being strained from swelling or if they are bearing a physical load. These waxes serve important roles for the plant and, likewise, for the material within an artifact. The waxes are important ultraviolet light absorbers, protecting the tissues beneath from degradation. They reduce permeability and limit moisture regain of the tissues containing them to protect the plant from biological and physical deterioration under wet conditions. In addition, the waxes also help keep moisture essential to the living plant from rapidly expiring in hot, dry conditions. From the maker's viewpoint, waxes lend to surfaces the quality of moisture resistance as well as degrees of gloss and color saturation integral to the proper functioning and appreciation of the object.

In the case of birch bark, Gilberg (1986) notes that suberin is one of the principal structural components of cork cells, comprising 85% of the cork cell of one species. Heating the material is one method of increasing lubricity in industry; it can result in distortion as well as a redistribution of the suberin.

### Heat and Specific Properties of Plant Materials

Plant materials have two general properties that are significant to their thermal properties. The first is thermal conductivity. Wood and plant materials have relatively low thermal conductivities (Table 4.2). This implies that heat applied to plant materials remains isolated and raises the temperature of the tissues.

*Table 4.2. Values of thermal conductivity for various materials (BTU–in/ft$^2$ °F Hr).*

| Material | k (cal/cm °C sec) | k (BTU– in/ft$^2$ °F Hr) |
|---|---|---|
| Copper | 0.688 | 2700 |
| Aluminum | 0.482 | 1400 |
| Concrete | $3.78 - 5.55(10)^{-3}$ | 11 - 16 |
| Brick | $1.65 \times 10^{-3}$ | 4.8 |
| Window glass | $1.23 - 2.48 \times 10^{-3}$ | 3.6 - 7.2 |
| Wood parallel to grain | $0.550 - .997 \times 10^{-3}$ | 1.6 - 2.9 |
| Wood perpendicular to grain | $0.224 - .396 \times 10^{-3}$ | 0.65 - 1.15 |
| Glass wool | $0.0929 \times 10^{-3}$ | 0.27 |
| Fiber insulation blankets | $0.0826 \times 10^{-3}$ | 0.24 |
| Water | $1.43 \times 10^{-3}$ | 4.15 at 20 °C |
| Air | $0.0568 \times 10^{-3}$ | 0.165 |

The second general feature is that, in the presence of heat, many of the mechanical and chemical properties of plant materials deteriorate at accelerated rates. While this rate is significantly dependent upon moisture content, length of exposure, temperature, and the volume of plant material being exposed to heat, it is clear that the rate of deterioration will be much faster at higher temperatures. A general table comparing relative rates of deterioration of wood is given in Table 4.3.

*Table 4.3. Loss of strength in modulus of rupture as a result of thermal exposure.*

| | Exposure time required for given strength loss at: | |
|---|---|---|
| Loss of strength (%) | 30 °C (years) | 100 °C (days) |
| 5 | 1,100 | 88 |
| 10 | 2,700 | 190 |
| 20 | 7,900 | 470 |
| 30 | 15,000 | 900 |
| 40 | 29,000 | 1,500 |
| 50 | 54,000 | 2,600 |

## Rates of Thermal Degradation

Thermal degradation has been defined by Beall (1986) as the temperature and time regime in which wood undergoes irreversible changes in its properties. Beall measured the mass loss when wood and its separated constituents were heated in nitrogen, and found that lignin, the hemicelluloses, and cellulose begin to degrade at different points and at different rates.

Low temperature degradation at slow heating rates and/or low temperatures occur in lignin and the hemicelluloses. Lignin—specifically, the low molecular weight protolignin—degrades first, but at a slower rate than the other constituents. The hemicelluloses are slightly more thermally stable than lignin. The decomposition of the hemicelluloses involves the splitting off of side groups to evolve organic acids (e.g., acetic acid). Degradation of cellulose does not begin until much higher temperatures.

Beall found that most species darken due to changes in extractives during thermal degradation. Anatomical changes were limited to pit membranes of

bordered pits. In charred wood, substantial cell wall crazing occurred from compression failures.

It is interesting to note that, although complete desiccation by heat would eventually lead to extreme shrinkage, Beall's research also shows that heating in steam increases the rate of degradation about tenfold. Clearly, changes in strength during degradation are a complex function of temperature and moisture content, since the presence of moisture dramatically accelerates wood hydrolysis.

## Chemical Deterioration

Besides deterioration caused by physical phenomena, deterioration reactions also take place as a result of inherent, evolved, or introduced chemical compounds. Again, the reactions take place in association with, and sometimes as a result of, other deterioration processes and their byproducts. The process is further complicated by the fact that, like physical deterioration processes, chemical deterioration processes take place at many levels of plant organization. Reactions to cellulosics, for example, can take place at the margins of crystalline regions, in amorphous regions of cellulose polymer aggregations between micelles, between aggregations of cellulose polymer in the microfibril, between microfibrils, and between fibrils within the cell wall.

Hydrolysis is probably the chemical deterioration process best documented in the conservation literature (Feller, Lee, and Curran 1985). Because it is a substantial contributor to deterioration of cellulose and hemicelluloses at all levels of organization, it will be reviewed separately. Next, other deterioration reactions will be outlined according to the component in which they take place: cellulose, hemicelluloses, lignin, pectic substances, suberin and cutin, and oils and resins. Finally, two other sources of applied chemical deterioration will be considered: pollutants and past conservation treatments.

### Acid Hydrolysis and the Stages of Deterioration

As noted, physical processes of deterioration combine with chemical reactions to complete the deterioration changes in materials. Swelling, shrinkage, thermal degradation products, and photo-induced free radicals are all precursors to more important chemical reactions. In many of these deterioration processes, organic acids evolve. Acetic acid, aldehydes, and carboxylic acids, as well as esters and their component fatty acids are all good examples of acidic byproducts of deterioration reactions of cellulose, hemicelluloses, lignin, resins, oils, and waxes. The presence of acidic compounds and moisture can lead to hydrolysis degradation, particularly of the polysaccharides of plant materials.

These reactions—which take place at a faster rate with increases in temperature, moisture content, and available bonding sites—result in decreased degrees of polymerization in hemicelluloses and cellulose. Decreases in degree of polymerization take place both in the hemicelluloses, found in the middle lamella and amorphous regions of the cell wall, and in cellulose with available bonding sites within the cell wall.

These shorter polymers are less capable of withstanding loads placed upon them and are more apt to become compacted upon shrinkage or to fail. The solubility of the polysaccharides and their component acids and sugars increases. A loss of moisture regain and amorphous regions occurs along with an increase in crystallinity, resulting in changes in the homogeneity of the cell wall as discussed earlier in this chapter under Collapse of Cell Wall Microcapillaries. Carboxyls and carbonyls increase, resulting in color changes and increased sensitivity to light degradation. Acidity of the material also increases, mostly because of the acidic byproducts of hydrolysis.

### The Process of Acid Hydrolysis

The covalent glucosidic bond between $C_1$-O-$C_4$ is the bond believed to be attacked by an acid. When an acidic compound donates hydrogen ions, or when hydrogen ions are liberated through oxidation, they will, in combination with water, break the $C_1$-O bond. The broken bond leaves a cyclic carbonium ion, which can join with an available water molecule to form a new ionic bond with $C_1$ by evolving a hydrogen ion from the water molecule.

A second protonation site is possible at the $C_1$-O bond within the cyclic glucose ring. There, a hydrogen ion bonds with the ring O to form a hydroxyl group for the $C_5$, opening up the ring and leaving, again, a positively charged carbonium ion. A water molecule can again evolve a hydrogen ion (acid) to stabilize the now-linear 6-carbon molecule.

### The Three Stages of Hydrolysis

The rate of hydrolysis is dependent upon several factors: hydrogen ion concentration, moisture content, temperature, and number of available sites accessible to acid migration. Feller, Lee, and Curran (1985), however, have pointed out that the rate of reaction is also controlled through the sequence of three discrete stages.

The authors identify references in the literature describing an initial rapid stage in which a limited number of glucosidic bonds are rapidly broken. These bonds have been referred to as the so-called weak link bonds that are sensitive because of physical strains placed upon them. It has been suggested that they may be bonds at the points where cellulose chains loop back upon themselves in crystalline regions.

The second stage identified in the literature cited by the authors is the hydrolysis of the bonds available in the amorphous regions of the cell wall. This stage is depicted by the rapid fall of the degree of polymerization of cellulosics until a leveling off point is reached. This is the point when nearly all glucosidic bonds in the amorphous regions of the cell wall have undergone acid hydrolysis.

Following this stage, hydrolysis takes place very slowly, as one would expect for the attack of glucosidic bonds on the margins of crystalline micelles. As these micelles are accessed through oxidation reactions and swelling or other physical processes, their hydrolysis becomes more possible.

## Chemical Deterioration of Cellulose

The deterioration of cellulose has now largely been described. Both oxidation and hydrolysis reactions take place at available sites on the margins of the micelles and in the amorphous regions between the cellulose aggregates. We know that the rate of the reaction is increased by heat and moisture content. Beall (1985) points out that the rate of deterioration was 10 times as fast when heat and moisture were combined, as with steam, than when heat alone was measured.

### Steam and Moisture

Steam treatments have been frequently used to increase plasticity in deteriorated plant materials to assist with reshaping and are documented in the literature (Pomerantz 1975, Govier 1980, Foreman 1971). Wet treatments for cleaning artifacts, some including alkaline swelling surfactants to increase wetting, are also numerous in the literature (Mason 1904, Judah 1937, Withers 1976, Baird 1976, Gunther 1978, Bakken and Aarmo 1981, Svenson 1986). We know that more sites can be made available by swelling the tissues with a polar solvent in vapor or liquid phase. The larger the dipole moment, the larger the relative swelling, and vice versa.

### Free Radicals and Sensitizers

We know that free radicals can absorb and transfer energies necessary for oxidation reactions wherever oxygen can reach. We also know that sensitizers can form complexes that can absorb energy and attack crystalline regions directly. Sensitizers can increase the absorbance spectrum for cellulose, increasing the rate of deterioration. These sensitizers can be applied by the maker and users of an object during its period of utility, in which case—while clearly important—they inherently flaw the material. They can also be applied subsequent to collection by collectors or by institutions.

The absorbance spectra of a great many materials suddenly become very important when this fact is considered. Heavy-metal insecticides and pesticides should undergo investigation as to complexes formed with cellulosics, as an example. The variety of oils, resins, and humectants applied to artifacts should also undergo systematic research.

## Chemical Deterioration of Hemicelluloses and Lignin

The hemicelluloses both in the middle lamella and cell wall are initially well associated with lignin. In new materials, lignin serves as a hydrophobic agent, limiting swelling and degradation to the hemicelluloses from those reactions that are accelerated in the presence of moisture. Unfortunately, plant materials of some age and prior utility have undergone numerous changes that have altered all of the component materials to some degree.

Lignin, as pointed out earlier, is one of the first components to be altered by photodegradation. The formation of free radicals from photodegradation also creates acidic groups and breaks acetyls away from the hemicelluloses, which they are protecting from swelling and chemical degradation. In aged materials that have already undergone uncounted cycles in swelling and shrinkage, light degradation, accumulated levels of thermal degradation, and perhaps biological attack, we have

compounds and structures that are much more susceptible to all processes in degradation. Hydrolysis of hemicelluloses results in shorter polymer chains, which have more limited mechanical properties.

**Hemicelluloses**

Hemicelluloses are deteriorated in fundamentally similar ways to cellulose: by oxidation and hydrolysis. There is, however, an important difference in the rate of deterioration. Hemicelluloses are located in noncrystalline, amorphous regions at all levels of plant tissue organization. In combination with pectic substances and lignin, hemicelluloses utilize their branched, irregular hydrated structures to form a gel that allows crystalline regions to move, deflect, compress, and rotate in response to stresses placed upon the fibers (Table 4.4).

Because the amorphous regions have sites that can make and break hydrogen bonds during hydration and dehydration of the gel, hemicelluloses are also susceptible to hydrolysis and oxidation reactions. Slowly, the degree of polymerization of the hemicelluloses is degraded and the large polysaccharides become degraded into smaller, more fragmented hydrocarbons. Yasuda, et al. (cited in Hon 1981a) report that hemicelluloses would break down into component monosaccharides after light degradation, followed by transformation into colored materials. Some of the degradation compounds are acidic, while others are chromophores and functional groups that contribute to free-radical oxidation.

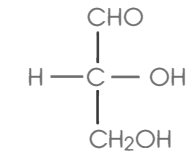
Many of these degradation products are water soluble. Combined with the soluble chromophores produced by the oxidation of lignin, these materials can often be seen as tidal lines on plant-material artifacts with water or solvent spills (Hon 1981a).

Wolf and Fullman (1980) also make a notable contribution to the deterioration literature in their review of Fijian tapa. The authors report the range of deterioration types typically found in the museum's Fiji collection. Damages described as endemic to the material included fungal growth, insect holes, rips, tears, areas of complete loss, poor restorations, and brittleness associated with the degradation of cellulosic fibers, which was particularly pronounced where cloths were smoked over wood fires to produce a deep brown color. The authors also note that in tapas that were wet treated, the pH of the materials was raised from approximately 4.5 before washing to between 5.5 and 6.0 after three changes of water. This indicated that acidic materials associated with deterioration were soluble and had been removed.

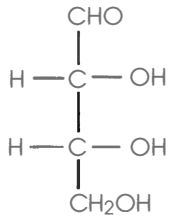
It is important to remember that degraded hemicelluloses, along with all other degraded components of plant materials, cannot be repaired, reversed, or replaced. Nor can the oxidation reactions or hydrolysis reactions be reversed. Areas that were once amorphous and that are now modified into more tightly oriented and crystalline regions cannot be recreated.

Clearly, however, steps can be taken to stabilize those hemicelluloses that remain intact and continue to contribute to fiber elasticity and strength. Changes in relative humidity, excessive moisture, temperatures, light energies, and physical stresses caused by improper support or structural damage can be controlled. It is clear that lower temperatures can dramatically reduce the rate of thermal degradation reactions. It is also clear that hydrolysis reactions can be limited by lowering temperatures.

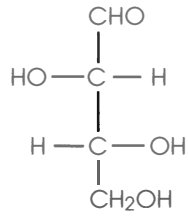
*Table 4.4. Some of the brancheal, irregular hydrated structures that permit hemicelluloses to form a gel.*



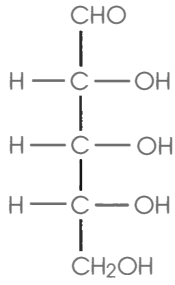
D-glyceraldehyde



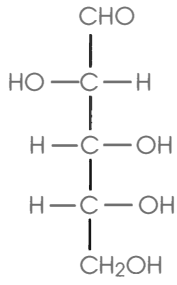
D-erythrose



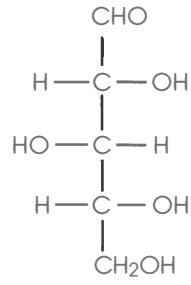
D-threose



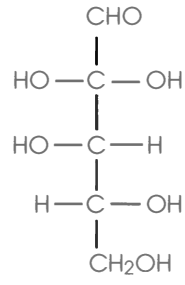
D-ribose



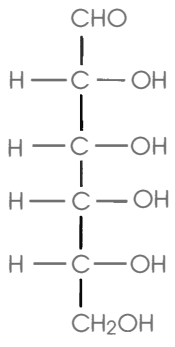
D-arabinose



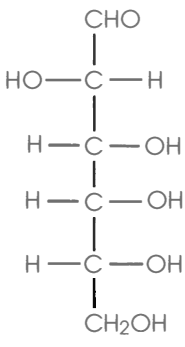
D-xylose



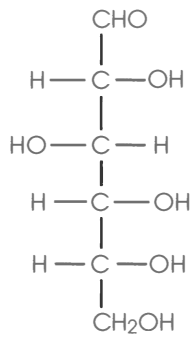
D-lyxose



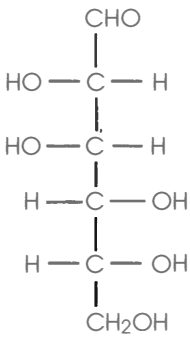
D-allose



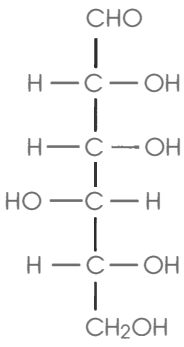
D-altrose



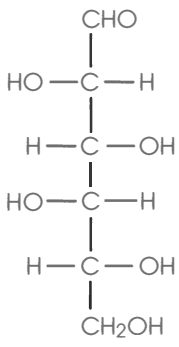
D-glucose



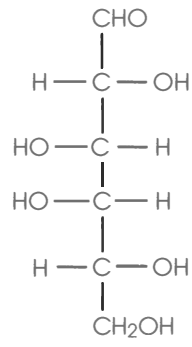
D-mannose



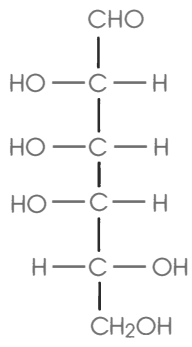
D-gulose



D-idose



D-galactose



D-talose

Of the other dependent factors of hydrolysis—namely, hydrogen-ion concentration, moisture content, and available reaction sites—moisture content is clearly the easiest to control. The preservation of the oldest plant material artifacts has been made possible by their dry archaeological settings. In this regard, it may well be that plant materials that have undergone the compaction of amorphous regions, the hydrolysis and oxidation of polysaccharides, and the degradation of lignin through aging can be stabilized without further loss of elasticity at relative humidities lower than the commonly accepted region around 50%. Research on this subject would be very useful to the conservation community.

### Chemical Deterioration of Lignin

It has been found that lignin is highly photoreactive. It absorbs ultraviolet light readily and utilizes the energy to quickly break bonds, forming free radicals and chromophores, which readily absorb light in the visible spectra. While ultraviolet light can penetrate only some 75 μ into the surface of woody tissues, the increasing absorption of visible and infrared light, which can penetrate some 200 μ, results in increased rates of deterioration (Hon 1981b).

In microscopic observations, ultraviolet-light-damaged, lignin-rich middle lamella resins in yellow pine were found to separate from the adjacent secondary cell walls. This separation results in poor intercellular adhesion and the loss of abrasion resistance and hardness. Chemically modified lignin is also less protective of associated hemicelluloses; it permits increased permeability, which can lead to more rapid physical degradation from shrinkage and swelling with changes in moisture content.

Lignin has also been shown to be partially soluble in ethanol, methanol, butanol, and benzyl alcohol, and to be highly soluble in alkaline solutions with water and alcohols. It is totally soluble in 4% sodium hydroxide (Florian 1981). Other solvents also swell lignin; some oils may soften it as well as increase its sensitivity to degradation by light.

The introduction of solvents into lignified plant materials must be carefully considered in light of the tendency of lignin to swell and, with age, to become increasingly soluble. If plant material is already degraded to some degree, a treatment that involves the use of solvents may endanger the stability of chemically modified lignin, which may be playing an even more important structural role in the artifact because of deteriorated cellulose (Florian 1981). It has also been pointed out that polyethylene glycol can solubilize lignin if some depolymerization of the PEG takes place over time (Florian 1981).

The chemical reactivity of lignin also suggests that reported treatments to lignin-containing tissues (Reed 1966) involving the introduction of acid scavengers or so-called alkaline buffers, such as those applied to tapa and barkcloths, may in fact deteriorate the remaining hemicelluloses that protect lignin from physical degradation and embrittlement.

Again, the best treatment strategies for the stabilization of deteriorating lignin are those restricting intervention or controlling environments. Low temperatures and low light levels seem particularly critical for the preservation of plant materials containing lignin. It is important to remember that artifact components made from plant parts often have large surface-to-volume ratios. Conditions commonly

thought of as acceptable for woods in furniture, for example, can be highly deteriorating for plant tissues used in other ways. Sensitivity to light deterioration—resulting in both the discoloration of materials and the degradation of structural molecular components—is one such area. Rates of oxidation, hydrolysis, and physical deterioration can be expected to take place at substantially faster rates, even on a per-mass basis, because of the generally greater surface areas.

### Chemical Deterioration of Suberin, Cutin, Oils, Resins, and Tannins

These materials begin as carboxylic fatty acids. They react with alcohols to form important esters. Those that react with triglycerides form oils, some of which go on to become resins. Others form long chain compounds known as plant waxes. Next to thermal and photolytically induced oxidation reactions, the most common types of deterioration problems for suberin, cutin, oils, and resins are apparently posed by solvents and other materials applied to them in the course of treatments within museums or by collectors.

### Impact on the Roles of Extractives within Artifact Material

Each of these compounds or classes of compounds plays an important role in cuticles, barks, cortex tissues, phloem, and xylem tissues. Some of the more important aspects of artifacts—such as color, resistance to biological degradation, moisture and permeability resistance, surface texture and toughness, resistance to light degradation and to soiling—are provided, in part, by these materials.

The physical deterioration processes which can be seen to accelerate from the absence or deterioration of extractives have already been discussed. The question becomes, then, how are these materials lost?

### Extractive Loss

Some extractives can be extracted by steam and/or hot water. Where the characteristics of these compounds were not required in the use of the artifact, they have often been extracted from ethnographic use. Where their role was useful to the artifact, they have often undergone some degree of deterioration and extraction from ethnographic use as well. In such cases, the compounds that remain provide an important degree of functional protection to the surrounding materials.

Unfortunately, many have been extracted as a course of treatment. As normal deterioration processes progress, many of these materials, as with most others in plant materials, become increasingly soluble. Wet treatments involving the use of steam or water are described and sometimes recommended in the literature. Often reports refer to quantities of brown and yellow colored materials which are removed, as in paper conservation. While many such colored compounds, as discussed, are deterioration products of lignin and hemicelluloses, others have their origin in the other extractives.

Solvents, too, frequently diminish important extractives from plant materials. Solvents may have been introduced in cleaning, reshaping, sterilization, drying of wet materials, and consolidation. Florian (1981) points out that the extraction methods for the analysis of extractives in cedar include hexane for some oils, fats, and resins, benzene for others, ether for color materials, hot water for tannins, and ethanol for other color materials. Although few of these exact solvents are used in conservation procedures today, because of the health risks, replacement solvents

with similar parameters are used and would have similar effects on many extractives. Again, it must be kept in mind that the solubility of aged materials is quite different than the extraction needs of new cedar wood described earlier.

## Chemical Deterioration from Pollutants and Previous Treatments

### Oils

Other materials applied to artifacts made from plant materials as parts of conservation procedures may also contribute to the deterioration of these compounds. Certainly, the variety of oils that have been applied to saturate colors or somehow stabilize moisture regain (which is impossible since oils are too large to penetrate the cell wall where swelling and shrinkage occur) have served to soften or dissolve waxes, cutin, and suberin. They have, no doubt, altered existing resins and oils to the point that any analytical characterization, for either inherent plant oils or those accrued in ethnographic use, is impossible.

### Glycerol

Trihydroxy alcohol glycerol may also lead to the solubility and changes of plant oils and resins, as well as contributing to their extraction. Waxes and resins themselves have been applied to artifacts made from plant materials, complicating the analytical problem still further and creating moisture gradients within various tissues.

### Mixture Recipes

Often, materials applied to artifacts made from plant materials are mixtures of compounds that are thought to aid in the preservation of the materials. Combinations of solvents, heavy-metal biocides, resins, waxes, and humectants can be found as preservation recipes in the records (Reed 1966, Horton-James and Townley 1978, Kronkright 1981, Bates 1980, Foreman 1971, Withers 1976, Odegaard 1986). In approximately 1900, C.P. Wilcomb, Curator of the Oakland Museum, described a procedure for a basketry treatment possibly suggested to him by Mason. He proposed using a lined dry goods box to hold baskets, to be liberally dashed with gasoline and left for two days. He also suggested treating baskets with corrosive sublimate in alcohol and surfacing them with paraffin dissolved in turpentine.

One of the earliest citations is from Otis T. Mason's 1904 U.S. National Museum report. Mason cites basketry as one of the "most fragile and perishable of human industrial products." He notes that insects, rust, heat, cold, too much and too little moisture, and the common accidents of life are hastening the dissolution of the world's collections. Mason recommends that baskets containing remnants of berries and other food should be carefully scrubbed with soap and water and rubbed with oil and dryer. He briefly discusses the common agents of decay known to him, cites E.S. Morse, and recommends as a wise procedure the Japanese practice of displaying treasured artworks for only short periods. Unfortunately, he also recommends poisoning the baskets with corrosive sublimate or arsenic in alcohol. This is followed by noting the necessity of thorough documentation.

### Fumigants

Several other classes of previous treatments should undergo critical review for their contribution to the deterioration of plant material components. Principal among these are fumigant gases. Methyl bromide, sulfuryl fluoride, and ethylene oxide have all been used, until very recently, as insecticidal fumigant gases for plant materials. In many museums, collections management policies required that an object taken out of controlled storage areas undergo a routine fumigation before reentering storage. This had the net effect of subjecting the most interesting or significant pieces in a collection to frequent treatments with fumigant gases after each exhibition or scholarly review.

Florian points out that treatment of plant materials with ethylene oxide and methyl bromide could easily result in methylation or ethylation of hydrogen bonding sites along the crystalline margins of amorphous areas (Florian 1987b). She notes, in fact, that a similar process of treatment of wood paper pulp with ethylene oxide results in ethylation linkages, producing a paper with a higher wet strength due to cross linkages using the methyl group. The same can be expected to take place with methylation as well.

### Halogens

The halogen series of atoms and their compounds are also very active and typically react with carbon quite easily. Some halogen compounds have nonhygrostable portions that can degrade into acidic and oxidizing compounds, including historically popular compounds such as paradichlorobenzene. Others are strong oxidizers. Either from cross linking, oxidation, or hydrolysis, the halogens, as a class are suspect in their preservation qualities. Much more research is needed to truly understand the reactivity of these compounds.

### Gaseous Pollutants

Thomson (1978) points out that gaseous pollutants overwhelmingly come from the burning of fossil fuels in power stations, factories, and automobiles. He identifies two general classes of pollutants: acidic and oxidative. The acidic category includes sulphur and nitrogen oxides and the carboxylic acids produced by wood and wood products. The oxidant category includes ozone.

#### *Acidic Gaseous Pollutants*

The conservation literature on the effects of acidic pollutants is growing at an increasing rate. Fitzhugh and Gettens (1971) describe the formation of acetates on shells and formates on lead and zinc. Oddy (1973) reports on the effects of metal corrosion, while both Padfield, et al. (1982) and Agnew (1981) consider the formation of calcium acetate and formates on shell materials. Chartier (1987) discusses strategies for protection of objects from sulphur and nitrogen oxides, pointing out that, in many cases, nitrogen oxides are more chemically active.

Carpenter and Hatchfield (1986), Leveque (1986), and Grzywacz (1987) report on recent findings of acidic gaseous pollutants in wood exhibit and storage furniture. Other important works on the subject include those by Blackshaw and Daniels (1978), Tennent and Baird (1985), and Miles (1986).

A review of the many mechanisms and chemically active compounds created by acidic gaseous pollutants is beyond the scope of this chapter. The literature cited

is becoming very complete in this regard, and as both Leveque (1986) and Grzywacz (1987) point out, research is becoming much more intense and focused. None of these studies, however, deals specifically with the effects of acidic gaseous pollutants on plant materials in artifacts. Until studies can be initiated that consider the effects of these materials on organic artifact materials, we must exercise great caution and extend our knowledge of the role of acidic compounds in plant materials. Their role in hydrolysis may be considerable and their deteriorating effects on waxes, cuticles, suberin, color compounds, and compounds that can serve as oxidation intermediates may also be important.

While the precise acidic species and mechanisms for acidic gaseous pollutant deterioration in plant materials may not yet be thoroughly researched in the conservation literature, steps can be taken to monitor the presence of acidic gases in exhibit and storage locations. Kenjo (1986) notes a relatively simple testing procedure for the presence of acidic and alkaline gaseous materials.

In this procedure, Kenjo suggests mixing equal volumes of 0.5% glycerol solutions of chlorophenol red, bromothymol blue, bromocresol green, and phenol red, which are then applied to one-cm-wide alpha cellulose filter paper "test paper strips." After twenty-four hours, Kenjo found that the acidic characteristics of the air could be assessed. Red, orange, and yellow coloration indicated decreasingly acidic conditions; yellow-green indicated neutrality; green, blue-green, and blue indicated increasing alkalinity.

Mason (1987), Mellon Fellow in Advanced Ethnographic Conservation at the Bishop Museum, is testing a similar procedure utilizing commercial pH-indicating test strips and glycerol activating solutions. If the procedure is found to be effective for monitoring acidic gases in concentrations normally found in museum environments, the procedure would make a welcome addition to the conservation literature.

*Ozone*

An outstanding discussion of ozone and its effects on many materials, including plant materials, is presented by Druzik (1985). Druzik notes that ozone is produced as a secondary reaction product through the combined interaction of sunlight, oxygen, oxides of nitrogen, and industrial hydrocarbons. He notes that indoor concentrations of ozone have been found to be higher than what was expected, depending on the type of air conditioning equipment. He documents the downwind movement of ozone-producing areas to nonproducing areas.

Druzik states that both chain scission and cross-linking in polymers can occur upon exposure to ozone. Most pertinent to the preservation of plant materials in artifacts is the fact that Katai and Schuerch (1966) found ozone evidence of a twofold deterioration mechanism in cellulose. The first is an indiscriminate oxidation scission of the polymer chain forming a number of different groups with chain lengths over 100 DP (degree of polymerization). The second mechanism is described as an ozone-induced hydrolysis which is not pH dependent.

Druzik also cites a study in which curcumin (the coloring agent in turmeric) was almost totally destroyed by ozone. The intriguing part of this study is that curcumin consists of two coniferyl alcohol molecules, joined tail to tail. As

Druzik points out, this suggests that similar methoxy-hydroxy-phenolic propanes in lignin may also be readily attacked by ozone.

## Mechanical Deterioration

Mechanical deterioration is a broad category that typically overlaps other types of deterioration. It includes a large and varied list of problems commonly found in artifacts made from plant materials. For this reason, conservators of these materials spend much of their time considering mechanical deterioration effects and the ways in which they overlap into chemical and physical deterioration categories.

Mechanical deterioration takes many forms. A typical list would include: abrasions, scuffs, tears, fractures, holes, losses, creases, folds, distortions, cuts, chips, splintering, dents, as well as applied accretions, such as dust, soil, grime, exhibit paints, and boiler soot. It is clear from considering such a list that mechanical damages tend to fall into two categories: things that have accumulated on the surface—and sometimes within the structure—of an object, and things that can be traced back to an application of a physical force or action exceeding the ability of the object or material to offer resistance.

### Mechanical Deterioration as Ethnographic Evidence

Within this category, we are again struck with the fact that it is often difficult, and sometimes impossible, to determine which mechanical deterioration is a part of the object—that is, which mechanical deterioration is ethnographic in nature, and which is abusive, having taken place through neglect or improper care.

Evidence of utility, patterns of use, and worn out areas can all illustrate normal use patterns for the ethnographic record. They can also direct the eyes of the conservator to inherently weak or fragile areas.

Patterns of abusive mechanical deterioration tend to confuse or obscure the ethnographic evidence. They may demonstrate a previous method of poor storage, such as attic soot and dust, breakage from stacking or insufficient space, or such things as folds, creases, and tears from being packed tightly in too small a drawer or cabinet. Such patterns may also show evidence of poor exhibition techniques, such as broken and torn elements from nails and tacks used to suspend artifacts from walls or distortions from having displayed an object resting artistically on its side, rather than on its base, as its structure was designed to function.

Determining the difference between ethnographic and abusive mechanical deterioration is not a simple matter. Sometimes, it cannot be done with existing technologies and budget limitations. Again, in this case, the importance of the object to the ethnographic record increases substantially. The fact that the condition of the object is so complex raises important questions as to the possible ethnographic use. This complexity is of far greater value to curators than dealing with objects which raise no questions at all. Extra care should be taken to ensure that no potential evidence is altered until such time as better determinations can be made.

## Mechanical and Related Deterioration Processes

The types of damage that fall into the category of mechanical deterioration are so numerous that many will overlap with physical, chemical, and biological deterioration processes. Dust, soot, grime, and other accretions are good examples.

### Dust, Soot, and Grime

While dust content varies from location to location, typical components include textile fibers, skin flakes, wood and vegetable fibers, mineral particles, insect parts, fungi spores, pollen grains, soot, smoke and exhaust particles, and pollutants. Fibers of all kinds compose an important dietary component for many insects that are damaging to museum collections. In addition, because dust is hygroscopic, it contains the additional moisture needed by many insects for optimum metabolic and reproductive conditions. The moisture also supports mold growth from the many spores contained in the dust.

Mineral particles are, of course, a major source of abrasion when they are moved across the surface in handling and cleaning. They also contain many metal ions and acid salts, which can lead to both chemical deterioration through moisture-induced hydrolysis and photodegradation through metal-ion-catalyzed oxidation. Even though this degradation may be limited to contact surfaces, these surfaces and their inherent protective components are important to both the appearance and preservation of the plant material making up the object.

Similarly, pollutants attached to particulates can cause acidic deterioration through hydrolysis with available moisture. We can also see how materials applied to surfaces in treatments that attract and trap dust or moisture—such as oils, glycerol, polyethylene glycol, soaps, and detergents—can accelerate all of the dust-induced deterioration processes.

## Mechanical Damage from Physical Forces

When considering deterioration such as tears, fractures, creases, holes, and losses, we enter an area that is well introduced by Odegaard and Kronkright (1984). They propose that understanding both the cause and effect of structural damage can be clarified if conservators learn to "read" objects for all the information they may have to offer us.

The authors outline a procedure for reading the structures found in basketry. It is not difficult, however, to generalize the steps in order to apply them to a wide range of artifacts made from plant materials. The steps they outline include:

1. Look at the object's general shape to determine how the object was originally meant to sit or rest, and how it was meant to be used.
2. Note the general methods of manufacture and kinds of structural elements the maker selected to build the piece. Note whether the elements are heavy or small, if the work was meant to be fabric-like or rigid, as well as the types of plant tissues used throughout the structure.
3. Find the direction, progression, and working orientation of the weaver. Understand where and how he or she started the work, built upon the start, and tied subsequent work into a continuous structure.

4. Note the placement and spacing of various types of manufacturing variations, indicating where the weaver or artist suspected a need for reinforcement, flexibility, rigidity, or economy.
5. Note how the start and subsequent additions of materials to quickly enlarge the shape were accomplished, as well as how the other elements of the basket were bound to the start.
6. If the object is woven, understand how fag and moving ends were secured for wefts and stitches.
7. Note how the rim, selvedges, finish, or termination of the work was executed and bound and how it functions to maintain the structural continuity of the piece. The authors note that the termination of work is often the point furthest away from where the work began. By properly executing a finish, the maker achieved continuity for all the fabric of the object between start and finish.
8. Note how design techniques were executed, what their impacts might be on materials around them, what impacts the materials around them might have, and what effects they have on the structure. Determine if they reinforce, stiffen, make more rigid, make stronger, make weaker, make more light sensitive, and so on, the materials around them.
9. Note native repairs done by the object's maker or user, to direct one's attention to inherent weaknesses and mechanical forms of deterioration that are of ethnographic origin. Distortions and abrasions can also indicate the method of use or wearing, as well as how the object was aesthetically meant to be seen.

## Impact of Mechanical Deterioration on Artifact Stability

In following the steps outlined above, the conservator can assess how the present mechanical damages affect the original functions of the object. Odegaard and Kronkright make the final point that plant-artifact structures, in combination with the qualities inherent in the materials used in creating them, must accomplish two fundamental things. The first is that the structure must distribute a load or stress placed upon it in handling, rest, or use in an even manner predetermined by the maker. The second is that the object must retain the form it was given by the maker.

If damage from handling, display, or storage configurations distorts or interrupts the structure in ways such that the elements no longer play the structural role they were intended to, deterioration will progress throughout the object until a new equilibrium is established.

Mechanical damage usually threatens the structural stabilization and degree of material loss in the artifact. Stabilization treatments, therefore, should address the specific responsibility of a damaged element or elements. If a warp in a woven structure is fractured and the continuity of the structure is altered, a repair technique must be devised that will address the role of the fractured warp. The same can be said of torn stitches in coiled structures, wefts in twined and plaited structures, strands in cordages, and fractured rim-reinforcing rods and handles on vessels.

The purpose of "reading" the structure of an artifact made from plant materials is to define conditions that are problematic to structural stability. Next, one must again consider the degree of compensation or recovery that will be needed by

a conservation treatment. A broken gourd or torn net may be perfectly stable if properly supported in storage. The same two pieces may need special securing to avoid damage during research handling or movement between buildings. The degree of recovery is different, again, if the objects are to be placed on exhibit and properly understood by museum visitors.

In addition to defining what is problematic about the object's structure, it is just as important to define what qualities remain and are contributing to the stability currently afforded to the piece. Any conservation treatment procedure must address both problematic and beneficial structural qualities to achieve truly improved preservation of the piece.

## Biological Deterioration

Deterioration of artifacts made from plant materials caused by biological sources has long been a concern to museums. Some of the earliest treatments recorded in the literature deal with various methods of killing insects in artifacts (Mason 1904, Wilcomb 1900). Since that time, the literature and discussions on the subject seem to focus on six general categories of biological sources of deterioration: humans, rodents, birds, reptiles, fungal and bacterial infestations, and insects.

### Human Sources of Biological Deterioration

Humans are among the most damaging sources of biological deterioration. Each time an object is handled by a person, for whatever reason, the opportunity exists for damage to occur. People also decide, either consciously or by default, the environment in which an artifact will rest. In museums this decision is typically made for large numbers of artifacts; improper or misguided decisions can negatively impact a great number of artifacts.

The role of conservators as a dimension in deterioration has already been touched on, as has the wide ranging impacts of conservation decisions on the preservation and analytical potential of artifacts made from plant materials. Our operational definition of deterioration makes it clear that our role as advocates for the preservation of the objects obligates us to protect the artifacts, even from ourselves.

Deterioration caused by human beings can perhaps best be understood by studying the actual forces acting on the object; for this reason, damage more easily falls into the categories of physical, chemical, and mechanical deterioration.

### Rodents

Mice and rats are certainly no strangers to museum collections and have frequently made their homes among artifacts made from plant materials. Damage often takes the form of chewing and gnawing marks on the artifact, usually with some loss of materials.

There are instances in which the rodent appears to have licked or grazed the outer surfaces of the artifact, possibly to remove nutrients in food or oil remains contained on the artifact from either ethnographic use or from application as a preservation treatment. There is evidence to suggest that strychnine powder was used to cover the surfaces of baskets as a control measure in this regard. Arsenic, mercuric

chloride, and cyanide compounds have also been applied to plant material artifacts to help control rodent damage. The popularity of the treatments appears to be widespread, particularly in collections built from before the turn of the century through the 1930s, but including items collected even very recently.

Clearly, these materials can be injurious to museum personnel working with or around the collection. There is frequently no written record and only seldom is an artifact tagged or labeled as containing toxic substances. It is therefore very difficult to assess the scope of these treatments. In addition to protecting the artifacts from oils, fatty acids, and perspiration salts, the risk of personnel injury from toxic compounds is the best reason for wearing protective gloves whenever handling a collection.

Rodents also leave behind various nesting materials such as chewed-up burlap, newspaper, and textile rags, many with soluble colors. These are often damaging to plant materials by themselves and when combined with urine and acidic excrement become even more so. Depending upon when the nest is discovered, mold and fungi may also be contributing to the deterioration of the artifact, living off the moisture contained in urine-soaked nesting materials.

## Birds

Although birds, unlike rodents, do not commonly nest in artifacts made from plant materials, they often nest in the buildings in which artifacts are stored. Birds bring with them many artifact-destructive insects, such as carpet beetles. The adult phases of these insects are winged, and they migrate widely. They can be attracted to interior spaces of collection areas by lights at night or warmer temperatures contained in sun-facing walls or heated rooms. Once an egg-bearing female finds suitable conditions to establish a population, artifacts can become a marginal food source or the principal site of an infestation.

## Reptiles

In many tropical climates, small insect-eating reptiles can frequent museum storage and exhibit areas. While they are not known, as yet, to eat artifact plant materials directly, they do leave behind staining excrement, which can be acidic.

## Fungi and Bacteria

It is, of course, the aim of conservation to provide artifacts with environments which will arrest and prohibit deterioration from fungi and bacteria. While the critical relative humidity needed to achieve a moisture content sufficient for the growth of fungi is dependent on a number of factors, both fungi and bacteria can typically be controlled at relative humidities below 60%. It is more common for fungal and bacterial damage to have taken place prior to collection of the object; this is typical of many archaeological objects.

### Bacteria

An excellent review of the literature regarding bacterial degradation in plant materials is provided by Florian (1981). Although it is beyond the scope of this paper to note all the features of bacterially degraded wood cited by Florian, several salient facts may be of use in diagnosing possible bacterial degradation. Further reading of Florian's work, and the references cited by her, is encouraged.

Florian points out that for bacterial deterioration to occur, wood must be nearly water-saturated. She cites an excellent review article by Leise and Greaves, noting that the decay pattern in both hardwoods and softwoods begins with the depletion of the cell contents of wood ray parenchyma cells, followed by the pectin-rich cross field pit membranes. Degradation of the bordered pits of softwood tracheids is also described by Greaves, using light microscopy, and supported, as Florian points out, by Greaves and Foster, using electron microscopy. The degradation of the pit cavity causes enlargement of the pit aperture and loss of pit membrane.

### Fungi

In the same article, Florian (1981) discusses the salient characteristics of fungi deterioration in wood, again with excellent citations to the literature. A summary of features presented by Florian may again prove to be useful.

Florian points out that fungi may occur when the plant is alive, when it is dead, stored in an artifact while in use, and when discarded. Thus fungi in an artifact need not be active. The wood-decay fungi can be understood to fall into four groups: surface mold, sap stain fungi, decay fungi, and soft rot fungi. Surface molds and sap stain fungi utilize carbohydrates and do not destroy cellulose or lignin.

Brown rot is due to decay fungi which digest only cellulose. The structural appearance of the tissues is maintained because the lignin matrix remains. The lignin is chemically altered, however, with increases in alkaline solubility and methoxyl content. Wood undergoes weight losses of up to 50% and suffers considerable volumetric shrinkage, which causes splits and cuboidal checking. The fungi hyphae enzymatically bore holes through the cell walls, lie in the cell lumen and digest the cell wall from the lumen outward.

White rot is due to decay fungi which digest only lignin. During decay, the thickness of the cell remains, but lignin-containing amorphous areas within the cell wall widen. The loss of lignin causes increased porosity and swelling, with ultimate collapse of the affected areas. White rot occurs frequently in pockets and has been called "pecky rot."

Soft rot is decay that occurs in wood of abnormally high moisture content and is the type of fungi decay most commonly associated with archaeological waterlogged or buried wood. Soft rot can be described as superficial, with a soft and easily eroded surface and a rapid transition from decayed to sound wood. The surface of dried materials is characterized as a thin, brown surface layer with cuboidal checking, and sound wood immediately below. The fungi hyphae penetrate the cell wall and lie in troughs which they dissolve for themselves only in the $S_2$ cellulose fibrils. Soft rot also shows preferential decay of late wood cells, causing exfoliation of surfaced growth rings.

## Insects

A comprehensive survey of insects that contribute to the deterioration of artifacts made from plant materials is far beyond the scope of this chapter. Lacking such a focused and comprehensive study, however, it is possible to fall back on the existing literature, which occasionally focuses on damaging insects but more often deals with control measures. A listing of insects that destroy museum collections published by Beauchamp, et al. (1981) may be the most comprehensive compiled thus far.

In a paper presenting a case study monitoring collection-damaging insects, Florian (1987a,1987c) demonstrates how biological characteristics of various insects correlate to locations in which populations were found in museum buildings. An additional discussion of museum pests can be found in publications by Ward (1976) and Florian (1978). In an excellent systematic evaluation of museum insect pest control measures, Story (1985) presents a literature review of typical insect pests and control measures. The author provides descriptions of roaches, crickets, booklice, silverfish, hide beetles, carpet beetles, clothes moths, furniture beetles, powderpost beetles, drugstore beetles, and cigarette beetles. Story reviews not only conventional fumigants and insecticides, but also insect-resistant containers, use of heat, nonheat radiation, low temperatures, other nonchemical methods, atmospheric gases, and pheromones. Other useful discussions of pest control measures can be found in Florian (1986) and Edwards, et al. (1981).

What the literature typically does not refer to, but conservators need to know, is that the variety of insect pests causing deterioration to artifactual plant materials is not restricted to insects commonly associated with wood. Insects which typically infest stored grains and grain products, tobacco, drugs, spices, flour, and even those commonly associated with proteinaceous materials are also found on plant material artifacts.

In some cases, these insects are actually gaining nutrients from the ethnographic deposits remaining on the surface of the artifacts. In other cases, the insects seem to be feeding on oils and accretions which were applied or accumulated on the object after collection. Dermestids are found to be eating the plant material itself, perhaps for small quantities of nutrients within, and perhaps because of a lack of other readily available proteinaceous food sources.

Insects such as clothes moth larvae and cockroaches, not immediately thought to damage plant materials, frequently scarify or, in the case of the grain moth, bore into the surfaces of plant materials. The cockroach and clothes moth do so to attach an egg case and pupae case, respectively, and the grain moth larvae has been found to bore into the pith of woody stems to pupate.

Sawtoothed grain beetles have been found feeding on willow shoots in basketry. Cigarette beetles, known to infest a wide variety of processed plant and dried herbaceous material, have been found forming galleries and destroying wood in the cabinetry lining of safes (author's observation; species identified by Dr. A. Samuelson, Department of Entomology, Bishop Museum). Recently, a species of bark beetle (*Hypothenemus* sp.) was discovered in association with damaged ethnographic objects made from dried leaves, leaf petioles, and plant fiber cordages (author's observation; species identified by Dr. Samuelson).

In general, it seems likely that insects commonly described in the literature as damaging to specific materials can also infest and damage artifacts made from plant materials, given the proper conditions. Such insects include those known to damage wood, grain, flour, dried vegetable materials, books, starch, tobacco, spice, cereal, and bark, as well as the entire Dermestidae family, cockroaches, crickets, silverfish, and firebrats.

Conservators should obtain good illustrations from the references listed here, and from entomological sources such as Mallis (1982) that include descriptions of typical biological characteristics and kinds of damage, in order to begin familiarizing themselves with the variety of damaging insects.

## Documenting Evidence of Deterioration: Tests and Analyses

It has been noted that no single factor is more critical to a successful conservation procedure than a systematic examination. If properly completed, such an examination accurately answers many of the questions about deterioration needed to define the most suitable direction for conservation measures. It must be the goal of the bench conservator to remove as much guesswork as possible about the artifact through the examination process. Accurate assessment of deterioration processes as well as remaining stable characteristics provides important insights into the preservation needs of an artifact.

There is a difference between procedures in support of conservation conducted by analytical laboratories and conservation scientists and the more simple tests needed by the bench conservator to document fundamental questions regarding the artifact and its deterioration. As mentioned, identifying some of the chemical, morphological, and mechanical consequences of deterioration can help to clarify the conservation challenges presented by a given artifact. Testing in the analytical laboratory can help to understand the rates, relative sequences, and conservation consequences of specific deterioration mechanisms. Just as importantly, the analytical laboratory can help identify the components and origins of utilitarian evidence conservators work so hard to preserve.

### Analytical Laboratory Testing

Erhardt, von Endt, and Hopwood (1987) recently demonstrated the use of gas chromatography combined with mass spectrometry to identify the deterioration products of purified cellulose paper pulps under hydrolyzing and oxidizing conditions. It is also possible to characterize other components and deterioration products of materials found in plant materials using gas chromatography. Oils, resins, gums, lignin, and hemicelluloses can all be characterized and investigated for the effects of aging process, fumigants, gases, and other conservation processes.

In his studies of paper and lignocellulosic materials, Hon (1981b) utilized electron spin resonance spectroscopy extensively to identify deterioration species and routes. Infrared spectroscopy and FTIR (Fourier transform infrared) can be used to identify acidic and oxidative byproducts of deterioration of both holocelluloses and other components such as oils, esters, resins, and waxes.

Many wet chemical tests exist that are used to measure deterioration products of cellulosics. The changes in the degree of polymerization of cellulose and hemicelluloses can be measured using viscosity-wet chemical methods. Carboxyls and carbonyls can be quantitatively identified by wet chemical methods. Such tests can help define the rates and sequences of deterioration reactions in plant materials. Other components like tannins, hemicelluloses, pectopolyuronides, and functional groups can be characterized using standardized wet chemical methods. Both instrumental and wet chemical methods require, for the most part, destructive sampling and sufficient sample quantities of tests to account for inherent variability. The testing generally requires some sample preparation to extract the compounds in question. It is also important to remember that simply identifying the quantity of a deterioration product in a given sample may not clarify any of the conservation needs of the artifact in the absence of data prior to deterioration. If it is merely a matter of identifying a deterioration product, simple infrared spectroscopy or thin-layer chromatography may be all that is required.

Mechanical tests for tensile, compression, bending and shear strength, hardness, and modulus of elasticity are also available for evaluating the extremely important and too frequently ignored mechanical consequences of deterioration processes. Again, to accurately make observations regarding the mechanical consequences of various deterioration mechanisms on plant materials, as well as to define which mechanical properties deteriorate first and to what degree, enough data must be accumulated to account for the large variability contained even within a single sample. Collecting this data requires many tests of representative materials—frequently, new materials artificially aged under accelerated conditions.

These procedures, however, necessitate carefully controlled experimental designs that offer a wealth of information regarding the stability of materials and the nature of deterioration reactions, yet often do not help the conservator to identify evidence within the object, which she or he must consider at the bench.

The conservator has more immediate questions regarding an object to be treated: What kinds of plant tissues are present and what specific qualities do they bring to the artifact? What are the morphological signs of deterioration? What is the nature of the various discolorations? Are the tenacious soils abusive or ethnographic? And what are they? Is this deposit fungi, wax polymorphisms, or salts? What will be the impacts of conservation procedures? Is there arsenic, mercuric sulphide, strychnine, or other poison(s) on this object? Such questions can sometimes be answered or clarified using relatively simple procedures in the conservation lab, removing much of the guesswork from the conservation process.

## Testing: The Nature of Materials

Knowing whether one is looking at primary or secondary lignified tissues, whether there is a thick, waxy cuticle or endodermis, if the material is a fibrous sheath from a leaf or a bundle of secondary phloem fibers can often explain conditions that may seem problematic on preliminary examination. Cracks and checks in the surface, darkening or yellowing colors, fraying or cracking fibers are all conditions that may be inherent qualities of the plant material and its constituent compounds. They are also conditions that could result from fungi degradation, photooxidation, thermal

degradation, and physical deterioration. Differences among various conditions are simply defined using a polarizing light microscope and hand sections.

The hand sectioning techniques require only extremely small samples and relatively little tissue preparation. Florian developed these useful techniques in conjunction with her own work (see Sampling of Artifacts in Chapter 2). She has made it clear that standard botanical histological techniques are not necessary to obtain the information needed for the bench conservator considering treatment (Florian 1977a). It is seldom necessary to determine the species or even genus of the plant material in an artifact. Understanding the general types of tissues present in the artifact may be all that is necessary to understand either the inherent qualities of normal aging in the plant material or to identify evidence of deterioration mechanisms.

Staining techniques can enhance our understanding of the artifact and its deterioration. Safranin O can differentiate between plant parts and many nonplant parts. Toluidine blue can distinguish between primary and secondary tissues. Phloroglucinol stain plus 25% hydrochloric acid can stain lignified tissues in contrast to nonlignified tissues. Sudan III will stain suberin and cutin in epidermal and phellem cells. Bromophenol blue will stain protein-containing materials in contrast to plant materials.

Plant waxes, as well as waxes applied as postcollection treatment, can best be identified using infrared spectroscopy and melting point determinations. Resins and oils may also be partially characterized using IR spectroscopy and thin-layer chromatography (Stahl 1969).

## Tenacious Soils and Deposits

Staining techniques can also be used to help characterize tenacious soils and deposits. A sample of soiling can be placed on a microscope slide and smeared with a cover slip, followed by staining and rinsing. Iodine potassium iodide will stain starch granules purple to purple-black. A sample of soiling can be smeared onto an alpha cellulose filter paper and sprayed or brushed with a .2% ninhydrin solution in ethanol in a fume hood. The paper is then developed on a hot plate or oven at 110 °C; a purple stain will appear where amino acids are present. Oils and fats can likewise be positively identified using the filter paper smear technique and staining with sudan III followed by rinsing.

Soils can typically be identified using polarized light microscopy, looking for the presence of abundant silica. Minerals, hairs, and plant and skin particles can be identified using the appropriate staining techniques, followed by washing with water.

Salts can most easily be detected through polarizing light microscopy or by the traditional silver nitrate test for chlorides. Arsenic can be tested by smearing a sample on a small platinum wire loop heated over a flame and watching for a light blue flame, or by using the procedure described by Hawks and Williams (1986).

Fungi hyphae and fruiting bodies can be stained differentially from other plant parts by staining with cotton lactophenol blue. Fungi parts stain lavender to lavender-blue while cellulose stains blue. Congo red can be used similarly to stain cellulose pink and fungi hyphae dark red.

## Deterioration Products

Deterioration products can be characterized to a useful extent by other simple techniques. The best known consists of measuring the presence of acidic byproducts of hydrolysis and oxidation reactions. This can be accomplished by using alphacellulose filter paper again. The paper is moistened and the pH measured using either a contact electrode or nonbleeding indicator strip. A sample is placed on the paper and wetted with a drop of water. Soluble materials will leach into the filter paper. These materials can then be tested again for pH. A more acidic reading than the control indicates the presence of soluble acidic deterioration byproducts. If the materials leached into the paper are colored, they may be further stained for the presence of lignin, starches, and tannins by teasing the stained fibers from the filter paper with tweezers and staining accordingly under the microscope for these materials, or by staining the paper directly.

The solubility of extractives in plant material may be roughly predicted using a similar technique. If a possible conservation treatment calls for the use of a solvent, a small sample can be wetted with the proposed solvent on alphacellulose filter paper. Several solvents on different filter paper pieces may be tried, to determine the possible extraction effects of each. Sample papers can be observed under ultraviolet illumination for fluorescence of extracted resins. Extracts can also be stained using the techniques mentioned, to further characterize them. Tannins can be identified by staining with 0.1% ferric sulphate in water, staining tannins purple-brown.

It can also be useful to remember that ultraviolet light fluorescence can identify many fungi present on the surface of the artifact, as well as help delineate the presence or former presence of pigments, binders, and previous treatments.

The presence of sugars can be tested using simple thin-layer or paper chromatography. This method also identifies the nature of the polysaccharides extracted by water, useful as an indicator of the relative degree of deterioration of hemicelluloses versus cellulose. Chromatograms can be used by concentrating overnight cold water extracts to about ½ ml under 40 °C. The extract is applied to the chromatographic surface and separated using Whaley's solvent and developed with silver nitrate. Sugar content of the polysaccharides can be characterized by first hydrolyzing in 25% hydrochloric acid.

As plant materials undergo hydrolysis and oxidation, their absorbance spectrum changes in the visible blue-to-ultraviolet region. We know that many deterioration products are good ultraviolet absorbers. This fact can be used to advantage to provide another simple indicator of deterioration, UV-spectroscopy. This is particularly true for partially discolored or faded objects. Even the commonly found ultraviolet meter can be used to measure differences in ultraviolet reflectance on both damaged and undamaged surfaces. Reflectance would be expected to decrease on deteriorated surfaces, as absorbance increases.

## Morphological Evidence of Deterioration

In extreme cases, deterioration can be observed to cause checking within the cell wall using polarized light microscopy. In such cases, relatively little strength remains in the plant tissues and the sample usually amounts to macerated fibers. SEM can identify earlier morphological signs of deterioration—as can light microscopy, to a lesser degree. Deterioration of bordered pits in softwoods can be an earlier sign of deterioration. Fraying of cell walls and loss of interfiber adhesion in the middle lamella is another good indication of deterioration that has advanced to the point of causing reductions in mechanical capabilities.

It may be possible to observe loss of cell wall homogeneity by staining cross sections with iodine potassium iodide for two minutes followed by rinsing with 65% sulfuric acid for one minute, followed by washing with water. Iodine potassium iodide is a specific red stain for cellulose that exaggerates failures within the cell wall. Contrast with surrounding tissues may be increased by staining for lignin in both cross sections and axial sections.

Observing longitudinal sections of ultimate fibers and small fiber groups while swelling in 1%, 5%, and 14% sodium hydroxide can be useful to obtain a relative sense of plant material deterioration. In this test, undeteriorated material of the same type as the material in question is swelled in the three solutions, under the microscope. Polaroid micrographs can be very useful in recording the results. The same tests are then applied to the deteriorated material and the results are observed. Deteriorated primary cell walls and cell wall failures allow swelling cellulosic materials to break through. Undeteriorated cell walls force swollen materials to extrude through the cross sectional ends of the fibers.

Conservators may want to use similarly basic methods to monitor the effects of treatments on tissue morphology. Not only can the extractive tendencies of a particular solvent be checked by the filter paper method mentioned above, that same sample can be taken after extraction and the morphological consequences of treatment can be observed. Hatchfield and Koestler (1987) have demonstrated how well SEM examination aids in this type of study. Even with very small sample sizes, changes in the material are very clear.

# References


**Agnew, N.**
1981 The corrosion of egg shells by acetic acid vapour. *ICCM Bulletin* 7(4):3–9.

**Arganbright, D.G.**
1983 Review of the properties of wood. In *Wood in art conservation: A seminar on wood for practicing conservators.* Richmond: University of California Forest Products Laboratory and the Western Association of Art Conservators.

**Atalla, R.H.**
1981 The crystallinity of cellulosic fibers: Dependence on history and influence of properties. In *Preservation of paper and textiles of historic and artistic value* II. J.C. Williams, ed. Washington, D.C.: American Chemical Society.

**Baird, G.**
1976 The care of Indian baskets. In *Northwest Indian basketry.* Tacoma, WA: Washington State American Revolution Bicentennial Commission.

**Bakken, A. and K. Aarmo**
1981 A report on the treatment of barkcloth. *ICOM Committee for Conservation Preprints*, 6th Triennial Meeting, Ottawa (81/3/4):1–4.

**Barrow, G.**
1972 *General chemistry.* Belmont, CA: Wadsworth.

**Bates, C.D.**
1980 Personal communication.

**Baugh, P.J.**
1981 Photodegradation and photooxidation of cellulose. *Developments in Polymer Photo Chemistry* 2:165–214.

**Beall, F.C.**
1986 Thermal degradation of wood. In *Encyclopedia of materials science and engineering*, Vol. 7. M.B. Bever, ed. New York: Pergamon Press.

**Beauchamp, R., J. Kingsolver, and T. Parker**
1981 Reference listing of museum pests. In *Pest control in museums: A status report, 1980*, S. Edwards, B.M. Bell, and M.E. King, eds. Lawrence, KN: American Association of Systematic Collections.

**Blackshaw, S.M. and V.D. Daniels**
1978 Selecting safe materials for display and storage of antiquities. *ICOM Committee for Conservation Preprints*, 5th Triennial Meeting, Zagreb (78/23/2):1–9.

**Boyd, J.D.**
1982 An anatomical explanation for visco-elastic and mechano-sorptive creep in wood, and effects of loading rate on strength. In *New perspectives in wood anatomy.* P. Baas, ed. The Netherlands: M. Nijhoff/W. Junk Publishers.

**Brown, W.H.**
1977 *Introduction to organic biochemistry.* Boston: Willard Grant.

**Carpenter, J. and P. Hatchfield**
1986 *Formaldehyde: How great is the danger to museum collections?* Cambridge, MA: Center for Conservation Technical Studies, Harvard University Art Museums.

**Chartier, D.R.**
1987 What you don't see can hurt you. The effects of nitrogen oxides on works of art. *IIC-CG 13th Annual Conference Abstracts.*

**Cumberbirch, R.J.E.**
1984 High absorbency viscose fibres. *Textiles* 3(13):60.

**Druzik, J.R.**
1985 Ozone: the intractable problem. *Western Association for Art Conservation Newsletter* 3(7):3–11.

**Edwards, S.R., B.M. Bell, and M.E. King**
1981 *Pest control in museums: A status report, 1980.* S. Edwards, B.M. Bell, and M.E. King, eds. Lawrence, KN: American Association of Systematic Collections.

**Erhardt, D., D. von Endt, and W. Hopwood**
1987 The comparison of accelerated aging conditions through the analysis of extracts of artificially aged paper. *AIC Preprints*, American Institute for Conservation 15th Annual Meeting Papers, 43–55.

**Feller, R., S.B. Lee, and M. Curran**
1985 Three fundamental aspects of cellulose degradation: Annotated bibliographies. In Supplement, *Art and Archaeology Technical Abstracts* 22(1). London: J. Paul Getty Trust and IIC.

**Fitzhugh, E. and R.J. Gettens**
1971 Calcite and other efflorescent salts in objects stored in wooden museum cases. In *Science and archaeology.* R. Brill, ed. Cambridge: MIT Press.

**Florian, M.-L. E.**
1977a Plant materials used in some ethnological artifacts: Structure, fabrication and deterioration related to conservation treatment. *AIC Preprints*, American Institute for Conservation 5th Annual Meeting Papers, 51–55.

1977b Waterlogged artifacts, the nature of the materials. *Journal of the Canadian Conservation Institute* 2, 11–15.

1978 Biodeterioration of museum objects. *Museum Roundup.*

1981 Analyses of different states of deterioration of terrestrial waterlogged wood. Conservation implications of the analysis: A review. *ICOM Committee for Conservation Preprints*, 6th Triennial Meeting, Ottawa, (81/7/9):1–9.

1986 The freezing process: Effects on insects and artifact materials. A literature review and recommended procedures for freezing insect-infested artifacts. *AIC Preprints.* American Institute for Conservation 14th Annual Meeting Papers, Textile Specialty Group Abstracts, 158.

1987a Assessment of insect pest control problems in museum buildings: Methodology and recommendations. A case history. *IIC-CG 13th Annual Conference Abstracts.* Ottawa.

1987b The effect on artifact materials of the fumigant ethylene oxide and freezing used in insect control. *ICOM Committee for Conservation Preprints*, 8th Triennial Meeting, Sydney, 199-208.

1987c Methodology used in insect pest surveys in museum buildings: A case history. *ICOM Committee for Conservation Preprints*, 8th Triennial Meeting, Sydney, 1169-1174.

**Florian, M.-L. E., C.E. Secombe, and J.C. McCawley**

1978 The physical, chemical and morphological condition of marine archaeological wood should dictate the conservation process. *Papers from the first Southern Hemisphere conference on maritime archaeology.* Melbourne, Australia: Oceans Society of Australia, 128–144.

**Foreman, L.**

1971 Preserve and protect your American Indian baskets. *The Masterkey* 45(2):56–63.

**Gibson, E.J.**

1965 Creep in wood: Rate of water and effect of changing moisture content. *Nature* 206:213-15. (As cited by N. Brommelle and A. Moncrieff, *Deterioration and treatment of wood*. Amsterdam: ICOM Subcommittee for Scientific Museum Laboratories and the ICOM Subcommittee for the Care of Paintings, 1969.)

**Gilberg, M.R.**

1986 Plasticization and forming of misshapen birch-bark artifacts using solvent vapours. *Studies in Conservation* 31(3):177–184.

**Govier, T.**

1980 Haida hat: Conservation of an 1899 basketry rain hat. *The Journal of the Canadian Conservation Institute* 4:12–13.

**Grattan, D.W.**

1980 The oxidative degradation of organic materials and its importance in deterioration of artifacts. *Journal of the IIC-CG* 4(1):17–26.

**Grzywacz, C.**
1987 Indoor air quality in museums. Paper presented at the Western Association of Art Conservators annual meeting.

**Gunther, E.**
1978 Indian baskets need care. *Northwest Arts* 6.

**Harris, J.F.**
1975 Acid hydrolysis and dehydration reactions for utilizing plant carbohydrates. *Applied polymer symposium No. 28.* New York: John Wiley and Sons.

**Harvey, R. and N. Odegaard**
1984 A stabilization technique for mending basketry. Poster Presentation. AIC 12th Annual Meeting. Los Angeles.

**Hatchfield, P.B. and R.J. Koestler**
1987 SEM examination of the effects of consolidation treatments on dry archaeological wood. In *Scanning electron microscopy.* Chicago: Scanning Electron Microscopy, Inc.

**Hawks, C.A. and S.L. Williams**
1986 Arsenic in natural history collections. *Leather Conservation News* 2(2):1–3.

**Hon, D.**
1981a Photochemical degradation of lignicellulosic materials. In *Developments in polymers* 3. N. Grassie, ed. London: Applied Science Publishers.
1981b Yellowing of modern papers. In *Preservation of paper and textiles of historic and artistic value* II. J.C. Williams, ed. Washington, D.C.: American Chemical Society.

**Horton-James, D. and P. Townley**
1978 A consolidation/lamination technique for the treatment of fibrous materials. *ICCM Bulletin* 4(2,3):60–63.

**Judah, E.L.**
1937 Basket repair. *Museum Service* 10(5):105–106.

**Katai, A.A. and C. Schuerch**
1966 Mechanisms of ozone attack on alpha-methyl glucoside and cellulose materials. *Journal of Polymer Science* 4:2683–2703.

**Kenjo, T.**
1986 Certain deterioration factors for works of art and simple devices to monitor them. *The International Journal of Museum Management and Curatorship* 5:295–300.

**Kronkright, D.P.**
1981 New directions in Native American basketry conservation. *AIC Preprints*, American Institute for Conservation 9th Annual Meeting Papers, 95–108.

**Krueger, J.**
1986 Taxonomy of degradation. In *Encyclopedia of materials science and engineering*, Vol. 2. M.B. Bever, ed. Oxford: Pergamon Press.

**Leise, W. and H. Greaves**
1975 Micromorphology of bacterial attack. Proceedings, Wood Products Pathology, 2nd International Conference of Plant Pathology, Minneapolis. Springer-Verlag: Berlin.

**Leveque, M.**
1986 The problem of formaldehyde: A case study. *AIC Preprints*, American Institute for Conservation 14th Annual Meeting Papers, 56–65.

**Lyall, J.**
1980 Various approaches to the conservation and restoration of aboriginal artifacts made from bark. *ICCM Bulletin* 6(2):20–32.

**Mallis, A.**
1982 *Handbook of pest control.* 6th ed. Cleveland: Franzak and Foster.

**Mark, R.E.**
1967 *Cell wall mechanics of tracheids.* New Haven: Yale University Press.

**Mason, J.**
1987 Personal communication. Bishop Museum, Honolulu.

**Mason, O.T.**
1904 *Aboriginal Indian basketry.* United States National Museum report. Reprinted in 1976, J. Adovasio, ed. Santa Barbara: Peregrine.

**Miles, C.E.**
1986 Wood coatings for display and storage cases. *Studies in Conservation* 31(3)114–124.

**Morrison, R. and R.N. Boyd**
1984 *Organic chemistry.* Boston: Allynn and Bacon.

**National Institute for Conservation of Cultural Property.**
1984 *Ethnographic and archaeological conservation in the United States.* Washington, D.C.: National Institute for Conservation.

**Oddy, W.A.**
1973 An unsuspected danger in display. *Museums Journal* 1(73):27–28.

**Odegaard, N.**
1986 Personal communication.

**Odegaard, N. and D.P. Kronkright**

1984 Giving your baskets a long, healthy life: A basic guide to basketry conservation. *Fiberarts* 11(1):43–49.

**Padfield, T., D. Erhardt, and W. Hopwood**

1982 Trouble in store. In *Science and technology in the service of conservation*, N.S. Brommelle and G. Thomson, eds. London: IIC.

**Pearlstein, E.**

1986 Fatty bloom on wood sculpture from Mali. *Studies in Conservation* 31(2):83–91.

**Pomerantz, L.**

1975 The lining treatment of a painted cedarwood mat. *AIC Bulletin* 16 (1):45–56.

**Reed, S.A.**

1966 A fortifying preservative for wood and wood fibers. *Curator* 1(9):41–50.

**Rosen, S.L.**

1971 *Fundamental principles of polymeric materials for practicing engineers.* New York: Barnes and Noble.

**Schaffer, E.**

1976 The preservation and restoration of Canadian ethnographic basketry. *Studies in Conservation* 21(3):129–133.

**Schniewind, A.P.**

1983 Mechanical properties of wood. In *Wood in art conservation: A seminar on wood for practicing art conservators.* Richmond, CA: University of California Forest Products Laboratory and the Western Association of Art Conservators.

1966 Über den Einfluss von Feuchtigkeitsänderungen auf das Kriechen von Buchenholz quer zur Faser unter Berücksichtigung von Temperatur und Temperaturänderungen. (On the influence of moisture content changes on creep of beechwood perpendicular to grain including the effects of temperature and temperature changes.) *Holz als Roh- und Werkstoff* 24(3):87–98.

**Stahl, E.**

1969 *Thin layer chromatography: A laboratory handbook.* 2nd ed. New York: Springer Verlag.

**Story, K.O.**

1985 *Approaches to pest management in museums.* Washington, D.C.: Conservation Analytical Laboratory, Smithsonian Institution.

**Svenson, A.E.**
1986 Africa, Zaire, Kuba: An introduction to raffia textiles. In *Textile conservation symposium in honor of Pat Reeves.* C. McLean and P. Connell, eds. Los Angeles: Los Angeles Conservation Center, Los Angeles County Museum of Art.

**Tennent, N. and T. Baird**
1985 The deterioration of Mollusca collections: Identification of shell efflorescence. *Studies in Conservation* 30(2):73–85.

**Thomson, G.**
1978 *The museum environment*. London: Butterworths.

**Ward, P.R.**
1976 *Getting the bugs out*. Methods manual #4. Victoria, BC: British Columbia Provincial Museum.

**Wilcomb, C.P.**
1900 C.P. Wilcomb Archives. California State Parks System. Sacramento, CA.

**Withers, M.**
1976 *Conservation of basketry in the Southwest: Collected papers in honor of Marjorie Ferguson Lambert.* A. H. Schroeder, ed. Papers of the Archaeological Society of New Mexico 3. Albuquerque, NM.

**Wolf, S. and G. Fullman**
1980 Notes on the treatment of Fijian tapa cloths. *ICCM Bulletin* 6(3,4):58–64.

# 5 Conservation of Artifacts Made from Plant Materials

*Ruth E. Norton*

Conservation consists of two primary functions. One concerns preventing or retarding deterioration of artifacts by controlling or modifying an artifact's physical and chemical environment and by increasing the awareness of those who come into contact with the artifact. The other involves altering the artifact through treatments such as cleaning, mending, and restoration to restore it to a known previous condition.

These functions are defined in the codes of ethics of most professional organizations of conservators. The Code of Ethics of the Australian Institute for the Conservation of Cultural Materials (ICCM 1986) defines them as:

*Preservation*

> All actions taken to retard deterioration of or prevent damage to cultural material. It involves controlling the environment and conditions of use, and may include treatment in order to maintain an object, as nearly as possible, in an unchanging state. In the case of archival material, moving image and sound, this may include transfer to another medium.

*Restoration*

> All actions taken to modify the existing materials and structure of cultural material to represent a known earlier state. Its aim is to preserve and reveal the aesthetic and historic value of an object and it is based on respect for remaining original material and clear evidence of the earlier state.

Certainly, the two functions overlap to some extent. Many conservation treatments are undertaken to both restore and stabilize an artifact. For example, mending a badly broken basket both restores it to an earlier condition and helps prevent further damage by protecting exposed elements from loss and making the whole basket more sound structurally. Other treatments alter the artifact material but are undertaken to retard further deterioration. For example, some deacidification and buffering treatments remove and add material to the artifact, but are done to retard its acid degradation.

The implementation of both functions of conservation must be based on a sound understanding of the chemical and structural properties of both the artifact

and the materials introduced into its environment and structure during preventive conservation and treatment.

In this chapter, preventive conservation measures are discussed briefly along with other general collection considerations in which conservators are involved in the section on collection care. This is followed by a more detailed section discussing conservation treatment procedures.

# Collection Care

The following topics are included because they are important aspects of caring for artifact collections and must be considered in any discussion of their conservation. Because a full review and discussion of collection care would be voluminous, and because this appears elsewhere in the conservation literature, no attempt has been made to address them in detail here.

## Ethical Considerations

Ethical considerations encompass respect for the physical, aesthetic, and nontangible integrity of the artifact.

### Nonalteration of the Basic Fabric of the Artifact

Artifacts are documents of the aesthetics, beliefs, life styles, and technology of a people. Alteration of such documents should be avoided unless there is a danger of loss if no action is taken.

Whenever possible, deterioration should be inhibited or arrested through preventive measures rather than through treatment that alters the artifact. In many cases, we don't know enough about the materials of construction, any native alterations, or the full effects of solvents, biocides, adhesives, and consolidants that may be used in the treatment to be able to ensure that damage or alteration of the artifact will not unintentionally occur. However, we do know that many treatments alter the fabric of the artifact to some degree—whether it is the subtle alteration of the cell wall structure or extractives with exposure to solvent vapor, or the obvious alteration of the structure and composition of a material with the introduction or extraction of adhesives and consolidants. When feasible and safe, support and treatment using mechanical means rather than chemical or adhesive means generally involves little or less permanent alteration of the fabric.

Nonalteration of the basic fabric of the artifact is the goal; however, economics, time, and circumstances may dictate compromise. For example, application of an insecticide may not alter the appearance of an artifact, but it can make it worthless for some forms of analysis and may promote degradation of the materials. However, if building construction, climate, or limited funds make it impossible to control insects, then it may be better to apply an insecticide rather than to lose the collection. As another example, the surface of an object might have areas covered by friable paint that would be damaged if those areas were rubbed or handled. Consolidation could make future analysis of the paint medium difficult or impossible. If stored and handled correctly and with care, it would not be necessary to consolidate

the paint. However, if the conservator knows that some members of the museum staff are not thoughtful in handling the collection and the conservator has no control over their access to the collection, it may be better to consolidate the paint so that it will not be irreversibly damaged. (At the same time, every effort should be made to educate the staff so that such action may not be necessary in the future.)

### Recognition of the Artifact's Nontangible Properties

Artifacts in a collection may be sacred; their original owners may have placed restrictions on their use and access. Such restrictions and the powers inherent in or invested in the artifacts should be respected.

Wherever there is access to the traditional owners of artifacts, they have a moral right to be involved in the conservation policies developed for those artifacts. Their involvement is an advantage to all parties.

Refer to Clavir, Shane, and Johnson (1986), Creamer (1976), Hawthorn (1976), Mibach (1981,1986), Mulvaney (1977), Renshaw-Beauchamp (1983), Rose (1985), and Wolf and Mibach (1983) for further discussion of these principles.

## Labeling Artifacts

An accession or registration number links an artifact to records of its provenance, photographic documentation, and conservation history. It is a necessary and important foreign addition to an artifact. As a foreign addition, however, it should alter the artifact as little and as safely as possible. The labeling of artifacts is addressed in Cameron (1983b:1–4), Daniels (1982:46–48), Norton (1984a:34–35), and Wolf and Denton (1985:2–3).

### Basic Principles

- The writing material and its support should have excellent long-term aging qualities and, if possible, should be resistant to extreme conditions and disasters.
- The label and its method of attachment should not immediately or potentially damage the artifact, and it should be removable without damaging the artifact.
- Labels should be unobtrusive but easy to find, and they should be consistent for artifact types.

### Label Types

Labels may be tied on, sewn on, adhered to, or written directly on the artifact; these methods are listed in decreasing order of permanent interference with the artifact. As far as possible, labels that involve the least manipulation of the artifact in application and removal, and the least application of foreign material directly to the artifact are preferable. However, materials and construction often dictate what type of label can be safely used. Tied-on labels, for example, cannot be used on textiles or barkcloth, since they involve piercing the fabric and result in distortions of the fiber

network; sewn or adhered labels would be more suitable. Many composite and basketry artifacts can have tied-on labels, but tightly woven baskets would be damaged; for these, adhered labels are more suitable.

### Tied Labels

The number is written in indelible ink on an archival-quality tag that is tied to the artifact. The tag should be no larger than necessary to reduce weight and should have smooth edges and rounded corners to avoid abrading the artifact. The tie cord should be of archival quality, nonabrasive, and of a diameter appropriate to the chosen location. Care must be taken that the label cords are tied around an area or an element of the artifact that is strong enough to carry the tag, that will not be damaged by possible abrasion, and that is open enough to take the cord. The tag should also be located where it is not likely to catch on other artifacts or storage furniture.

### Sewn Labels

The number is written in indelible ink or embroidered with thread onto a cloth strip or tape that is then hand-sewn onto the artifact. On textiles, the label should be sewn on through one layer of cloth if possible, so that the needle can be inserted from both sides of the cloth, and the needle should pass between threads. On objects, sewing should only be done over strong elements, and where the construction is open enough to allow the needle and thread to pass safely between elements without damage. The label should lie smoothly over the artifact surface, puckering neither the artifact nor the label, and the stitching should be loose enough that no distortion of the artifact results.

### Adhered Labels

The number is written on a paper label that is adhered to the artifact. This method is generally used on artifacts such as barkcloth and whole leaves and those made of tightly woven constructions to which labels cannot safely be tied or sewn. It is less intrusive than writing the number directly on the artifact because less foreign material penetrates the artifact material and most of the adhesive is removed with the paper, leaving only a small amount of residue to be cleaned off.

For most artifacts, a medium-weight paper is used. The paper is trimmed to an appropriate size; the surface area of the artifact covered should be as small as possible. When the ink is fully dry, the paper label is pasted, laid in position, and tamped into place (see directions for paper mends). (To remove the label, roll a barely dampened swab over the paper surface until the paper is damp. After a few moments, the paper may be lifted off with tweezers. Most of the adhesive lifts off with the label; residue can be removed with a damp swab.) For very dense, smooth surfaces, like the epidermal surfaces of leaves and monocot stems, even a fairly thick paste may not adhere strongly enough. An adhesive made of a mixture of equal parts of a starch or methylcellulose paste and an acrylic emulsion has greater adhesive strength and is as easy to remove with the damp swabs as a pure starch or methylcellulose paste. For surfaces that can tolerate no moisture, the label can be adhered with Paraloid B-72 in solution or as a solvent reactivated film, or with heat reactivated tissue made with BEVA 371 or a low $T_g$ acrylic or vinyl acetate resin or emulsion.

### Labels Written on the Artifact

The number should be written as small as possible and in an inconspicuous location. To avoid penetration of the ink into the artifact, an isolating varnish is first applied to the immediate area; to avoid loss of the number by abrasion, a varnish is applied over the number. Numbers should not be applied on openly fibrous or porous surfaces that would make complete removal of the varnish difficult or impossible.

A thin coat of a varnish, such as Paraloid B-72 (10-20% w/v solution in acetone), is brushed onto the surface that is to receive the number; the area covered should be no larger than needed for the number. When the varnish is completely dry, the number is written with a fine nib pen and indelible ink—black for light surfaces, white for very dark surfaces. When the ink is completely dry, a thin coat of varnish is painted over the number.

## Materials Used for Labels

Generally recommended materials for standard museum conditions include:

- Writing: permanent, waterfast, pigment inks such as black India ink and white Chinese ink
- Support: acid-free paper and cotton cloth
- Attachment: cotton thread and cord, starch or methylcellulose paste, Paraloid B-72 in solution or as a solvent or heat reactivated film, or BEVA 371 or low $T_g$ acrylic or vinyl acetate resins or emulsions as heat reactivated films
- Varnish: Paraloid B-72 in solution

In collections in the tropics, labels are often lost or made illegible through insect activity and mold growth. In such cases, materials more resistant to insects and mold should be considered. Paper tags may be coated with Paraloid B-72. Synthetic papers like Tyvek (spun bonded polyethylene fiber) and Reemay (spun bonded polyester fiber) could be used instead of cellulose fiber paper. (These are, however, considerably more expensive and more difficult to write on.) Tags could be made of polyethylene or polyester film strips with the numbers written on or embossed with machines like Dymo label guns. Polyester fiber cloth could be substituted for cotton cloth. Polyester or nylon cord could be used to tie on tags.

These materials would also be more likely to survive water leaks and floods, but some synthetic films and fibers can create problems in case of fire, since they can melt onto the artifact. The disaster potential of the museum, insect and mold problems, and accessibility of labeling materials, must all be considered when selecting labeling systems for a collection.

## Location of Labels

Generally, registration numbers are attached in a place that is not visible when the artifact is displayed or photographed in order to avoid unnecessary removal and replacement. A standard and readily accessible number location for artifact types minimizes handling of the artifact (for example, on mats the number should be placed

on the back of the lower left hand corner, and when they are rolled up the end with the number should be visible).

An argument can be made for registration labels that are clearly visible in storage. Especially if storage is crowded, the handling of artifacts can be reduced if the registration numbers can be seen easily. On the other hand, since permanent numbers are best placed in an unobtrusive location on the object, storage numbering may best be done using tags or numbers directly on storage shelves, boxes, racks, or rolling tubes.

## Conservation Surveys

The first step in considering the conservation treatment of a collection is to find out what the collection as a whole needs. This is the function of the conservation survey. Artifacts in storage and display are examined for material type, condition, and urgency of treatment. For example, is immediate stabilization necessary? Is treatment desirable as soon as feasible? Is it desirable, but can wait indefinitely? Or is no treatment needed? The outcome of such a survey can help to identify collection treatment priorities, probable person-hours required for each task, whether the collection has isolated problems or general areas of instability, and stabilization problems that require research in order to find appropriate solutions. Collection surveys are not just one-time events. Collections should be examined periodically, on a regular basis, to monitor the condition of artifacts and to look for mold, insects, dirt, and so on, which would indicate the development of environmental problems in storage and display. Refer to Rose (1985) and Schur (1981) for discussions of the goals and implementation of conservation surveys.

## Storage and Display

General standards and recommendations for handling artifacts, environmental factors (light, relative humidity, temperature) in storage and display, materials that may be safely used in storage and display, and storage systems and furniture are well covered in the conservation and museology literature (see Blackshaw 1982, Blackshaw and Daniels 1979, Graham-Bell 1986, Greene 1978, Johnson and Horgan 1979, and Thomson 1978). Except for the following comment on tropical conditions, these topics will not be reviewed here.

Most recommendations in the conservation literature on environmental conditions in display and storage refer to collections in temperate climates and in controlled museum environments. However, many collections are housed in museums in which environmental control by full air conditioning systems is precluded both by lack of funds for installing and maintaining the systems or by the museum building design. (Also, many museum buildings are historical monuments and cannot legally or ethically be altered radically.) More attention needs to be paid by the museum and conservation profession to creative environmental adaptation, such as designing for and utilizing natural ventilation, shading, and insulation for temperature and light regulation and using insect-resistant materials and design. This is especially important in tropical climates where high temperatures and relative humidity support insect and mold growth, which cause rapid and extensive damage to organic

museum collections, and where inadequate economic support for museums very often precludes high-technology construction, installation, and maintenance. Much can and is being done in some institutions to limit damage through observation of microclimates within the building, frequent inspection and cleaning of storage and display areas, and general application of common sense. Recommended standards for collections adapted to temperate climates may not necessarily be appropriate for tropical conditions. The fact that organic artifacts were made and used—and are now housed—in a very humid environment must be taken into consideration. If they are moved to a comparatively low relative humidity environment (such as the 50 ± 5 % RH generally recommended in the literature), cells will shrink, causing cracking, loosening of joints, and the loosening of weaves. A basket, for example, may not remain as stiff or firm as intended, and may be more susceptible to distortion, loss of elements, and crushing. Perhaps organic artifacts made and used in tropical climates should be kept in as high a relative humidity as possible without encouraging mold growth. Since most molds grow readily above 70% RH, recommended RH levels for organic materials might be just below this. (Even this level, however, is much lower than is usually possible during wet seasons without the use of desiccants and dehumidifiers.)

## Storage Systems for Artifacts Made of Plant Materials

Most of the general storage systems discussed in the conservation literature are suitable for artifacts made of plant materials. Discussions of special storage systems and techniques for specific artifact collections and types can be found in the conservation and museology literature. Much of this literature is concerned with storage furniture design for particular artifact types. For examples, refer to Cranstone (1958), Gowers (1958), Havyatt (1980), Idiens (1973), Norton (1984a), Phillips and Gaulton (1983), Pretty (1976), Satterwait and Chadwick (1978), and Ward (1978,1982).

## Accessible or Visible Storage

Accessible storage is a concept gaining popularity as demands for access to collections increase and as the role and responsibilities of museums evolve. It is desirable for collections to be stored in such a way that they are readily visible to researchers and interested members of the public. Yet, accessible storage involves considerable planning and both solves and raises conservation problems (see Ames 1977,1985, Cameron 1982, Force 1975, Howatt-Krahn 1983, and Wolf 1980).

## Exhibition Planning

Exhibition planning is necessary to produce an exhibition that is visually and intellectually successful, as well as physically safe. The curator's selection of the subject and approach of the exhibition is only the first step. The objects on the preliminary exhibition list must be examined to determine whether they can be safely exhibited; what treatment will be necessary to prepare them for exhibition and how much time will be involved in that treatment; what their mounting requirements will be and the time and cost involved in preparing the mounts; what special environmental factors need to be considered; and the construction and maintenance costs involved. Such

preliminary considerations by the curator, the conservator, the display staff, and the director or financial advisor can determine the contents of the exhibition, as well as the time and cost involved in producing it successfully and safely. Hurried production of exhibitions can lead to damage of the objects through inadequate stabilization or poor mounting, the use of improper case materials, unsafe environments for the objects, or mishandling during installation.

## Protection, Support, and Mounting of Artifacts for Storage and Display

Safe storage and display of artifacts requires not only a safe climate and appropriate storage and display furniture, but also specific support and protection measures for individual artifacts and artifact types.

### Protection

Boxes protect artifacts from dust, abrasion, and crushing. Acid-free boxes can be purchased from suppliers of conservation and archival-quality materials. Such boxes can also be made easily using acid-free corrugated board (see Appendix 2). The only disadvantages of these boxes are their cost and the fact that the artifact cannot be seen without opening the box. Clear plastic polystyrene and translucent polyethylene storage boxes are readily available in a variety of sizes at most stores that sell household supplies. Such boxes have the advantage of somewhat lower cost, artifact visibility, and the protection they offer from ceiling water leaks. However, they have the disadvantage of melting onto the artifact should a fire occur in storage. The long-term stability of molded polystyrene may also be questioned.

Folders for small flat artifacts provide protection from dust, abrasion, and crushing and are a convenient means of supporting an artifact while also allowing it to be easily turned upside down for examination. Folders can be made easily using acid-free mount board and corrugated board (see Appendix 2).

Artifacts are often wrapped in paper or plastic sheet to protect them from dust. This is effective and safe as long as the paper is of archival quality and the plastic sheet is polyester, nylon, or polyethylene. The main disadvantage of wrapping in paper is that the artifact is not visible and handling could be dangerous to fragile or protruding elements. Plastic sheet avoids this problem and provides some protection from ceiling water leaks, but becomes a danger in case of fire. High-RH microclimates can also develop if the plastic is tightly wrapped or sealed in fluctuating temperature environments.

Choosing whether to use protective boxes, folders, or wraps, and what material to use, depends to a great extent on the particular storage area under consideration. The danger of damage caused by dust, crushing, and water leaks may outweigh the potential danger of fire.

### Supports

Some artifacts may be stored safely or displayed on flat, padded surfaces or sewn or tied to padded vertical surfaces. Others are best stored rolled and displayed hanging or on standard mounts. Still others require individually designed and contoured mounts to fully support them during storage and display. Mounts not only provide support for the artifact, but also allow safe handling and movement. The construc-

tion of some contoured supports can be time consuming and expensive. To reduce time and materials costs and to reduce handling of artifacts, it may be advisable to make storage mounts that are also suitable for display of the artifact when it is possible or likely that the artifact will be displayed in the future. Since the size, weight, shape, construction technique, and material of artifact types vary considerably, types of supports and their construction are only generally discussed here. References are given for supports for specific materials, artifact types, and collections.

Support types include pillows, coiled cushions, and cut or cast contour forms. Some examples of packing techniques (such as tying and sewing onto backings) are also useful for storage, display, and support during handling.

*Pillows*

Pillows provide easily made and inexpensive cushioning and support for light-weight objects that do not require a contour support. If used with individual trays or portable drawers, they provide convenience and protection when handling or moving an artifact. Pillows made of cotton cloth filled with polyester fiberfill are frequently used in storage. Pillows covered with appropriately colored and textured cloth were used by Walston, Coote, and Horton-James (1985) to display fragile artifacts.

*Rings and Coiled Snakes*

Baskets, vessels, and other artifacts with rounded bases require support to take stress off the base and to prevent rocking. Rings and coiled exterior forms made from "snakes" of cotton cloth filled with polyester fiberfill provide cushioning, support, and protection from abrasion. Rings are of a sufficient diameter to support the lower walls of an artifact and to prevent the lowest part of the base from carrying weight. Coiled forms are used for tall, very flared, and/or fragile artifacts where the walls require more support than can be provided by a single ring. For rings, snakes (about 5 cm to 10 cm in diameter) are cut to the appropriate length and the ends are sewn together. For coiled forms, the object is inverted and the snake coiled from the base outward to the appropriate height, pinning the coils together as coiling progresses. The coils are then removed from the artifact and hand-stitched together on the exterior. Some forms may require some stitching on the interior; interior stitches must not have lengths exposed that could catch on and tear elements (see Kronkright 1980 and Odegaard 1986).

*Cut and Shaped Interior and Exterior Forms*

Forms of the required shape for support are cut, allowing 3 mm to 5 mm for padding the surfaces that will be in contact with the artifact. Forms have been made using acid-free corrugated board, closed-cell polyethylene foam, sealed wood, and sealed wire and wire mesh. The surfaces in contact with the artifact are padded with cushioning materials such as polyester fiberfill and closed-cell polyethylene foam sheet, and covered with acid-free tissue paper, cotton or polycotton cloth, or stockinette. For fibrous artifacts or those constructed of interworked elements, the smoother surfaces of tissue paper and finely woven cloth are more appropriate (for examples, refer to Chesna McNeil, et al. 1986; Drummond 1987; Govier 1980; Mibach 1986a; Niinimaa 1984,1986; Norton 1984a,1984b; and Ward 1982).

*Wood and Metal Frameworks and Pallets*

Larger artifacts such as canoes, shields, spears, some musical instruments, and some household items require pallets and/or framework structures to support and move them safely. All wood and metal supports should be sealed to isolate vaporous components of the wood and to prevent contamination with corrosion products. Surfaces in contact with the artifact should be padded with materials such as foam of an appropriate density, thick felt (3 mm to 5 mm), and silicone medical tubing (for examples, refer to Phillips and Gaulton 1983; Walston, Coote, and Horton-James, 1985; and Ward 1978,1982).

*Cast Contour Forms*

Contour forms may be cast as sheets or solids to conform with the load-bearing surfaces or backs of artifacts. Contour forms are also necessary for artifacts made of—or incorporating structural components of—resinous cements, many of which exhibit cold-flow leading to deformation at ambient temperatures. The artifact may simply rest on the form or may be secured to it with padded side clips, brackets, or ties. A padding material and a nonabrasive covering are secured or placed between the artifact and the form for cushioning and to accommodate some movement of the artifact with fluctuations in relative humidity. Materials used for contour forms include fiberglass-reinforced polyester or epoxy resin, phenolic or glass microsphere-filled polyester or epoxy resin, polyurethane foam, and papier mâché (for examples, refer to Gilberg and Barclay 1987, Gilberg and Grant 1986, Clark and Burmingham 1986, Walston and Gill 1979, and Walston 1988).

**Display Mounts**

Many of the support types described previously are suitable for display. In addition to supports such as pillows and contoured mounts, other forms of mounting for display include hanging flat textiles, mats, and barkcloth, and suspending artifacts from overhead or vertical surfaces. In both cases, the condition of the artifact and the materials and techniques used to apply hanging devices are important considerations in creating a safe mounting.

*Hanging Flat Textiles, Mats, and Barkcloth*

Artifacts are often hung by folding over a dowel or tube, or by securing the top edge with Velcro, from a rod, or with pressure clamps. Folding over a dowel or tube and securing the top edge with pressure clamps does not require sewing and adhesive attachment of mounting devices. Velcro sewn to a cloth backing strip and cloth tubes or rolling strips for holding suspension rods may be attached to textiles and mats by sewing or by reactivated adhesive and to barkcloth only by reactivated adhesive. Cloth backings should be stitched to plaited mats to avoid the distortion of stretching along the bias weave, and also to textiles with heavy supplementary decoration or weak areas. For details on the materials and methods of application of hanging devices and on the appropriateness of different techniques for artifacts of various constructions and conditions, refer to Gresson 1988; Norton 1984a; Welsh 1984; Wolf 1982,1983b; and to the conservation literature on textile display.

*Suspending Artifacts*

Artifacts may be suspended in display if they are strong enough for their weight to be safely carried by selected components or if they can be reinforced to allow safe suspension. Artifacts are frequently suspended or secured to vertical surfaces or posts. Here again, the points that secure the artifact must be structurally sound and these are usually the structural components of the artifact. Some artifacts, if they have weak areas, heavy decoration, or no components particularly suitable to carry the weight of the artifact, are suspended vertically by stitching them to a backing or interior form from which they are suspended. For examples of suspending artifacts, refer to Drummond (1987) and Walston, Coote, and Horton-James (1985).

## Pest Management

Pest management is obviously of great concern with all plant materials. In tropical climates, which are most conducive to pest growth, pest management is probably the most immediate and difficult problem in caring for collections.

Although one still finds references to the eradication of museum pests, any practical consideration of reduction of pest damage to artifacts concerns a broader, common-sense approach to controlling or managing pests, rather than trying to eliminate them. With increasing awareness of health and safety factors, environmental impact, and alteration of artifact materials, reliance on biocides is lessening in favor of alternative methods of killing pests, such as freezing (see Florian 1987), and habitat modification to discourage pest infestation and growth.

Pest management is essentially based on knowledge of the pests' life cycles and environmental requirements and habits, as well as on good building design, vigilant housekeeping, and judicious use of biocides. Refer to Story (1985) for a detailed discussion of pest management.

## Transportation/Shipment

The packing of artifacts for shipment involves providing physical support, cushioning, and protection against microenvironmental atmospheric changes. Cushioning against vibration, resonance, and shock through the use of an appropriate type and grade of foam, and maintaining a stable microenvironment through the use of buffering materials, preconditioned packing materials, shields, and insulating materials, are issues that have been closely examined with regard to the shipment of paintings (Green and Hackney 1984, Sitwell 1983, Staniforth 1984). Given that the principles and designs are directly applicable to the shipment of most ethnographic objects (Staniforth 1985, Piechota and Hansen 1982, Piechota 1986), it is not necessary to examine them here. When considering cushioning design and materials, a major difference between paintings and many artifacts made of plant materials is that the latter are usually very light in weight and have a very low static stress (the weight of the object divided by the area of its bearing surface). Considerations regarding the shipment of anthropological collections are discussed by Piechota (1986) and Mibach (1986).

The proper packing and crating of artifacts is a costly undertaking. If one is considering shipping collections like paintings and works on paper that are generally of fairly uniform size and shape, the undertaking is simplified and time and cost reduced, because the packing can be standardized and the crates reused. Ethnographic artifacts, on the other hand, vary considerably in size, weight, shape, materials, and construction, making it necessary to custom design and construct packing systems (see, for example, Ford, Head, and Kertesz 1985, Norton 1984b, Oak and Mibach 1983, Piechota and Hansen 1982).

Certainly, well-designed and constructed packing and crating systems are essential to the security of the artifacts for long-distance travel where several modes of transportation and much handling are involved. They are equally important for traveling exhibitions where the rigors of travel are compounded by repeated packing and unpacking and mounting and dismantling. Although relatively few artifacts undergo extended tours, many artifacts must unfortunately undergo afternoon excursions. The conservation laboratories, exhibition areas, and storage areas in many museums are located in separate buildings and an artifact may travel meters or kilometers if it requires conservation treatment or is to be displayed. Objects to be treated at regional conservation centers must travel between the museum and the center. Such artifacts are subjected to the same dangers as artifacts traveling across the continent and ideally should receive the same packing; but, realistically, few museums can afford it.

For one-stop, short itineraries, a vehicle with good suspension and shock absorbers may be selected. The interior can be padded and outfitted with hardware for securing large or boxed artifacts. Large objects can be wrapped with padded blankets, quilts, and pillows; air mattresses have been useful for transporting canoes (Walston, Coote, and Horton-James 1985). Artifacts can be inexpensively packed to provide sufficient support, to protect them from abrasion and jarring, and to provide some protection in case of shock and overturning during movement. Some examples of packing designs for small artifacts are illustrated. (Some diagrams do not illustrate the acid-free tissue with which the objects are wrapped to protect them from abrasion.)

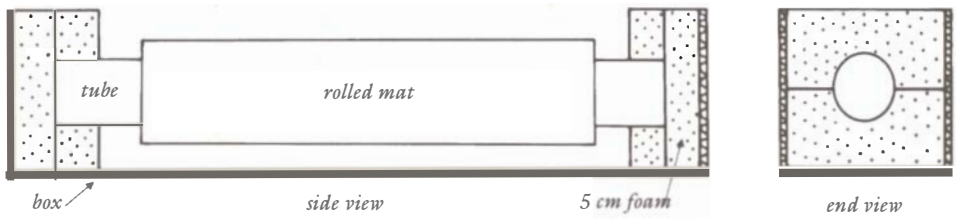



*Figure 5.1. Example of packing design for rolled objects.*

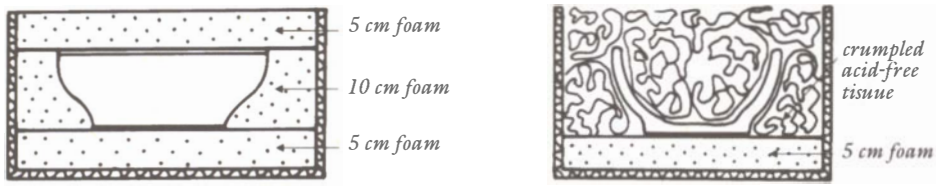



*Figure 5.2. Example of packing designs for encasing objects with (a) foam and (b) crumpled tissue.*

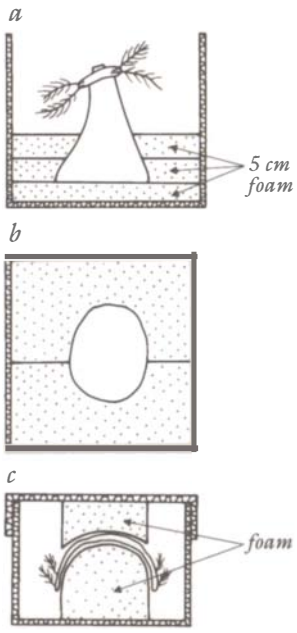



*Figure 5.3. Examples of packing design for collaring and mounting objects: (a) side view and (b) top view of collar, (c) side view of mounted object.*

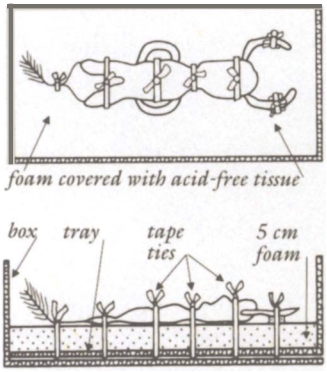



*Figure 5.4. Example of packing design for objects with fragile protruding elements, top and side views.*

*Figure 5.5. Example of packing design for objects sewn onto a stretcher, top and side views.*

*Figure 5.6. Example of method for packing objects between pillows, top and side views.*

## Rolling Objects

The ends of the rolling tube are encased in a collar of low-density foam; the ends of the inner box are lined with low-density foam. (Very large mats rolled on heavy tubes would require a higher-density foam.) This method of packing absorbs vibration from the bottom and sides of the box while also suspending the roll so that no weight rests on the mat (see Figure 5.1).

## Encasing Objects

The shape of the object is cut out of foam so that the object is completely surrounded with the foam packing (see Figure 5.2a). Alternatively, the object may be surrounded with crumpled acid-free tissue. When crumpling, leave one-quarter of the tissue uncrumpled: wrap this around the crumpled wad so that a smooth tissue surface is in contact with the object (see Figure 5.2b).

## Collaring and Mounting Objects

The object is held with a collar or contoured pieces of foam (Figure 5.3). This is useful when there are areas of the object that cannot withstand pressure (feathers, pigment, tassels, etc.).

## Tying Objects

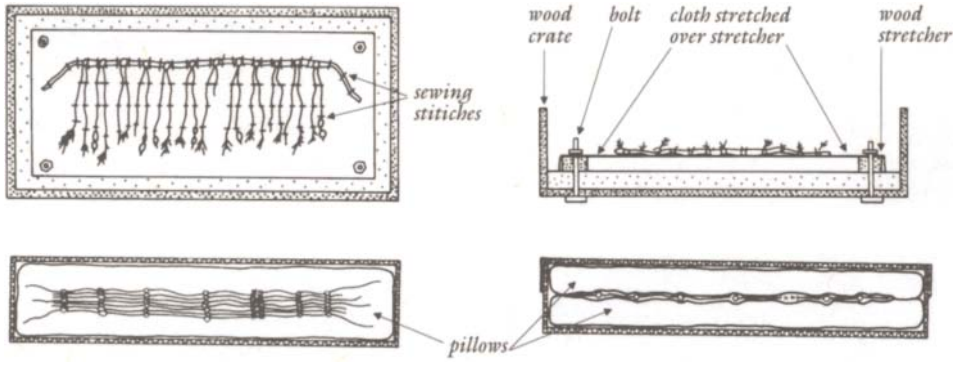
Objects that cannot be braced against movement because of protruding elements are tied to a tray through a sheet of foam (Figure 5.4).

## Sewing Objects

Heavy cotton cloth is stretched over a stretcher (Figure 5.5). The object is sewn to the upper surface of the cloth with running stitches. The stretcher is bolted to the crate through a layer of foam; bolt holes are slightly larger than the bolt diameter.

## Sandwiching Objects Between Pillows

Pillows are made of dacron wadding covered with cotton cloth (Figure 5.6). Slight pressure from the lid holds the object in place.



## Field Conservation

For ethical, social, political, and economic reasons, the acquisition of artifacts from their site of manufacture and use occurs on a much smaller scale now than it did during the last several centuries. However, field studies involving the acquisition of artifacts are still being pursued internationally by authorized expeditions of foreign museums and organizations, nationally by national museums studying ethnic groups within their countries, and locally by communities and ethnic groups. In each of these situations, conservation considerations should be included in the early planning stages.

To fully observe, record, interpret, and preserve the information and material available during ethnological field studies, Losche and Walston (1982) argue strongly for a team including an anthropologist, a conservator, and a botanist/ethnobotanist. With such a team, a fuller and more accurate understanding of the materials used, the artifact construction, and the material, social, and spiritual context and use of the object may be realized. This information is of anthropological interest and of immediate importance to the conservator responsible for the care of that material.

Conservation planning for field collection begins with a consideration of the types of materials that are to be studied and collected, the probable demands of those materials for stabilization and safe shipment, and the facilities (storage and/or display space, staff, and stabilization facilities) available at the museum for coping with the material when it arrives. Knowledge of the materials to be collected, the stability and conservation problems usually associated with those materials, and the environmental conditions at the site and at the museum enable one to predict what supplies for stabilization and packing may be necessary to take, and what arrangements for storage and conditioning facilities will need to be made. This planning is especially necessary for humidity-sensitive materials such as wood, bark, bamboo, and leaf sheaths that are to be moved to environments very different from their place of origin. Although planning is most obviously necessary on major expeditions involving radical changes in the artifacts' environments, the same considerations are important when collecting one or two objects to be moved to locations with similar environments. (See Vandyke-Lee 1979; Losche and Walston 1982; Walston 1984; Walston, Coote, and Horton-James 1985.)

# Conservation Treatment Procedures

The aim of this section is to examine the purposes of conservation treatment procedures, to consider the effects of these procedures, and to review past and current techniques used in carrying out these procedures. Most of the information presented is not new. Many of the techniques and opinions presented have evolved through the experience of many conservators and conservation students and constitute current conservation practice. Because they are common knowledge and practice (and, as such, have not been published), it is not possible in many cases to credit them to specific individuals and institutions.

The treatment of artifacts is discussed in terms of general treatment procedures. Reference to specific artifact materials and types are made where appropriate and useful in the context of these procedures. Some general considerations regarding examination and treatment should be mentioned before discussing specific procedures.

This may sound painfully obvious, but the purpose of examining and treating an artifact must be borne in mind and fully understood by both the conservator and the curator. Is an artifact being examined specifically to identify an intriguing instability, or is it apparently stable and being examined to determine a suitable support or mount for display? The depth of detail in examination may differ considerably depending on the objective. Is the object being treated to stabilize and support it for dead storage, for a study collection, for display, or for a loan? Problems that can be addressed by supportive packing for storage may require mending, consolidation, or restoration if the artifact is to be handled or displayed. Is the artifact to be displayed in the context of its cultural use, or is it to be highlighted as an "art object?" Some restoration may be required for the latter but not for the former.

Ideally, any treatment should be reversible. This ideal can be sought by the selection of appropriate techniques and materials in treatment. However, some treatments, though theoretically sound, are practically irreversible (for example, the consolidation of pigments or the application of adhesives to porous materials). When these treatments are necessary, every effort should be made to use materials that are as stable as possible. Some procedures, such as cleaning, are by nature irreversible, and their application must be fully considered so that irrevocable damage to the artifact and loss of its aesthetic and documentary integrity does not occur.

Discussions of reversibility, however, usually focus on the ability to safely and effectively remove anything applied to the artifact, and emphasizes the stability and resolubility or removability of the material. This only addresses part of a broader concept of reversibility. Conservators have become increasingly aware of the extent to which exposure to solvents and other foreign materials alters irreversibly the artifact material (see Chapters 1 and 4). So, the real issue in reversibility is not just the safe removal of applied foreign material, but also the effect of exposure of the artifact to foreign material, whether vapor, liquid, or solid, during and after the application of a treatment. In this sense, almost all treatments, except those involving mechanical support or mending, are irreversible to some extent.

Given that most treatments will involve some irreversible alteration to the artifact, the conservator's task is to determine whether treatment is advisable, or whether the loss of some aspects of the artifact's documentary value outweighs the benefit of treatment. Factors such as the condition of the artifact, the type and extent of prior contamination through previous treatment and environment, the provenance, the intended use of the artifact and the collection as a whole, the uniqueness of the artifact, and the anticipated type and extent of alteration will influence the final decision. The conservator must be aware of the positive and adverse effects of treatment materials and procedures, and must be knowledgeable and flexible in the consideration of materials and methods of application so as to minimize adverse effects.

## Documentation

### Identification of Materials, Construction, and Cultural Modification

Ideally, the materials and construction of an artifact, native alterations, and alterations after collection should be fully recorded. In practice, the degree of documentation is limited by our knowledge of materials used in artifacts and the cultural function and use of artifacts, and may be regulated by practical demands dictated by time and priorities.

The materials used to construct artifacts may reflect tradition, availability, and personal selection. The use of a particular material to create a particular artifact may be very strictly dictated by tradition and social or religious strictures; for other objects, the choice of material may be more fortuitous, reflecting availability or the subjective preference of the maker. Availability of a material is dictated variously by climate, cultivation, trade, and external cultural influences. Thus the use of a particular material may provide important evidence of climatic change and environmental modification by human presence and agricultural practices, evidence of the importance of a material reflected in the desire to cultivate it or trade for it, evidence of trade routes and regional intercultural contacts, and evidence of historical contact with radically different cultures. Besides its value as a source of cultural information, the identification of the materials used in an artifact is important to an understanding of the degradation and stability of an artifact and to the development of safe and effective preservation and treatment procedures. Construction technology and cultural modification are equally important for the cultural information that can be derived from them and for the identification and selection of appropriate preservation, treatment, and supporting procedures.

The importance of materials is beyond doubt; our ability to accurately identify and describe them may be limited. Anthropological literature is a valuable aid, but, as discussed in the introduction to Chapter 3 and by numerous authors (see, for example, Rose 1985; Losche and Walston 1982), information may be limited, inaccurate, or unintentionally mistaken, and so should be used preliminary to, or in conjunction with, analysis. Probable identification of materials can be made from the literature and from examination by biologists, conservators, and curators familiar with plant resources of particular areas. Verifiable identification by anatomy and/or composition requires expertise and reference collections. Without reference collections or expertise, it is often possible to identify only the general plant type and tissue (for instance, the tangential epidermal split section of monocot stem, resembling rattan in general appearance and in magnified cross section). Fortunately, this general description of the material holds many clues to general anatomical characteristics, strengths, and weaknesses, as well as to probable chemical constituents (refer to Chapters 1 and 2). Construction types, where visible, can usually be identified or described using standard classification nomenclature and diagrams. Native terminology is sometimes used and is valuable as long as the full significance of the terminology is understood and the vocabulary is applicable to the specific area of origin and/or use.

## Examination and Treatment Records

It is essential to keep a full and accurate record of all work done in treatment. An object is a document: any alterations made to that document must be recorded to avoid possible confusion in future analysis of that document. Should the object require conservation in the future, the conservator will need to know what has been done in the past in order to understand its present condition, to develop a treatment compatible with the previous treatment, and to reverse the previous restoration if necessary. Information found in and about the object and treatment procedures used and/or developed by each conservator who works with an object are important additions to the general body of conservation knowledge. This information may be lost unless it is recorded.

Since it is a part of the object's permanent record, a copy of the treatment record should be kept in the museum registration or curatorial file on that object, as well as in the conservation laboratory files.

Laboratory treatment records should include a Daily Work Sheet, an Object Examination and Treatment Report, and a Photographic Record. Because it is unwise to use ink pens when working with an object, the Daily Worksheet is written in pencil. All other reports and records, however, should be written in permanent ink or typewritten on good quality paper (acid-free, buffered if possible).

### Daily Worksheet

A diary should be kept for every object worked on. This diary or journal should include the dates, times worked, all of the conservator's observations, and other relevant information on the work. The description, condition, tests, proposed treatment, and treatment reports are written based on the information recorded on the Daily Worksheet.

### Object Examination and Treatment Report

1. Laboratory number
2. Owner
3. Owner or museum accession/registration number
4. Brief description. A brief description of the object for identification purposes. Information regarding the object's provenance (place of origin, maker, age, history of ownership), if known, should be included.
5. Number of items. This is the number of items included under a particular laboratory number, not the number of pieces. If an object is broken, it is recorded as one object, "x" pieces.
6. Dimensions. Overall dimensions of the object. Note height, length, width, depth, and diameter, as appropriate for each object.
7. ID photograph or sketch. Optional, but quite useful.
8. Examination/treatment requested. Work requested of the conservator. For example, examination of materials and construction identification, examination for authenticity, examination for condition evaluation, evaluation of stability for display or transport, exhibition mount design and/or preparation, packing for

transport, treatment for stabilization only, treatment for stabilization and restoration, treatment to remove labels, and so on.

**Diagrams**

Diagrams should be clear line drawings of the object in black ink.

The purpose of the diagrams is to document the dimensions, construction, and condition of the object. The number and detail of the drawings will depend on the construction and condition of the particular object. The location of measurements should be clearly indicated.

Where details of description or condition are indicated with cross-hatching, shading, or similar codes, a key to their meaning should be included.

In cases where there are several types of extensive damage, transparent overlays on a drawing or black-and-white photograph may be clearer than a drawing overcrowded with information.

**Full Description**

This section should start with a general introductory statement of what the object is and what materials it contains.

The description should be well organized and clearly written. If the object is of simple construction, it is customary to first describe the structural components —their appearance, materials, and methods of construction. This description is followed by a discussion of the decorative elements on the object. If the artifact's construction is complex, one would first outline the major sections making up the object, and then describe the structural and decorative composition for each section.

When examining an object, one usually searches the literature for information concerning the manufacture and function of the object. If it is pertinent, this information can be included in the description report. It must be clearly indicated that this is information gathered from the literature, as opposed to that which the conservator has directly observed. All statements should be footnoted with full bibliographic information.

**Labels and Documentation**

Structure and location of all labels, numbers, documentary marks, and so on, found with or on the object should be indicated. Labels are extremely important to the curator in establishing the provenance of an object, and records should detail the support, medium, method of attachment, and other similar information. Areas of nonfading adhesive residue, and other evidence that clearly indicates a lost label, should also be noted.

**Condition upon Receipt**

This section should begin with a general statement on the general condition/ stability of the object. For example, the statement should indicate whether the object is structurally stable but could benefit from surface cleaning, whether it is broken but otherwise sound, whether it is broken and in danger of further damage if not repaired, whether it is structurally unstable and in need of immediate treatment, and so on.

The present condition of all structural, surface, and decorative elements should be described in detail. One should first state what one sees; if any interpreta-

tion as to how or when a particular condition occurred can be made on the evidence of the object, this can be stated as long as it is clearly indicated that it is an interpretation. If it is known how damage occurred, this should be included.

If an object has been previously repaired or restored, the nature of the restoration and its condition should be described. If possible, an indication of whether this is a native repair or a postcollection restoration should be made.

### Tests

Discussion of each test should include what was tested and why, a description of the test and/or the reagents used, the results of the test, and the conclusion or interpretation made as a result of the test.

### Proposed Treatment

The development of a treatment proposal, a joint effort between the conservator and the curator or owner, should begin with consideration of the goal of the proposed treatment. Is the object only to be stabilized against further damage, or is it to be restored? Is the object going into storage? Into a study collection? On display? Will it be on loan? These issues should be clarified through discussion with the owner or curator prior to examination of the object.

The time or money involved in treatment may be factors in determining the type or extent of treatment to be done. If so, it may be necessary to estimate the time and cost involved and to propose alternative treatments to be considered by the owner or curator.

A treatment proposal should outline what the conservator proposes to do, why, and the steps involved in doing it. For example, if an old restoration is to be removed, one would not merely say, "Remove old adhesive with acetone." One would describe the proposed treatment: "Remove the old restoration because it is disfiguring and unstable: (a) soften old adhesive with a vapor chamber of acetone; (b) remove softened adhesive with acetone and cotton swabs." If it is not feasible at this stage to determine which of several possible treatment steps will be used, the necessary treatment approach should be stated and the possible steps that might be used should be listed.

### Treatment

If the treatment is basic and uncomplicated, the report can be a simple statement of what was done to the object and what methods and materials were used to do it. For example: "Surface dust was removed from all surfaces using a soft brush (sable watercolor brush size 2) to lift the dust and a vacuum to evacuate the loosened dust (household vacuum cleaner with 2 cm diameter nozzle). The split at the rim was repaired on the interior and exterior surfaces of the basket using Japanese paper (Usamino, thickness 0.05 mm) adhered with rice starch paste ([trade name], starch, and deionized water)."

If the treatment is complicated—involving a complex object with a number of different components, or unexpected problems arise during the course of treatment, or modification or development of a procedure is required to solve a problem—it is best to write a summary of the treatment for a quick reference, followed by a detailed report that describes and evaluates the treatment. The summary briefly but concisely states what was actually done to the object and what methods and materi-

als were used to do it. The detailed report should include a discussion of exactly what was done, how it was done, the conservator's observations on the success or failure of treatment steps, discussion of other approaches or treatments suggested by the treatment, and so on. This record is valuable to the writer and to other conservators when developing the treatment of other objects.

For all conservation materials used in the treatment, the trade name, grade, manufacturer or supplier, and composition must be included in the report. This can be done in the text when the product is first mentioned, or in an appendix to the report. For example: "10% w/v Acryloid B-72 in toluene (Acryloid B-72: an ethyl methacrylate/methylacrylate copolymer resin [manufacturer name and country of origin]). Leather dye ([trade name]: an alcohol-based dye [manufacturer name and complete address])."

Full bibliographic information should be included for any references used during the course of the treatment.

**Storage and Display Recommendations**

Recommended light and RH levels for the material should be stated. Any special requirements or precautions for physical protection, support, mounting or handling of the object should be included.

However, recommendations will depend somewhat on the owner of the object. If the object is held by a small museum with no professional conservation staff or by a private owner, ideal light and RH levels, physical protection, display and mounting requirements should be stated. But practical realities must also be considered. If the object is going back to a private owner who cannot provide a museum-quality controlled environment, there is no point in telling him or her only that a bamboo quiver, for example, must be kept at 55 ± 5% RH. It is not realistic. Instead, one should add that the quiver is in danger of cracking if the relative humidity is very low or fluctuates dramatically between high and low, and suggest that the owner try to keep the RH as even as possible by keeping the quiver away from direct sunlight, drafts, and heating or cooling elements.

**Worktime Summary**

The number of hours involved in examination, treatment proposal, and treatment should be recorded. This will aid in estimating hours for contract work and for conservation and exhibition planning.

**Photographic Documentation**

Photographs for conservation records are normally made using black-and-white film and prints, as these are more stable than color. Color prints are known to discolor in time, and color rendition on printing can be inaccurate. Color slides vary in stability and color rendition depending on the film type and manufacturer, but are generally considered to be more stable than color prints. When it is necessary or desirable to document an object in color, color slides are normally used. (It may also be useful to build a collection of color slides of object deterioration, storage and display techniques, and basic conservation treatments for use in lectures and teaching. In addition, treatments and experiments intended for public presentation should be documented with color slides, which are the customary format for illustrating conference presentations.)

The condition of the object and the treatment carried out should be fully documented in black-and-white film (35 mm roll film or 4-by-5 in sheet film is customarily used). Full documentation includes before-and-after shots of the entire object and details of particular problems, as well as treatment shots of the full object and/or details showing particular changes in condition or specific treatment steps where appropriate. Merely using any old photograph is not acceptable; the purpose of a photograph is to document a condition, a change in condition, or a procedure. Before, during, and after shots should be made of the full object from the same angles with the same background and lighting. Detail shots to document the treatment of a particular problem should always be made of exactly the same area and with the same lighting so that visual comparison before, during, and after treatment may be made. To do this effectively, the examination and the treatment proposal should be well thought out before starting to photograph. One can't know what photographs are needed until one knows what one is dealing with and what will be done to the object.

Each photograph of the entire object, and of details if possible, should contain a photographic gray scale, a metric scale, the object laboratory or accession number, and a notation for before, during, or after treatment (BT, DT, or AT). Shots of details too small to allow this information should at least contain a metric scale. Some conservators prefer a colored background, while others prefer neutral grey or black. Colored backgrounds can create dramatic photographs, but they have the strong disadvantage of influencing the viewer's perception of the object's colors.

Information about each photograph taken should be recorded on a photographic record sheet at the time the photograph is taken. This information should include: the object number, stage of treatment, aspect, film type, film and frame number, lens used, aperture, speed, type of lighting, background color and material, and object distance from the camera. Unless obvious, it is also useful to note what the photograph is supposed to show. Besides the obvious value of this information to anyone using the photographs, the information is necessary to ensure consistency of aspect and exposure in before/during/after photographic series.

## Cleaning

Cleaning involves the removal of surface dust, grime, accretions, stains, and other alterations made to the artifact after collection. Postcollection alterations considered to be significant to the history of the artifact may be considered an exception. Cleaning may be done mechanically and/or with solvent action.

Cleaning is an irreversible process and should be approached with caution. Care must be taken that accumulations resulting from native use of the artifact are recognized and not disturbed during the removal of postcollection alterations. If there is any doubt as to the origin of material found on an artifact, it is best to leave it undisturbed since it cannot be replaced if it is later found to be significant.

In everyday usage, cleaning has a positive, benign connotation. This is not necessarily true when considering the cleaning of artifacts. The removal of disfiguring or damaging foreign accumulation is good for the artifact. The process of cleaning, however, can be damaging or can itself result in further alteration of the artifact. For example, vacuuming incorrectly can lift or disturb fibers and thread;

aqueous solvents, unless very judiciously applied, can cause damage through swelling of cell walls; and nonaqueous solvents may remove soluble components of plant tissue as well as foreign material. Compromise must be made between what is desirable to remove and what may be removed safely.

## General Principles

Distinction should be made, if possible, between patination and material accumulated during use, and dust, dirt, and grime acquired after collection. Distinguish between folds, creases, and alteration or distortion of the original form resulting from native use and those resulting from museum storage and display. Distinguish between native alterations and repairs and postcollection restoration and maintenance residue (e.g., early practices in some institutions of feeding baskets with oils and applying protective varnishes and waxes). The former is considered to be part of the artifact, while the latter is generally considered to be foreign to the artifact.

Making distinctions between native and museum alterations may be difficult in some cases. Information on the native use and care of the artifact, and the materials and techniques of manufacture and native repair are essential. The date of collection and the postcollection history can be useful in assessing what materials would or would not have been available for particular repairs. Familiarity with a particular museum collection—its characteristic dust and dirt and the restoration materials and techniques used in the past—is useful in assessing accumulation and repairs.

It is often inadvisable or impossible to remove all foreign material from the object when cleaning. Small particles of dirt may be trapped in fibers and pores; grime and accretions may penetrate deeply into the fibers. It would not be possible to remove this dirt without damaging the surrounding fibers. Previous restoration materials may be insoluble, or soluble only with solvents likely to cause considerable damage to or degradation of original material.

Types of foreign accumulation include: loose surface dirt, embedded surface dirt, grime/soot (dirt containing grease and oils), accretions (coherent matter deposited on the surface or possibly penetrating below the surface), stains (discoloration of the plant material with little or no particulate matter), restorations, and waxes, oils, and varnishes applied after collection.

## Mechanical Cleaning

Mechanical cleaning entails physically picking up or removing dirt particles.

### Vacuum Suction

Dirt is sucked off the surface. If the vacuum is properly controlled, this allows dirt to be removed with very little if any disturbance to the fibers. Vacuuming can effectively remove loose particulate matter, mold bodies, and some insect residue lying on the artifact's surface.

Industrial and household vacuum cleaners or laboratory vacuum systems may be used as the source of suction, although a more sophisticated variable-control vacuum pump would be best, as it allows greater control over the strength of suc-

tion. Flexible plastic hosing attached to the vacuum source is used to direct the suction onto the surface of the artifact.

For general removal of loose surface dirt and insect debris, a fairly large diameter (2 cm to 4 cm) hose is used. To prevent the object's surface from being lost or damaged by the suction, a plastic screen (the screen edges should be bound with cloth to prevent the sharp edges from abrading or tearing the artifact fibers) is placed over the artifact's surface, or a fine net fabric is tied over the end of the hose (Figure 5.7). The end of the hose is firmly held level with, and just above, the surface of the net. Vacuum suction can be reduced by raising the level of the hose slightly. It is useful to use the fingertips of the hand holding the hose as a guide. The other hand should lie lightly on the screen to prevent movement of the screen; the hand follows the movement of the hose. Large-diameter hoses should never be used without a screen or net to protect the object from the suction. Artifacts with insecure surfaces or surface decoration obviously cannot be vacuumed.

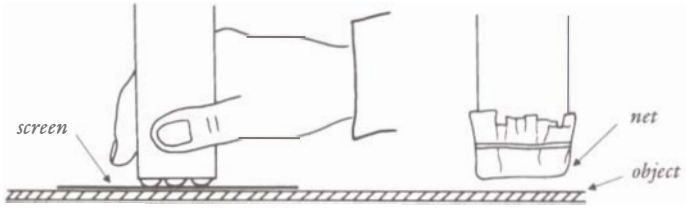



*Figure 5.7. Vacuuming artifacts using a screen or hose net.*

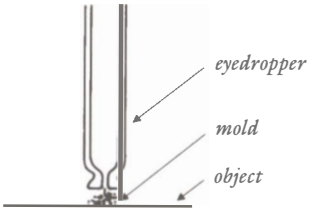



*Figure 5.8. Eyedropper over object with mold.*

To vacuum hard-to-reach areas, carved and contoured areas, and secure surfaces adjacent to insecure surfaces, smaller-diameter hoses (0.5 cm to 1 cm) are necessary. The ends of these should usually be covered with net. Hoses of smaller diameter are coupled to larger diameter hoses with tube adapters.

To remove dust from recessed areas and areas close to insecure fibers and decoration, and to remove mold bodies, it is most effective to attach an eyedropper or pipette to the end of a narrow hose. The eyedropper is held perpendicular to the surface, directly over the material to be removed (Figure 5.8).

It is wise to install a trap in the vacuum hose to collect any dirt and other loose particles that are removed from the artifact. This makes it possible to collect the dirt for analysis and to examine what is being removed to ensure that no material (such as pigment) is being removed. Some vacuum systems contain traps. Traps can also be easily made using Erlenmeyer filtering flasks (Figure 5.9).

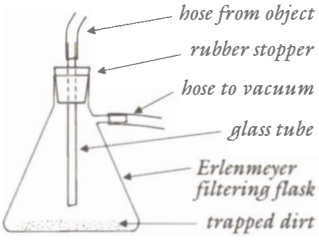



*Figure 5.9. Erlenmeyer filtering flask trap.*

**Brush and Vacuum**

The brush is used to flick dirt off the surface while the vacuum hose is held close by to evacuate the loosened dirt. To effectively catch the loosened dirt, the hose should be large (3 cm in diameter). The brush should be a soft-to-medium natural bristle or hair brush (watercolor brushes, calligraphy brushes, oil painting brushes). The ends of cut synthetic fiber brushes are too abrasive; synthetic hair brushes may be used if the ends of the hairs are tapered, not cut.

The brush is used with a flicking motion, not a scrubbing motion. The idea is to flick the dirt up and off the artifact's surface, not to scrub it deeper into the fibers. The vacuum hose should be held in front of the brush so it can catch the dirt as it is lifted. It makes little sense to brush dirt up only to have it fall back onto the

object. Brushing can remove more dirt than vacuuming alone, but care must be taken not to disturb fibers or to push dirt further into them.

### Compressed Air or Gas

A jet of compressed air or gas is used to blow the dirt off the surface. This method can obviously not be used on highly degraded fibers or near flaking and friable paints. Compressed air or gas should be used in a spray booth, fume cupboard, or under a bench evacuation hose so that the dirt is evacuated as it is blown off.

Various equipment can be used to create the jet—from rubber bulbs and compressed air canisters, to compressed gas cylinders and air compressors with pressure control. The more control you have over the pressure and the size and direction of the air jet, the better. Rubber bulbs are gentle, but it can be hard to control the direction of the nozzle. Air brushes used dry allow control over the pressure, shape, and direction of the jet. Air nozzles on a flexible hose can be attached to compressed gas cylinders or to air compressors to give fine control over pressure and direction of the jet.

Compressed air or gas jet cleaning can remove loose surface dirt and some embedded surface dirt; it can remove some grime and soot if these are not compacted. It can also be used to dislodge insect residue from under elements or hard to reach areas.

### Tools

In some cases, it may be safer to remove the bulk of compact accretions mechanically rather than with liquid solvents. Material dissolved by the solvent may be pulled into the fibers before it can be lifted off. Reducing the bulk of the accretion mechanically also means that the amount and duration of exposure of the plant material to solvents may be reduced. If and how much material can be removed mechanically will depend on the accretion and the plant material surface: an accretion can be more safely and easily removed from a hard epidermal surface than from a fibrous or porous surface. In the latter case, it would be possible to scrape off the accretion only to the uppermost level of fibers and the remainder that is embedded in the fibers would have to be removed with solvents.

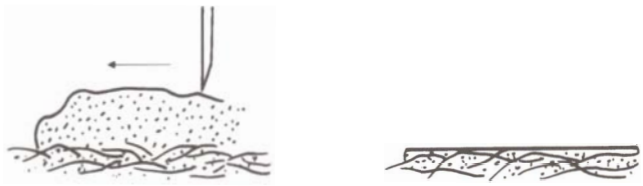
General methods of approach using fine hand tools include:

- Chipping by pressing down on the edge of the accretion and breaking off a section using a blade or a pointed tool (Figure 5.10).
- Scraping off the surface of the accretion using a flat blade tool (Figure 5.11).
- Abrasion may occasionally be useful in removing the surface of accretions. Small swabs made with very fine steel wool (Grade 0000), small bits of fine sand paper glued to or wrapped around applicator sticks or match sticks, and sections of emery board have been used. Very fine abrasive strips (abrasive on polyester film) are available from dental supply houses.

With the first two methods, one would try to use the gentlest tool possible. A pointed wood stick or a blunt-edged spatula should be tried first. Metal needles and scalpel blades should be used only if gentler tools do not work and if great care

*Figure 5.10. Chipping the edge of an accretion with a hard epidermal surface.*

*Figure 5.11. Scraping the surface of an accretion with a fibrous or porous surface.*



is taken not to puncture or cut the object. Frequent vacuuming with a fine hose or pipette is necessary to remove all accretion and abrasive particles when using any of the above techniques.

The use of electrical tools such as vibrotools, electrical engraving tools, drills and grinders, and Airbrasive units—used for removing dense compact accretion and corrosion products from some types of objects—are generally not needed in order to remove most foreign accumulation of dirt and grime, and are not recommended for plant materials. However, exception may be made for removing thick, hard, dense museum restoration materials like epoxy, polyurethane, polyester resins, and other fill materials which cannot be successfully or safely removed with solvents. These may be removed as far as the upper surface of the plant material by grinding off with fine carborundum or diamond grit heads on a flexible-shaft or dental drill.

## Solvent Cleaning

Solvent cleaning entails removing dirt and accretions by bringing them into suspension or solution in an aqueous or nonaqueous liquid and then removing the liquid.

### Initial Considerations

Solvent cleaning is a controversial conservation issue for very good reasons. Many factors must be considered, and we know too little about some of those factors to make sound decisions.

It is necessary to consider what is to be removed, what must be left undisturbed, and finally, what solvents and methods of application would most safely and efficiently do this.

#### *What to Remove*

Foreign accumulation is defined not by what it is, but by whether it should be there. Rice starch residue on a used Filipino cooking vessel is part of the artifact, but starch residue left by a starch paste mend of a vessel is a foreign accumulation. Body oil deposited by the hunter on a spear grip is part of the object, but body oil deposited by museum visitors touching an artifact is a foreign accumulation. Paint applied by the artist is part of the artifact, but paint spattered by a careless exhibitions officer is a foreign accumulation.

Given that almost anything can be a foreign accumulation, its characteristics will vary considerably, and the cleaning agents and methods necessary to remove it

will vary accordingly. Loose surface dirt may be most readily picked up with a polar solvent, grime may require nonpolar solvents, and some paints and adhesives may be soluble in only a few organic solvents.

The location of the foreign accumulation can also influence the agents and methods necessary to remove it. Loose dust sitting on heavily painted areas of a Samoan barkcloth may be removable mechanically or by rolling with a swab barely wetted with a solvent; but the same dust sitting deeply among the fibers of unpainted areas of the same barkcloth may be able to be removed only by bringing it into suspension in a solvent bath (not necessarily recommended).

The need to remove foreign accumulation must also be considered. Is it aesthetically necessary? Is it only slightly disfiguring, or is it so disfiguring as to disturb the artistic integrity or viewers' appreciation of the artifact? Does the foreign material pose a physical or chemical threat to the stability of the artifact? Is a dense and hard accretion causing breakage of neighboring or underlying fibers, or is it causing no apparent threat to them? Is a particular dirt relatively neutral and inert, or is it highly acidic, causing degradation of the plant material? If it is a threat to stability, must it be removed, or can it be neutralized or inactivated by treatment or by environmental conditions? In other words, can the viewer and the object live with the foreign accumulation, or does it have to go?

*What to Leave Undisturbed*

One never merely removes a foreign accumulation; one removes that accumulation from something. One must be familiar with the characteristics of that something (the artifact) so as not to disturb, damage, or otherwise alter it in the process of removing the foreign accumulation.

The artifact surface is variable and complex in structure and composition. Surfaces may be dense and hard, friable, porous, or fibrous. The surface may consist of the natural, undisturbed surface of the plant material. The natural plant tissue surface may be altered during processing: removing layers of waxy cuticle; removing the dense epidermis, thereby exposing a fibrous, porous surface; retting, beating, and washing, leaving an open mass of fibers. The artifact surface may be stained or may consist of paints and oils applied by the artist, and it may be patinated with oils and dirt accumulated during use. (At times decoration and patination may be uncomfortably similar in character and solubility to the foreign accumulation one would like to remove.)

Decoration and patination in many cases so protects the plant material substrate that with local, short application of very small quantities of solvent, the substrate will be unaffected. The main concern is to not disturb the decoration or patination. With less-protective coatings, decoration, and patination, however, the plant material must be considered—that is, with exposed plant material one must consider solvents that will not cause swelling, accelerate degradation, or extract cellular and intercellular material.

Although cellulose and hemicelluloses are the main constituents of most plant tissues, their percentage of the total mass varies, as do percentages of lignin, pectin, extractives (latex, gums, resins, oils, fatty acid waxes), and minerals. Such variation depends primarily on tissue and plant, but also on aging and on processing, which can dramatically alter composition and texture. A solvent that causes

considerable swelling of one type of plant tissue may cause little or no swelling of another tissue type—for example, water on conductive and storage tissue versus water on some outer bark. Because plant composition is complex, it may be difficult to find a solvent that causes no swelling and degradation of cellulosic components, no extraction of resins, oils, and waxes, and does not affect surface patination. Florian (1977), Kronkright (1981), and Gilberg (1986) have addressed the importance of understanding the structure and composition of plant materials in developing conservation treatment. Considerably more information needs to be dug out of the botanical and biochemical literature and obtained from examination and analysis of processed and aged materials before we can make sound decisions on the suitability of specific solvents for use with specific plant tissues.

*Agents and Methods of Application*

With so much variation in plant tissues, compounded by changes and additions made during artifact production and during native and museum use, one may be justifiably confused when deciding what solvents and methods of application could be most safely used in treatment. The decision not to clean may often be a reasonable conclusion. This is not to imply that cleaning should never be done; cleaning for stabilization or aesthetic reasons is often justified. The point is to examine as many factors as possible, decide if cleaning is necessary or desirable under the circumstances, and choose solvents and methods of application least likely to cause damage or disturbance.

**Potential Damage by Solvents**

*Swelling*

This may result in distortion, loss of shape, and stress—especially on weaker elements. Kronkright (1981) discusses the swelling effect and mechanism of water and the nonswelling effect of petroleum spirits on conductive tissue. Florian (1977) includes the swelling effect of water on xylem, phloem, and monocot stems and leaves. Gilberg (1986) found heavily suberized outer bark swelled with exposure to the vapors of semipolar solvents like methanol, ethanol, acetone, and dimethylformamide, but not with exposure to the vapors of nonpolar solvents like petroleum distillates and toluene or to highly polar solvents with high hydrogen-bonding capacity like water.

*Dissolution and Extraction of Soluble Components*

Exposure to water could dissolve and extract starches and deteriorated pectin and hemicelluloses. Florian (1977) suggests that solvents used to decompose and extract plant extractives for biochemical analysis should be avoided in conservation treatment. The outer bark of white birch contains hydrophobic but ether-soluble substances, alcohol- and alkaline-soluble tannins, and suberin, which is insoluble in water and alcohol but may be dissolved in other organic solvents. The cuticle and cutin of monocot epidermal tissue is saponified by alkaline aqueous and alcohol solutions and the wax is extracted with petroleum ether, diethyl ether, hot chloroform, and n-benzene. A white surface bloom on birch bark following exposure to methanol and ethanol vapor suggested to Gilberg (1986) that betulin (a tri-terpene resin) may have been dissolved and carried to the surface.

*Further Degradation and Change*

Gilberg (1986) found that those solvents that most effectively softened birch bark (apparently those most readily absorbed by the suberin) also caused delamination and discoloration and released drying tension between the bark layers, causing greater curling upon dissipation of the solvent than had occurred with original seasoning of the bark. Kronkright (1981) relates that further embrittlement of fibers by accelerated deterioration of carbohydrate-based components occurs upon exposure of aged material to moisture.

Clearly the effect of solvents depends to a large extent on the plant species, tissue, and composition. One cannot dictate, then, that a particular solvent should never be used or that another solvent is safest to use. Some general guidelines might be made, however:

- Water and moisture are capable of swelling the carbohydrate components of plant cells and may accelerate further degradation and so should be avoided on many plant tissues.
- Epidermal tissue and outer bark with high resin, phenol, and fatty acid components or coatings will be fairly hydrophobic and are more likely to be damaged by the dissolution of these components with nonaqueous solvents than by the swelling effect of moisture.
- Alkaline aqueous and nonaqueous solutions—that is, solvents with added surfactants or ammonia, often used to improve cleaning efficiency—should perhaps be avoided. The use of surfactants also increases the time the artifact is exposed to solvent as rinsing to remove residual surfactant is necessary.

Alteration during manufacture and use may change the plant material by extracting some components and removing some tissue, changing its susceptibility to damage with particular solvents. The addition of paints and oils in decorating and finishing and the addition of grease, dirt, and proteinaceous and carbohydrate materials during use and ritual may completely coat the plant material, making the choice of solvents dependent on their solubility rather than on the solubility or sensitivity of the plant substrate. Unless they completely isolate the plant material, the solvent selected must be a compromise between what is least damaging to the surface alteration and what is least damaging to the plant material. Materials added during artifact production and use may be extremely sensitive to solvents—for example, some paint media, iron mordanted dyes, and turmeric (see Lee, Bacon and Daniels 1985). Their sensitivity may be the determining factor in solvent choices open for consideration. Previous treatment and museum environment may also have altered the object's materials, influencing its reaction to solvents.

**Method of Application**

How the cleaning solvent is applied may be a deciding factor in determining its suitability for a particular artifact. The amount of solvent the material is exposed to, the length of time the material is exposed to the solvent, and the amount of mechanical action necessary to remove the foreign accumulation must all be considered. Very generally, solvents can be applied locally, as a vapor, or by immersion.

*Immersion*

Immersion of an artifact in a cleaning solution is rarely necessary and is generally not recommended because swelling, extraction, or alteration of components would occur most readily during immersion. Immersion cleaning found sometimes in practice is the washing and "dry cleaning" (immersion in nonaqueous solvents) of textiles, costumes, and occasionally barkcloth. Arguments for the washing and dry cleaning of textiles include removal of abrasive and hygroscopic dirt, removal of body oil and perspiration, and raising the pH toward neutral. Using these two methods with ethnographic textiles and costumes is to be discouraged, because much evidence of use is lost, and many such textiles (such as burnished monocot leaf fiber cloth) cannot be washed without alteration of surface finish. Washing and dry cleaning should only be considered if the textile or costume is endangered or disfigured by the presence of dirt, body oils and perspiration, and acid.

One recorded instance of garments of feathers and spun plant fiber nets cleaned by immersion in water and in white spirits was concerned primarily with the cleaning of the feathers (Petersen and Sommer-Larsen 1984). The effect of the cleaning on the plant fiber netting and binding was not specifically examined other than to report that no shrinkage of the netting occurred. Loose fiber samples (*Phormium tenax,* cotton, and wool) from Maori cloaks were tested for cleaning in water and detergent with and without ultrasonic activity (Barton 1986b, Barton and Weik 1987). Degraded black-dyed *P. tenax* fibers fell apart with immersion in water. Undyed *P. tenax*, cotton, and wool were examined visually and with the scanning electron microscope. Cleaning was more effective with ultrasonic activity and, both with and without ultrasound, no visible damage such as fracturing, breakage, or surface disruption, and no change in thread twist, dimension, or dry tensile strength were found. In both of the above examples, examination of knotted and tightly woven and twined spun fibers for possible swelling damage to confined fibers would have been of interest.

Immersion cleaning of barkcloth cannot be generally recommended. Barkcloth with resinous paints can not be immersed in many nonaqueous solvents. Many barkcloths are decorated with loosely bound pigments and dyes that may be moved or lost by immersion in solvents. Swelling of sewing and reinforcing cordage could lead to stress and tearing, and dissolution of laminating pastes could lead to delamination with immersion in aqueous solvents (although this did not occur in two samples washed in water by Firnhaber 1979). Dissolution of plant components, fragments, scents, and so on, may also alter evidence of manufacture. Recent experiments on the aqueous immersion of barkcloth (Firnhaber 1986) concerned the feasibility of raising the pH of extremely acidic barkcloth. One hour of immersion in water resulted in an increase in pH with little or no visible alteration of texture.

*Vapor*

Exposure of the artifact to solvent vapor for cleaning purposes would only rarely be necessary or advisable, but in some cases it may assist in the removal of previous restoration or damage involving overpainting or varnishing. The idea is to soften the adhesive, fill, paint, or varnish with the solvent vapor so that it may be removed with minimal exposure to liquid solvent and mechanical action. The effect of the solvent

vapor on the swelling and dissolution of the plant materials, on its decoration and patination, as well as on the foreign accumulation must be fully considered.

*Local Application*

The most controllable solvent application method is to apply the cleaning solution locally. The precise area exposed to solvent, the amount of solvent used, and the time of exposure can be fairly tightly controlled.

**Swabs.** In application using cotton swabs, the swabs should be made to a size appropriate for the particular job. For removal of discrete spots, it should be possible to apply the swabs to a spot without overlapping onto the adjacent surface. For removal of general surface dirt from basketry constructions, the swabs should be small enough to be confined to one exposed element section at a time (to allow even cleaning of each section and to allow rolling or rubbing only in the fiber direction). For removal of general surface dirt or varnishes from larger smooth surfaces (like bamboo culm or wood), larger swabs allow more even cleaning. Cotton wads held by tweezers can also be used.

The amount of solvent on the swab is controlled by blotting. When removing relatively loose particulate matter from smooth surfaces, if a polar or semipolar solvent is used, the swab need only be just barely dampened (roll the wetted swab on a blotter to remove most of the solvent). The matter is attracted to and lifted by the swab, leaving very little solvent on the artifact surface. Where more solvent action is necessary to soften or dissolve more compact or bound matter, it may be necessary to roll a fine film of solvent on the surface (only lightly roll the swab on the blotter, leaving more solvent in the swab). The film carrying the suspended or dissolved matter is then picked up first with barely dampened swabs, then with dry ones.

The mechanical action used may be influenced by the foreign matter and by the surface being cleaned. Rolling generally deposits solvent and then lifts both the solvent and the foreign matter. Rubbing with the swab can disturb the foreign matter allowing it to be more readily or quickly lifted; but on somewhat porous surfaces it could also push the matter into the surface. One should avoid rubbing open, fibrous surfaces, since fine fibers may be easily broken or dislodged. Rubbing may alter surface texture; matte, unfinished wood surfaces, for example, can be burnished by rubbing.

**Blotting.** Soft, open fibrous surfaces, such as those in barkcloth, cordage, and fibrous strands, may be disturbed by rolling or rubbing action. These surfaces can sometimes be cleaned with solvent that is dropped on, to suspend or dissolve the foreign matter, then picked up with a blotter. This may be done from one surface only, but often the dissolved matter is carried into the artifact material before it can be blotted up. This can sometimes be lessened by saturating the immediate area with a solvent in which the foreign matter is not soluble and which is not miscible with the cleaning solvent.

**Flow-through.** If the artifact material is thin and both sides accessible, a flow-through method may be more effective. The side most affected by the foreign matter is laid face down on a blotter and the solvent dropped on from the less affected side. The matter becomes suspended or dissolved in the solvent and is carried through to be absorbed by the blotter underneath.

**Suction.** Vacuum suction may also be used to draw out the cleaning solvent, using a vacuum pipette above or a vacuum suction platform or table below the area.

**Poultices.** Where longer exposure to the solvent is necessary to dissolve the foreign matter, poultices of cotton wool, paper pulp, or particulate diatomaceous earth saturated with solvent can be used. The poultice is placed over the area to be cleaned. When using particulate poultices, a piece of very fine paper, like lens tissue or L-tissue, should be placed over the area before applying the poultice to prevent the particles from becoming embedded in the artifact surface. As the solvent evaporates, the dissolved matter is drawn into the poultice. The poultice can be covered with plastic sheet initially to increase the exposure time.

### Cleaning Tests

Spot tests are done to determine the most efficient solvent to use in cleaning, and to determine if the solvent may be used on the object without adversely affecting the object material or appearance.

#### *Testing Unwanted Material*

It may be possible to scrape off a few particles of the material that can be placed on a watch glass, covered with a drop of solvent, and watched under magnification for softening or dissolution. If small particles of the material can be removed, these could be tested with color indicator tests to identify the material type, assisting in cleaning solvent selection. For specific color indicator tests refer to: Chapters 2 and 4 of this book, Morrison (1982:48–55,60–67), Feigl and Anger (1966), and Grant (1961). The solubility parameters for some of the identified materials may be found in references such as Gardon and Teas (1976). If spot tests must be done directly on the artifact, the test should be done on a small area (approximately 3 $mm^2$) of the object, under magnification, in an unprominent location, if possible.

Usually, a tiny cotton swab (3 mm to 5 mm long), lightly wetted with the test solvent, is rolled back and forth over the test area. The swab and the material are observed for any reaction while rolling. If no effective change occurs with the rolled swab, a small poultice test can be used to see if more concentrated or prolonged exposure might work. A poultice made of a tiny wad of cotton wool saturated with the solvent can be placed on the test area; the poultice is kept saturated by replenishing the solvent with a micropipette, if necessary. The poultice is lifted periodically to check for any reaction of the unwanted material and of the artifact.

On thin, open material to be cleaned with blotter and/or suction, a blotter is placed under the area and a drop of solvent placed on the test spot. The solvent is picked up with a piece of thin blotter or the fibers of a torn edge of blotter or the solvent is allowed to flow through to the underblotter. Both blotters and the artifact are observed for reaction.

#### *Testing the Artifact Material*

Solvents that successfully removed the unwanted material should then be tested on the artifact material and observed for color and texture change, extraction of components, and so on.

*Records*

All observations should be recorded: the material tested, the location on the artifact, the test method, the reactions, and the length of time it took for each reaction to occur. The reaction and nonreaction times should be recorded, as it is important to know not only what change occurred, but also how long it took for that change to occur. Other things being equal, one would generally select the solvent with the quickest dissolution action and the least mechanical action.

When working with a collection where previous mending and restoration materials of similar appearance are found on artifacts, it is useful to plot the solvents in which the materials are soluble, partly soluble, and insoluble on a Teas solubility triangle. Eventually an area of solubility for a material should develop which could assist in choosing solvents and solvent mixtures when that material is found again. Similarly, it would be useful to develop areas of solubility for components of artifacts such as resins, paint media, and oils from specific cultural groups and components of plant material such as cutin and suberin. This would assist in selecting solvents which could safely be used on the material, and might assist in the identification of these material types. Refer to Gardon and Teas (1976) and Hedley (1980) for information on the theory and use of solubility parameters and the Teas solubility triangle.

## Removal of Previous Alterations

It may be desirable to remove postcollection marks, labels, coatings, restorations, and mounting devices if they are disfiguring or damaging, or are no longer significant or functional.

### Native Repair and Postcollection Repair

A distinction should be drawn between those repairs made by the people who created and used the artifact and those repairs and restorations made after the artifact was collected or acquired. Native repairs are part of the artifact and generally should be kept, although exception to this is sometimes made if the native repair is causing such stress that the artifact is in danger of being lost or suffering extreme damage. Postcollection repairs and restorations are usually not considered to be a part of the artifact and may be removed if they are disfiguring, inaccurate, or are deteriorating so that they no longer stabilize the artifact.

However, some of these, although disfiguring, may be impossible to remove without further damaging the artifact because of method of application or choice of material. Such repairs can only be accepted and the disfigurement alleviated as much as possible.

For example, a break in a wood figure painted with thick, matte paint had been mended with hide glue and a considerable quantity of excess glue had run out and penetrated the paint for several centimeters below the join. Further, the drying and aging glue had shrunk, pulling some of the badly discolored paint from the surface. It would not have been possible to remove the disfiguring and damaging glue without losing most of the paint bound in it. The lifting paint was resecured. In another example, a painted tree fern trunk figure had been repaired with liberal quantities of epoxy resin that had seeped and dribbled over everything. One could

only alleviate the disfigurement by grinding off (using diamond grit bits on a flexible-shaft drill) most of each dribble and overpainting the remaining surface.

In some cases, a postcollection repair may be an important part of the history of an artifact and should be retained. This might be the case, for example, for material acquired and repaired by a particular individual and now studied and displayed in the context of that individual's life and aesthetics.

### Previous Labels and Marks

Earlier accession numbers, collectors' labels, field collection numbers, and so on, are very important in establishing the provenance of an artifact. Besides numbers and labels remaining on the object, evidence of labels, numbers, and marks may exist on the artifact in the form of adhesive residue, discoloration, unfaded patches, or holes where labels were tied or sewn on.

All this information should be documented when examining an artifact; it should be removed or disturbed only upon consultation with the owner. Intact labels that are removed and photographs of labels, marks, and evidence of labels that will be destroyed during removal should be kept with the permanent records for the artifact.

### Removal of Postcollection Repair and Restoration

The variety of methods and materials used in repair and restoration and the variation in artifact construction as well as in plant material structure and density makes generalization about removal difficult. Several approaches will be mentioned here. However, each artifact presents its own special problems and restrictions which can only be safely handled by using considerable common sense along with a knowledge of the materials.

#### *Removal Using Mechanical Techniques*

Thread, cordage, and added plant material that are not adhered should be gently extracted from the artifact using tweezers and spatulas. Thread and cordage should be cut above and below each point of entry into the artifact so that they can be gently pulled out or lifted off with the fingers or tweezers without tugging and ripping (Figure 5.12).

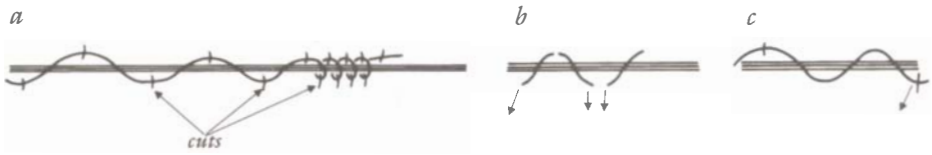



*Figure 5.12. Thread or cordage should be clipped (a) and removed gently without tugging (b), not pulled straight through (c).*

Adhesives, fills, paint, and thick ink can be removed from surfaces mechanically with the use of tools (see Mechanical Cleaning section) if the foreign material has deteriorated so that it is crumbly and poorly adhered, or if it has lifted slightly from the surface. Mechanical removal may sometimes be used if the foreign material is on a hard epidermal surface. It is often not possible if the foreign material is on a weak or deteriorated epidermal surface or on a fibrous, porous surface. Diamond grit bits on a flexible-shaft drill can sometimes be used to remove the bulk of thick, hard surface deposits.

The bulk of larger areas of fill may be excavated with fine grinding and cutting bits on the flexible-shaft drill and with fine chisels and scalpels. The size of the artifact and the area of fill may require the use of larger hand tools like saws, rasps, and gouges—for example, major replacement sections on wood canoes.

*Removal Using Solvents*

Solvents are used to soften or dissolve the foreign material. Softened material may then be removed mechanically and dissolved material removed by mopping up the solvent in which it is dissolved. Immersion of the artifact in solvent to dissolve and wash away the foreign material cannot be recommended because of likely damage to and removal of plant material components and artifact decoration and patination.

The foreign material may be dissolved and removed with the appropriate solvent applied by cotton swab, poultice, or blotter.

The foreign material may be softened by placing the artifact in a chamber filled with the vapor of the appropriate solvent. The bulk of the foreign material can then be removed with a wooden stick, spatula, or dry swab. The residue is then removed with a cotton swab dampened with the appropriate solvent.

*Combined Methods*

In many cases, removal of foreign material requires a combination of mechanical and solvent methods—removing the bulk of the material mechanically, then removing the remaining residue with solvents. This is often advantageous, as it requires less exposure of the artifact to solvents, and reduces the amount of foreign material, which could be drawn into the artifact with the solvent.

**Removal of Common Marks, Tapes, and Adhesives**

The following is not an exhaustive or definitive list; it is merely a list of some of the things that have worked when removing common marks, tapes, and adhesives.

- Pencil: Artgum erasers, kneadable erasers, Groom Stick
- Crayon: wax solvents such as chlorinated hydrocarbons, petroleum spirits, toluene; prior mechanical removal of heavy deposits is advisable
- Ballpoint and felt-tip pen: dimethyl formamide, ethanol, and acetone
- Pressure-sensitive tape: tetrachloroethylene, acetone, toluene, toluene/ethanol 60/40; residual stain may be alleviated with tetrahydrofuran. Refer also to Smith, Jones, Page, and Dirda (1984)
- Gummed cloth or paper tape: hot water; hot water plus acetone or ethanol
- Starch paste: warm water; warm water plus a bit of ethanol
- Animal glue: hot water; hot ammoniated water
- Cellulose nitrate adhesive: acetone (for spot test for cellulose nitrate, see Koob 1982)
- White emulsion glues: Can be difficult. Some may soften or dissolve in acetone or toluene. Many old white glues are insoluble or will only gel in solvent (white glues can often be lifted from a surface after prolonged immersion in water, but this is not recommended for plant materials)

- Epoxy: removal of epoxy is difficult. Epoxies do not dissolve; they may only swell in some solvents. Dichloromethane or dichloromethane/methanol/xylene mixed in proportions of 90/5/5 or 80/10/10 have been found to be most successful on a variety of epoxies (Scott 1986). To achieve swelling, the adhesive must be immersed in the solvent. This is not recommended for plant materials because natural resins, waxes, and oils in the plant material will be leached out. Mechanical removal of gross surface residue using a diamond grit may be the only treatment possible.
- Silicone adhesives: Erhardt (1983) suggests a solution of 10 ml dodecylbenzene sulfonic acid, 8 ml dichloromethane, 5 ml toluene, and 18 ml xylene to soften silicone adhesives on inorganic materials. In most cases, this solution could not be safely used on plant materials. Mechanical removal only may be possible.

## Reshaping

The principle behind relaxing and reshaping is to condition the material so that it can be moved to a new shape without causing breakage or crushing of tissue. Bending plant material that is stiff, dry, or brittle will only break tissue instead of reshaping it plastically.

### General Considerations

In general, artifacts that have become distorted in shape after collection should be restored to their original shape as far as possible. This approach is advisable for several reasons. First of all, an artifact should be seen and studied in its original shape. Also, distortion can break fibers and cause stress in areas that are unsupported. Finally, distortion and folds can prevent artifacts from being properly and safely stored, displayed, and studied. Severely degraded plant materials may be too embrittled to allow sufficient conditioning for safe reshaping. In this case, the distortion must be accepted and the artifact adequately supported to prevent breakage or further distortion.

Any distortions resulting from the use to which an artifact was put during its life before collection should be retained. Such distortions provide evidence of such use and are considered an integral part of the artifact. Reshaping should be considered only if these distortions are severely endangering the artifact by causing stress that could lead to further damage. The value of the distortion as ethnographic information weighed against the danger to the artifact should be considered by the conservator and the owner or curator when selecting the appropriate treatment for an artifact.

Distortion may occur due to folding, insufficient support in storage and display, and crushing in overcrowded or improper storage. Once reshaped and properly supported, artifacts distorted by these causes tend to retain their proper shape.

Distortion also occurs as artifacts react to environmental conditions, particularly to relative humidity. Swelling and contraction of plant cells occur with changes in moisture content below the fiber saturation point, and the cell moisture

content responds directly to changes in ambient relative humidity. Plant materials restrained while drying during artifact production will retain that shape as the cell wall microfibrils are locked in place. However, should the cell moisture content increase, then the locking bonds release and the microfibrils become free to move. And move they will ... to a position with less tension. (Microfibrils do not necessarily move back to their original position in the growing plant; cells in a growing plant may be under tension or compression.) In such cases, reshaping is problematic, as the artifact's shape cannot be regained without conditioning and then drying under restraint, and even that shape cannot be maintained unless the moisture content of the material can be strictly maintained. Reshaping in some of these cases could cause splitting, and would be pointless in any case unless the artifact's moisture content were controlled. Swelling and shrinkage of materials under partial restraint may lead to buckling and splitting as tension develops between restrained and unrestrained areas. Distortion of some elements of composite artifacts causes stress on weaker elements. Reshaping of elements in composite artifacts may be impossible since differential movement of various elements during conditioning could create further damage, and some elements may not be accessible for restraint during drying.

## Conditioning

### Solvents

Solvents can condition material through plasticization by bond breakage and replacement. Bonds affected may be in the cellulosic components of the cell or in wax and resin components of the cell or tissue. Conditioning invariably involves some degree of swelling and degradation of the cellulosic and/or extractive components.

In the fresh state, much water is bound within the cell walls. When a plant dries, much of this water is lost. The cell wall components are drawn more closely together and become locked together as their former bonds and attraction to water are replaced with bonds and attraction to each other. To condition the cell walls, this attraction must be broken and replaced to a certain extent to allow movement of the components across one another. Given the high degree of swelling and relaxing in cells with a high percentage of cellulose and hemicelluloses upon exposure to water vapor, moisture apparently regains its old position quite readily, especially among the hemicelluloses and amorphous cellulose. The higher the percentage of cellulose and hemicelluloses and the lower the tissue density, the more rapidly this process appears to occur.

Gilberg (1986) found that, with tissue with very high percentages of extractives (lignin and suberin—the suberin composed of fatty acid wax and tri-terpene resin), neither the highly polar and hydrogen-bonding water vapor nor the nonpolar hexanes had an effect, but semipolar solvents caused marked to moderate swelling and relaxing. He suggests that these semipolar solvents replaced bonding between the wax and the resin components of the suberin. This hypothesis was further supported by the observation that some resin appeared to have been carried to the sample surface with evaporating solvent.

Other polar and semipolar solvents, such as alcohols, are also effective in plasticizing plant tissue with or without high percentages of extractives.

Solvents may also condition materials through their lubricative behavior. Kronkright (1981) conditioned baskets containing a variety of plant tissues with vapors of Stoddard Solvent (an aliphatic petroleum distillate b.p. 350 °F to 410 °F), a solvent with lubricative yet limited swelling behavior. The mechanism of the lubricative behavior was not discussed.

The choice of solvent to condition a particular plant material seems to depend to a fair extent on the composition of the plant material in the artifact. Ideally, one wants sufficient conditioning with minimum swelling. For high extractive content tissue, semipolar solvents appear most effective, but the specific solvent used would be a compromise among degree of relaxing, degree of swelling, and degree of side effects like discoloration and component extraction. For other tissue, polar, semipolar, and nonpolar solvents are effective to varying degrees. The extent of relaxing, swelling, and side effects of particular solvents on specific plant tissue should be considered. Clearly, the compilation of more specific data on the effect of solvents on plant tissue would be useful: the swelling behavior, the conditioning behavior (lubricating, plasticizing), and the extent and effect of degradation, dissolution, and reconstitution of the tissue components. (See the Cleaning section of this chapter and Chapter 4 for relevant information on effect of solvents on plant tissue.)

**Methods**

Methods of introducing the conditioning solvent recorded in the conservation literature include: soaking, local application of liquid, misting, steaming, and use of a vapor chamber. To reduce internal stress by sharp permeation gradients, it would be best to introduce the conditioning agent slowly and as evenly as possible. Conditioning in vapor chambers seems most appropriate. Direct application of the relaxing solvent in liquid form should be avoided because of the likelihood of staining and dissolution of plant components, and also because it creates a higher concentration of solvent than necessary and a sharp permeation gradient. Steaming also does not humidify the interior and exterior cells evenly and may easily result in condensation of the steam on the artifact surface. Misting may sometimes be used with thin, low-density materials like barkcloth.

Vapor is usually introduced into the chamber by evaporation of solvent from containers of the liquid or blotters saturated with the liquid placed in the chamber. Ultrasonic vaporizers, steam vaporizers, and drum humidifiers are also used. Care must always be taken not to oversaturate the atmosphere in the chamber, possibly resulting in condensation on the artifact or dissolution of plant material components. If water vapor is used, it is wise to introduce a mold inhibitor (for example, a few drops of saturated solution of thymol in ethanol on a piece of wet blotter placed in the chamber).

Localized conditioning may be necessary for practical reasons with large artifacts, or because only certain components of composite artifacts require or can tolerate the conditioning. Plastic sheet or bag chambers containing solvent-saturated blotters can be built around the area to be conditioned. A spacer, such as polyester batting or screen, should be placed between the artifact and the blotter to avoid wicking of the solvent into the artifact.

## Blocking

Once conditioned, the artifact is gently manipulated into its correct shape and held in that shape (blocked) until the conditioning vapors are dissipated. Blocking can be done in a variety of ways, depending on the shape and character of the particular artifact. Badly misshapen objects may need to be reshaped gradually. The artifact should not be forced; it should be opened out or its shape adjusted in stages, with conditioning during or between stages.

Flat artifacts like mats, barkcloth sheets, and flat textiles, are usually laid flat between blotters and covered with thick papermakers' felts or several layers of heavy blankets. If additional weight is needed, thin plywood or Masonite sheets can be placed on the padding and weighted with sand bags; glass plates are also used if great additional weight is needed. Care should be taken not to apply too much weight, or the object will become unnaturally flat and slightly high areas could be crushed. Felt pieces, sand bags, and small glass plates are useful for flattening locally.

Three-dimensional artifacts can be blocked with foam blocks and collars, styrofoam bead bags, crumpled tulle, polyester wadding, balloons, sand and lead-shot bags, gentle clamping devices—whatever suits the particular shape and strength of the object. Any weight on the interior of the artifact should be balanced by an equal support on the exterior, and vice versa. Undue force should not be exerted on the artifact in an effort to block stubborn areas; it is better to live with a distortion than to risk fracturing an object in an attempt to alter it. The artifact surface should be protected from abrasion and foreign particles with tissue paper, thin blotter, or cloth.

## Reshaping Using Solvent Plasticization

In this method, the artifact is conditioned to allow the materials to be safely moved to a new position. The artifact is then blocked to hold that shape until the conditioning solvent is fully dissipated. Drawbacks of this method include some inevitable alteration of the material with exposure to the conditioning solvent. Whether this alteration is significant would depend on the condition of the artifact and on whether the artifact had been exposed to those vapors before. For example, another brief exposure to water vapor may make relatively little difference to a woven floor mat that has spent most of its life in a high or fluctuating relative humidity environment and that had been washed periodically by its original users.

## Reshaping Using Passive Deformation

Artifacts are frequently distorted in display and storage if they are inadequately supported. This occurs as the force of the weight of unsupported areas causes slow movement which, in turn, is allowed by the movement of water molecules in the plant tissue (refer to the section in Chapter 4 on Physical Deterioration). This same process can be used to advantage in the reshaping of artifacts that are not in an extremely degraded condition. The process takes much longer than using solvent plasticization to condition the artifact. However, it involves no more of the conservator's time and is less traumatic for the artifact.

Artifacts are blocked or supported in storage in such a way that distorted areas are encouraged to gradually move back into their original position. The shape is gradually adjusted through periodic adjustments to the support as movement occurs. For example, sections of Egyptian mummy casing were reshaped over a period of twelve months. The originally convex-shaped sections had been crushed and flattened through poor storage. They were placed on tissue paper and a flat tray. Cotton wool wads were inserted between the tissue and the tray, periodically adding more wads until the proper shape had been achieved.

## Deacidification

Acids attack cellulosic and other components of plant tissues resulting in a weaker and more brittle material, more susceptible to further deterioration (refer to the section in Chapter 4 on Chemical Deterioration). Most plant materials used to make artifacts are naturally somewhat acidic and can become more acidic through manufacture, use, and poor storage.

Most research on deacidification has occurred in the field of paper conservation, and its application to other fields has been considered by textile, painting, and objects conservators. Deacidification of cellulosic fibers in paper has been achieved either by removing or by neutralizing acids present in the paper (refer to paper conservation literature for materials and methods applied to paper).

Removing acids is usually done by washing the paper in water. As discussed in the sections on Reshaping and on Consolidation in this chapter and in Chapter 4, immersion in water causes considerable swelling across the grain of plant materials, leading to crushing of interworked elements, and causes degradation and extraction of components of plant tissue. Thus, removing acids from most plant material by washing can not be generally recommended. Exceptions might be made in some cases for artifacts in which fibers have been extracted or highly separated, like some textiles, barkcloth, and cordage. These artifact types have been successfully washed, and in some cases alkaline buffers have been applied in aqueous baths. The benefits to be gained by removal of acids must be weighed against the arguments against washing.

In some cases, removal of harmful acid by washing may not be effective. Erhardt and Firnhaber (1987:227) note that the dicarboxylic acids produced by the oxidation of unsaturated fatty acids present in oiled Hawaiian tapa are bonded to the oil matrix and cannot be washed out.

Neutralizing acids takes place either by introducing particulate buffering alkaline agents or by exposing the paper to neutralizing vapors. The introduction of particulate buffering alkaline agents to plant materials in general has the following drawbacks:

1. Depositing or precipitating particulate matter in the cells and in the cell walls may cause structural damage to the cell.
2. The agents are applied in solution in water or alcohol. Water is not recommended for most plant materials for reasons mentioned earlier. While many artifacts apparently can be safely exposed to alcohol spray or bath, the patina, dye, paint, and applied decorations of many artifacts could be damaged by this

exposure. Clavir (1976) noted damage to element sheen and to some dyes of baskets tested.

3. Adequate penetration of the buffering agent through dense epidermal and fiber bundle layers of the plant material has not been confirmed. A sprayed application is not likely to penetrate well, except around highly separated inner bark fibers or extracted monocot fibers. Immersion application could be successful. Clavir found that the pH of plant elements deacidified by immersion techniques was raised from a pH ranging between 3.0 and 5.2 to a pH ranging between 5.0 and 7.4. However, it was not determined whether this rise represented an increase in pH throughout the element or just in the outer layers.

Clearly, further work is required on deacidification by the introduction of buffering alkaline agents. However, even if good penetration could be achieved, the number and type of artifacts that could safely be exposed to spraying or immersion in water or alcohol are very limited.

Neutralizing acids by vapor-phase deacidification may be more promising, since full penetration of a vapor should be more easily achieved. Kronkright (1981) reports satisfactory results using bicarbonate of cyclohexylamine vapor. Bicarbonate of cyclohexylamine vapor is also used with metals as a vapor-phase corrosion inhibitor, but is not felt to have residual effect; inhibition ceases once the metal is removed from the vapor (Pearson 1987). The mechanism of acid buffering on cellulose may be somewhat different from that of corrosion inhibition of metal and so may have a permanent effect, but this requires confirmation. Kronkright (1987) has discontinued deacidification treatment of baskets due to concern over the effect of alkaline environments on plant materials. Clavir (1976) reports that 10% ammonia vapor did not achieve a permanent increase in pH and that it darkened plant fibers.

Deacidification treatments were developed primarily for the treatment of paper, and may be applicable to artifact types such as some barkcloth and textiles in which plant fibers have been extracted and processed to remove some noncellulosic components. With most artifacts of plant materials, however, we are concerned with materials that are much more complex in structure and composition than paper. The processes of removing acids and introducing neutralizing buffers may themselves cause damage. Many plant material components are subject to degradation in alkaline environments (refer to Chapter 4 and references cited therein). Further examination of deacidification and buffering of plant materials is necessary to determine:

- pH tolerance of specific plant materials
- effects of deacidification on noncellulosic components
- degree of penetration of alkaline buffers and neutralizing vapors by pH measurement of sections through the thickness of plant materials
- permanence of vapor-phase neutralization

## Consolidation and Restoration of Flexibility

Material that is friable, highly fragmented, or splintered may require consolidation to prevent loss of material and/or to strengthen areas that require mending or are load-bearing. Consolidation may involve holding fragments together by the addition of external support material. For example, mat and textile fragments may be sandwiched between two layers of fine gauze stitched together around the fragments. This type of consolidation is essentially a mending technique and is discussed in the sections on mechanical and adhesive mends.

The treatment generally referred to when discussing consolidation involves the introduction of a binder to hold friable, fragmented, and splintered material together. The principle is to introduce enough binder to adhere fragments together, but not enough to alter the material appearance. Alteration of the appearance usually consists of darkening or surface gloss.

Darkening and surface gloss can be caused by allowing the solvent in which the consolidant is dissolved to evaporate too quickly, thus drawing the consolidant to the surface. Besides resulting in darkening and gloss, this also results in poor internal consolidation and the formation of a highly consolidated skin. The selection of a slower evaporating solvent and/or the use of a chamber to slow evaporation of solvent should remedy this. Darkening and gloss can also be caused by using a consolidant of too high a concentration and/or viscosity. Such a consolidant cannot penetrate into the material and merely forms a surface skin. Darkening and gloss can also result from the application of too much consolidant. This fills the voids around particles rather than coating and adhering the particles, thus saturating the color of the material. Some stiffening of flexible material usually occurs with consolidation. When post-consolidation flexibility is desirable, and a lot of consolidant is necessary, consolidants that are not rigid on setting should be used (that is, consolidants having low glass-transition temperatures or low molecular weights). Thus, successful consolidation depends on the choice of consolidant and solvent, the amount used, and the methods of application and drying. Because artifact materials vary considerably, thorough pretreatment testing on unprominent areas of the artifact or on similar material is necessary to avoid disfiguration.

If a consolidant is used that remains resoluble over a long period of time, consolidation is theoretically reversible. Practically, this is often not the case. Dissolution and extraction of the consolidant, which usually requires immersion of the artifact in a solvent bath, may not be possible or safe for the whole artifact. Since most consolidation cannot be considered a fully reversible treatment, every effort should be made to select consolidants having excellent aging properties. Also, consolidation should be used only if no other alternatives, such as restrictions on handling or supportive mounts, are possible or feasible.

In the case of resinous material, consolidation may also be done by reforming—partially plasticizing the resin with solvent until the fragments are soft enough to slump together. This may be done by applying the solvent locally with a brush or poultice, or by placing the artifact in a vapor chamber. The amount of solvent or concentration of the solvent vapor and the time of exposure vary considerably with resin type and quantity. Prior testing of resin fragments is recommended to ensure

that the desired degree of reforming occurs. Reforming may be only a temporary measure, as cracking often recurs eventually. Still, repeated reforming may be preferable to the addition of a foreign material to the artifact.

## Local Consolidation

The ends of elements of basketry may be crushed and splintered. This occurs most frequently at element ends exposed at the rim or base, and along break lines. This may result in loss of fibers and splinters, and—if the loss occurs at a break line—may make the elements too weak to be safely joined. The edges of thick, porous monocot leaves and stems are also found similarly crushed and frayed.

In such cases, it may be desirable to consolidate and strengthen these ends and edges. Consolidants that have been used include acrylic resins (Acryloid B-72, 5% to 20% w/v solutions in toluene, xylene, or diethylbenzene), polyethylene glycol waxes (mixtures of PEG 1500/PEG 4000, 10% to 20% w/v in ethanol), and methylcellulose (Methocel A4C, 1% to 2% w/v in water/ethanol 3/1). The element ends should be straightened before or during the application of consolidant, and the splintered ends may need to be manipulated together after application and during drying. Several applications of the consolidant may be necessary.

Some other types of plant materials may require consolidation of friable or fragmenting areas and of broken edges prior to joining.

The dense exterior layer (hypodermis) of the gourd wall gives rigidity and strength to the gourd even if the large-celled mesocarp is weak and brittle. As the hypodermis is thin, however, mending of broken gourds depends on adhesion along the mesocarp. If the mesocarp is brittle and friable, consolidation may be necessary to establish a sound mend. Selected acrylic resins (such as Acryloid B-72, 10% to 20% solutions) penetrate and consolidate well and do not interfere with adhesion as waxes may. They are applied by brushing dilute solutions onto the surface of the edges to be joined (repeat when dry as necessary).

Plant resins and resin cements (resin plus fillers such as plant fibers and fragments, hair, and earth) may become finely fractured and fragmented, possibly due to embrittlement from slow loss of volatile terpenes (essential oils) and fine fracturing with shock and abrasion. Fragmenting resin and resin cement on Australian Aboriginal tools and containers have been consolidated with methylcellulose (Methocel A4C and A15C, 1% to 2% w/v in water). The tip of a pointed brush loaded with the solution is touched to the surface and the solution is allowed to be drawn into the fragmenting areas. Application is repeated as necessary after drying. A water-soluble consolidant was chosen to prevent softening of the resin during application or removal of the consolidant. Cornu and Heuman (1982) successfully treated cracked reinforced tree resin boards from New Guinea by reforming. The resin at the cracks was reactivated with small quantities of solvent applied to the cracks. When tacky, the cracks were drawn together. When dry, the resin remained bonded. Small fragments were consolidated with poly(vinyl acetate) emulsion (which would, however, require nonaqueous solvents for the future removal of the consolidant). Direct application of solvents and consolidants may cause apparent darkening. In many cases, this seems to be caused by the washing away of fine surface dust lightly

held by the resin, leaving an area that reflects light less diffusely than the dirty areas. Local reforming using solvent vapor could avoid this. A small vapor chamber is made over the area. This chamber contains blotters moistened with solvent which are prevented from touching the resin with several layers of polyester screen.

The fragments of the outermost portion of adventitious roots of carved tree fern trunk are easily dislodged when old and dry, and exposed roots easily break off with movement and handling. Consolidation is difficult because the dense roots do not allow penetration of consolidants into the roots themselves, and the intermeshed structure of the root mass often provides few points of contact for adhesion between roots. Adequate consolidation of the interior has been achieved by injecting consolidant (Methocel A4C, 3% w/v in water and ethanol) below the surface using a syringe with a large-bore veterinary needle. After drying, application was repeated until adequate consolidation was achieved. Methylcellulose imparted greater strength and considerably less darkening than the acrylic and vinyl acetate resins tested. Where appendages have been inserted into the trunk, considerable loss of root fragments has often occurred, and consolidation may need to be augmented with a filler putty of methylcellulose and sawdust (Methocel A15C, 8% w/v in water, with sawdust added until a thick, damp putty is formed) to provide adequate seating for the appendage. Consolidation of exposed, visible surfaces remains a problem, as coating of roots sufficient to achieve adhesion to each other causes some darkening.

Coconut-fiber cordage presents a problem similar to that of tree fern trunk roots because the fibers are thick, very dense, become brittle with age, and the fibers in cordage are not densely packed. Attempts to consolidate sennit using resins in solution and pastes have not proved physically or visually satisfactory.

The dry and brittle remains of the palm leaf petiole are inherently insecure. The remnants of parenchyma tissue between fibers are lost with handling and movement. The fibers are widely spaced and brittle. Because of its open structure, consolidation is difficult. Spraying with methylcellulose (Methocel A4C, 0.5 to 1.0% w/v in water and ethanol following a pretreatment of sprayed water and ethanol) has been more successful than spraying with other consolidants tested. However, this has not been fully successful; only the smaller fragments could be fixed to the fibers. Greater quantities of consolidant fixed the larger fragments, but resulted in noticeable darkening.

## Consolidation of the Whole Artifact

Degradation can be so severe throughout the artifact that the artifact is too weak to support itself or to be handled and mended. In such cases, consolidation of all the fibers may be necessary to restore internal strength.

For some plant materials, certain consolidants have been found to be inappropriate for full consolidation by immersion. Kronkright (1981) reports that some synthetic resins caused color change and rigidity to baskets. Tworek (1985) found that Paraloid B-72 (an acrylic resin), Revacryl 452 (an acrylic colloidal dispersion), and Methocel A4C (a methylcellulose paste) imparted color and texture changes and made pandanus leaf strips overly stiff and brittle.

Leechman (1944) comments on materials used to impart some strength and resilience to brittle fibers: celluloid did not impart enough tensile strength, beeswax applied in turpentine was better but had some drawbacks. He suggests that fibrous material be soaked for two weeks in a solution of 59% glycerine, 40% water, and 1% formaldehyde following pretreatment of immersion in water for 24 hours.

Bakken and Aarmo (1978) used 10% PEG400 in water applied with cotton swabs to pandanus leaf strips that were well wetted as a result of washing by immersion in water. Considerable swelling of the leaves when wet was noted. The treatment was designed both to consolidate and to restore flexibility.

Kronkright (1981) reports success in consolidating basket elements using medium-molecular-weight polyethylene glycol waxes. The basket was immersed in 15% PEG 1000 and 2% PEG 4000 in methanol and held under a vacuum of 5" Hg for several hours. The basket was then dried in a methanol vapor chamber. Strength and flexibility were recovered and no color and texture changes were noted. No swelling of the plant fibers was observed.

Byrne (1984) consolidated the degraded barkcloth on an Easter Island effigy figure by applying 5% PVA AYAF, a poly(vinyl acetate) resin.

Allington (1986) used hydroxypropyl cellulose (Klucel E) and polyethylene glycol wax in water to consolidate artifacts of grasses and cordage. The artifacts were immersed in a bath of 2% to 3% Klucel and PEG 550 for periods of several hours to several days. Reshaping was done during immersion and drying.

The Canberra College of Advanced Education Objects Conservation Laboratory, in 1986, briefly examined the appearance and effectiveness of consolidation of samples of several woven plant materials using methylcellulose (Methocel A4C) and polyethylene glycol waxes (PEG 1500 and PEG 4000). Plant material included fine palm leaf strips, loosely spun unidentified dark fibers of very fine to large diameter, and *Pinus palustris* needle fibers with considerable quantities of nonfibrous tissue remaining with the fibers. The unidentified fibers and the pine needle fiber samples were both fairly brittle, and fiber fragments and nonfibrous tissue fragments were readily dislodged with gentle handling. Samples were immersed in the consolidant solution, held at 25" Hg vacuum for 2 hours, and dried slowly in ethanol vapor. Methocel A4C in 0.5%, 1%, 5%, and 10% w/v solutions in ethanol caused stiffening, but no color change, in all samples. Consolidation was ineffective in the 0.5% and 1% concentrations. The 5% and 10% concentrations secured only the finest fiber and nonfiber fragments and resulted in thick deposits of consolidant on fiber surfaces and between fibers. Other fibers remained easily dislodged. PEG 1500 and PEG 4000 combined in 30% and 4% respectively, 15% and 2%, 10% and 1.3%, and 7.5% and 1% w/v solutions in ethanol imparted some stiffness to all samples, and, in the fibrous samples, slight to severe darkening with increasing concentration. The lower concentrations, with only slight darkening, secured only the finest fiber and nonfiber fragments. The higher concentrations, with moderate to severe darkening, were somewhat more effective in securing fragments and fine fibers, but resulted in some gloss and the deposit of consolidant between fibers.

Firnhaber (1986) reports on efforts to find a consolidant to reduce brittleness of oiled Hawaiian tapa. Impregnation with PEG 1000 regained flexibility, but

resulted in some color change for a period of two years. Impregnation with Klucel H resulted in stronger, thicker tapa which, however, had not regained flexibility.

Given the swelling occurring with aqueous applications, treatment using nonaqueous solutions would appear to be safer to use if consolidation is necessary. Since it is quite likely that components of the plant material may be leached out in immersion baths (see Florian 1977), the time of immersion should be kept to a minimum. It would seem that successful consolidation depends very much on the character of the plant material, with close, fine fibrous and nonfibrous materials much more successfully consolidated than coarse, dense fibrous materials.

The work of Kronkright (1981) and Tworek (1985) indicates that the method of application is important if adequate penetration into basketry elements and pandanus leaf strips is to be achieved. Kronkright's consolidant was applied by immersion in a solution bath under vacuum (5" Hg for several hours). Tworek found that best penetration was achieved by pretreatment of the leaf strips in an ethanol bath under vacuum (24" Hg for one hour) followed by immersion of the leaf in the 10% v/v solution of PEG 200 in ethanol under vacuum (24" Hg for one hour). Penetration was slightly less if the leaf was not pretreated. Application by: (1) one- to two-hour immersion in the solution, and (2) immersion of the end of the leaf in solution allowing the solution to be drawn into the leaf by capillary action, produced acceptable but incomplete penetration. Application by brushing the solution onto the epidermal and cut edge surfaces of the leaf resulted in very little penetration.

It would appear, then, that effective penetration of consolidants into some plant materials can be achieved only if the object is subjected to prolonged immersion in nonaqueous solutions, preferably under vacuum. This would limit treatment to moderately small objects without elements or decoration that are sensitive to prolonged exposure to ethanol or that would be damaged by the air bubbles emerging from the leaf under vacuum (as many paints, resins, and patinations might be). The potential for degradation and leaching out of plant material components during immersion in ethanol should also be considered.

Since many artifacts of plant materials may not be able to undergo consolidation by these methods because of dyes, paints, or applied decoration, and since the application process and the presence of consolidants, such as oils and some waxes, promote degradation of plant material components, other approaches bear consideration. Sandwiching between fine cloth, such as silk crepeline or Stabiltex (polyester crepeline), might be appropriate. Lining with heat-reactivated tissues or with Japanese paper and paste, or constructing padded contoured mounts might adequately support the artifact. Strict handling conditions could be imposed. Some artifacts may need to be well packed for dead storage until such time as an appropriate treatment may be developed.

**Restoration of Flexibility**

Most nonrigid elements can be temporarily conditioned to allow reshaping. As soon as the conditioning agent evaporates, however, elements are again as stiff or as brittle as they were before relaxation.

Attempts have been made to permanently restore flexibility to stiff and brittle elements. Some methods add an oil, which also acts as a mild insect repellant.

Other methods add low-molecular-weight humectants (materials which are hygroscopic) to the fibers.

The following is a summary of treatments published in the conservation literature. (These methods are not necessarily recommended. Refer to Chapter 4, Chemical Deterioration from Pollutants and Previous Treatment.)

Crowley (1969) used 5% v/v oil of camphor in methanol brushed on palm leaf manuscripts. Agrawal (1984) used oils of camphor, citronella, and lemon grass wiped on palm leaf surfaces; excess oil was wiped off after a few minutes. He cautioned that too much oil or too frequent oiling leads to a build-up of tacky oil and dust, leading to possible discoloration of the leaf. Marsh (1980) used 5% oil of camphor in methanol, brushed on palm leaf surfaces, for manuscripts in tropical climates, and 2% PEG 100 in water, brushed on, for palm leaf manuscripts in other climates.

Bakken and Aarmo (1978) used 10% PEG 400 in water applied with cotton swab to pandanus leaf strips that were well wetted as a result of washing by immersion in water. Considerable swelling of the leaves when wet was noted.

Schaffer (1976) used a solution of 25 g PEG 600, 20 g glycerine, and 55 g ethanol/water (7/2). The solution was brushed onto a basket daily until the desired properties were restored.

Tworek (1985, 1987), in experiments to examine the feasibility of improving flexibility, found that both 10% v/v PEG 200 in ethanol and 10% v/v glycerol in water, applied by vacuum immersion and capillary action, imparted improved flexibility to monocot leaf strips (pandanus). Glycerol produced the greatest improvement; however, darkening of some areas of the leaf occurred, and, because it was water based, considerable swelling occurred across the grain of the leaf. The PEG 200 produced slightly less improvement in flexibility, but there was no darkening, and because it was not applied in water, swelling was negligible. Other materials which were felt to have lubricative properties (PEG 1500) or which formed flexible films (BEVA 371, Revacryl 452) were also tested, but were found unsuitable; if penetration was achieved, the leaves became stiffer.

Firnhaber (1986) reports that PEG 1000 regained the flexibility of brittle oiled tapa, but resulted in some color change for a period of two years. Impregnation with Klucel H did not increase flexibility. Erhardt and Firnhaber (1987) report that PEG 1500 made brittle oiled tapa more flexible.

From these reports, it would appear that impregnation with low to medium molecular-weight humectants can improve the flexibility of some plant materials. Why they should do so is not clear. The presence of humectants would raise the moisture content of the material, but that does not necessarily mean that the moisture content of the cell walls is raised. If the humectant is located primarily in the cell lumens or in leaf lacunae, the moisture would be primarily held there. The high attraction of water to the humectant could actually desiccate the cell wall in medium- to low-relative-humidity environments. Or, it may be that, if the humectants achieve penetration into the cell walls and into the middle lamella, they may function by physically blocking the amorphous cellulose, hemicelluloses, and intercellular cementing substances from drawing together and bonding during drying. This blocking would reduce the rigidity of the tissue.

Good arguments can be made against adding humectants to artifacts. Humectants on the surface of the artifact would attract dust in periods of high relative humidity. The process of introducing the humectant involves soaking the artifact in aqueous or nonaqueous solvents (sometimes under vacuum), exposing the material to the associated swelling of fibers and dissolution of components. Tworek also found that severely degraded areas of pandanus leaf absorbed more humectant than stronger areas, and blotchiness resulted as the higher humectant concentration caused darkening of those areas.

Improving the flexibility of plant materials could be of benefit in cases where stiff elements would break when artifacts are handled and where elements are flexed in the normal course of examination, storage, and display. However, it may be safer to restrict the use of the artifact. Most artifacts, even though they were supple when originally made and used, do not need to be supple in a museum environment.

## Mending

Mending involves the joining and reinforcement of cracks, breaks, and areas made weak or insecure through degradation, use, or abuse. Mending may be necessary to prevent further damage of the artifact from occurring. For example, splintered rattan strips that support large contour feathers radiating from a figurine should be mended to prevent further splintering of the rattan and damage to the feathers. Damage need not be mended if cracks or weak areas do not reduce the stability of the artifact and are not themselves likely to become worse. Mending may also be desirable for aesthetic reasons. It may not be necessary to join the parts of a broken figurine, for example, but the study and appreciation of the artist's intent may be difficult or impossible if the figurine is not intact.

To preserve the visual, structural, and functional integrity of the artifact, mends must unite the artifact as accurately as possible. For example, the horizontal elements of a twined basket with a split from the rim should be individually and correctly aligned; broken warp threads of a warped backstrap loom should pass through the heddles and shed rods as originally intended. With severely broken artifacts, it may not be initially obvious how parts are related. Mending should only be done after thorough examination of the artifact itself, and study of related artifacts and relevant literature.

Mending may not necessarily be possible or desirable. For example, a small wooden shield which had completely split longitudinally in the past had subsequently warped out of alignment. Forcing the halves into alignment would place great stress on the wood, and further splitting or release of the mend would probably result. If the halves were humidified and held in alignment under pressure while drying, warping would probably recur with the release of pressure and the wood's response to ambient humidity. It would be safest in this case to use supportive mounting, such as clipping the shield halves to a support contoured to fit the back of the shield, rather than mending. The wood would not be stressed, yet the shield would regain much of its original appearance.

As far as possible, mends should be made using stable materials and materials that can be reversed with no damage to the artifact. "As far as possible" becomes

the operative stricture in practice. The best we can do in our choice of mending materials is to try to use those that, from aging tests, aging characteristics predicted from the probable chemical mechanism of deterioration, and aging characteristics observed in practice over the years, are the least unstable and/or deteriorate in a manner least likely to damage an artifact. Reversibility with no damage to the artifact is probably not entirely possible with adhesive mends. Complete removal of all adhesive which has penetrated into a material is often not practically possible. Solvents applied to materials of such mixed composition as plant tissues are bound to cause some alteration. One can only choose solvents based on the educated guess that they will cause the least change, and adhesives and methods of application that can be removed most efficiently.

As far as possible, mending methods chosen should be those least likely to cause permanent alteration of the basic fabric of the artifact. Given the alteration inherent in applying and reversing mends using adhesives and solvents, mechanical mends would be the best choice if this criterion only were considered, since they can be applied and reversed with no alteration of the material of the artifact. However, the choice of method is more immediately dictated by the artifact construction, location of the damage, and the condition of the materials. Where mechanical mends cannot safely or effectively be used, adhesive mends are necessary.

The choice of mending technique may also depend on the intended use of the artifact. Two Egyptian coffins, for example, were mended with very different techniques, because one was to be used as a study piece and one was to be displayed in an art gallery. The original resinous cement and spline joins of the study piece had failed and had not been contaminated by subsequent mending and restoration. This piece was mended using unadhered dowels, so that the coffin could be dismantled for study and analysis of the original construction techniques and materials. The piece for display was already significantly and permanently contaminated with unsuccessful previous repairs. In order to make the wood structure secure enough to allow restoration of the surface linen, ground, and paint, it was mended with adhesive and losses were filled with carved wood blocks and adhesive putty.

Mends should be compatible in strength with the artifact. Ideally, the mend should be strong enough to give the artifact the required support, yet be weak enough to yield under stress before the artifact does.

Mends should be visually subtle, yet should be discernible upon examination of the artifact. For this reason, it is worth considering the use, whenever possible, of repair materials different from those of the original fabric of the artifact, and different from materials known or likely to have been used in native repairs. Unfortunately, because of the nature of many artifacts, some of the safest and most effective mending materials are quite similar to those of which the artifact is made. This makes detailed documentation of treatment all the more important.

General mending techniques include the following:

**Mechanical Mends:**

- sewing, tying, binding
- splints
- packing

### Adhesive and Reinforced Adhesive Mends

- adhesive applied in solution/dispersion
- adhesive alone
- adhesive putty
- adhesive used to adhere threads, patches, and linings
- adhesive reactivated by heat or solvent

## Mechanical Mends

Mechanical mends involve the use of thread or strands to sew, tie, or bind elements together and splints to hold elements together and provide support. They are most suited for mending composite, basketry, and cordage constructions where elements are interworked to create or bind a structure. They can be used only where a structure is open enough to allow passage of a needle, thread, splints, and so on, where undue stress will not be placed on the elements, and where elements are strong enough not to be cut by thread. When mechanical mends have been properly positioned so that artifact elements are not distorted or stressed, abrasion and cutting of elements have not occurred.

The mending material should match the general color tone of the area to be mended so as not to be visually obtrusive. Material not available in suitable colors can by dyed or stained to achieve the desired color (see Appendix 4, Dyeing Cellulosic Materials with Fiber-Reactive Dyes).

The following materials and techniques are examples, not rigid rules to be followed. A fair amount of ingenuity may be called for when designing mechanical mends. Basic methods must be adapted to suit the construction of the artifact, the location of the break, and the kind, size, and condition of its elements.

### Sewing, Tying, and Binding

Usually, threads of a diameter and color appropriate for the size and color of the construction elements are used. Threads of a medium angle of twist are best. A thread of a tight angle of twist easily crimps and so is difficult to work with, and it may contract in length too much with great increase in relative humidity. A thread of a loose angle of twist tends to fray easily. Size 50 mercerized cotton sewing thread is most commonly used. (Size 50 polycotton and polyester sewing threads also appear to be appropriate.) Cotton embroidery floss and machine embroidery thread can also be used where lower abrasion resistance can be tolerated. For very fine constructions, silk thread or very fine polyester thread (unravelled from Stabiltex) may be less conspicuous. For larger, heavier constructions, crochet cotton, cotton cord, or linen thread may be necessary. Paper strips, nylon packing cord, and plant materials such as raffia, which are available from many hobby and craft shops, are useful where a broader binding material is necessary or desirable.

Slade (1985) studied cotton, polycotton, polyester, and nylon monofilament threads to compare their strength and their cutting/abrasion action on basket materials (pandanus and palm leaves, and rattan stem). She found that polycotton and polyester threads had greater tensile strength than cotton, but that threads of comparable diameters had no discernible differences in cutting/abrasion action. Nylon monofilament showed very high tensile strength, as it elongated considerably

before breaking, making it unsuitable for purposes where considerable weight or other tensile stress is involved. The abrasion resistance of threads decreased with decreasing tightness of the angle of spin. No conclusion could be made on the effect of thread diameter on cutting/abrasion action. Threads of all fibers, diameters, and twist compressed rather than cut the basket materials. The degree of compression, and of fracturing if it occurred, seemed to depend more on the density and amount of degradation of the basket material than on the strength, diameter, and angle of twist of the mending thread. On experimental samples of monocot leaf and stem, considerable pressure and many back-and-forth movements of the thread were necessary to produce compression.

*Binding and/or Joining Elements*

Broken spun and plaited cordage easily unravels and may need to be wrapped or tied to prevent this from happening. Loose, unfinished cordage ends may be found unravelled as a result of precollection use. If further unravelling seems likely, the cordage should be tied just below the unravelled portion. Joining broken ends or attaching ends to a restoration or mending thread can be done by wrapping or whipping. Techniques used for these mends are illustrated in Figure 5.13.

*Securing Adjacent Elements and Cordage*

Insecure wrapped cordage and broken elements can be stitched and tied together and to adjacent sound elements. For example, a type of Australian Aboriginal knife sheath is made by closely wrapping rolled sheets of paperbark with hair string. The paperbark crumbles easily and the last five to ten rows of string often become loose. They cannot be secured by stitching or adhering them to the paperbark or to an inserted substrate. There is room, though, to insert a needle and thread under and

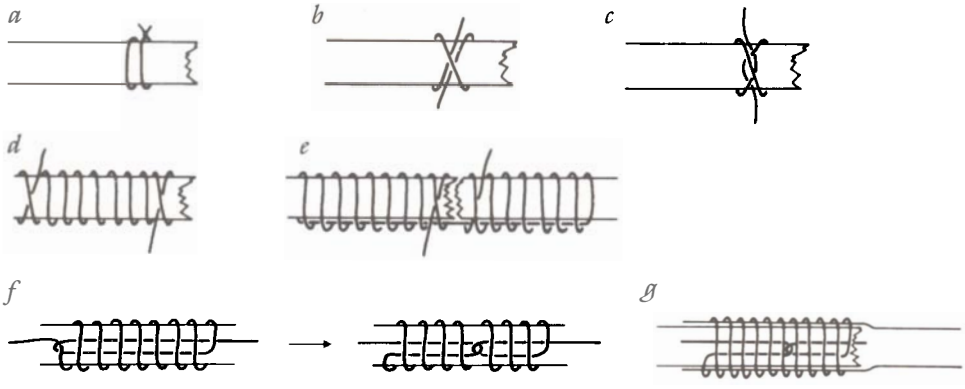



*Figure 5.13. (a) Overhand knot securing unravelled end. (b) and (c) Half hitches securing unravelled end. (d) Wrapping and half hitches securing end. (e) Wrapping and half hitches joining broken ends. (f) Formation of whipping. (g) Whipping securing restoration cord that has been unravelled to encase broken element end.*

*Figure 5.14. Tied loops.*

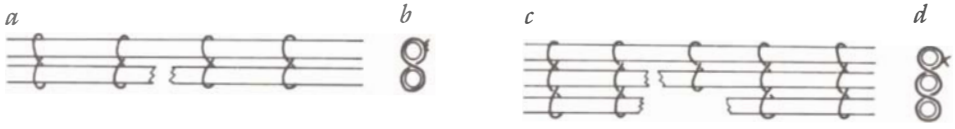



*Figure 5.15. Figure-eight stitches, (a,c) front view and (b,d) side view.*

between them to couch them together and to several of the adjacent secure rows. Horizontal breaks on some coiled basketry structures have been successfully secured with figure-eight and couching stitches. These techniques are especially useful when the foundation element is large or when the active elements almost completely cover the foundation, making adhesive and adhered patch mends less suitable.

Single-tied loops (Figure 5.14), figure-eight stitches (Figure 5.15), and couching (Figure 5.16) are used. If a number of elements are to be secured together, or if it is visually important to have the mending thread visible over only one element at a time, figure-eight or couching stitches are more appropriate. Couching provides better support and less chance of squeezing the elements. When securing broken elements, at least two stitches should be placed at either side of the break, so that the possibly weak broken ends do not bear the full weight of the elements.

*Securing Parallel but Widely Spaced Elements*

The basic stitch (Figure 5.17) is suitable for open wrapped coiled constructions where the passive element is horizontal. For open twined constructions, where the passive element is vertical, the securing thread must go at least two horizontal rows on either side of the break. Otherwise, the row of twining near the break is likely to be pulled off the ends of the vertical elements. As shown in Figure 5.18, either (a) secure the two rows on either side of the break with the basic stitch (step 1), then secure the rows across the break (step 2), or (b) use a variation wrapping stitch that joins several rows with one thread.

*Reinforcing Cord, Fabric, and Plastic*

Badly broken or weak materials may require attachment to a cord, fabric, or plastic reinforcing material.

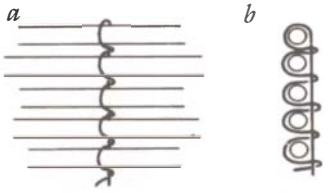



*Figure 5.16. Couching, (a) front and (b) side view.*

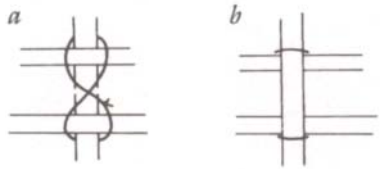



*Figure 5.17. Basic figure-eight stitch for securing elements, (a) back and (b) front view.*

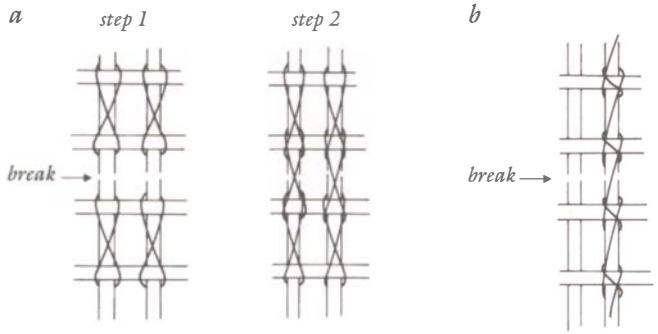



*Figure 5.18. Securing elements with (a) figure-eight stitch and (b) wrapping stitch.*

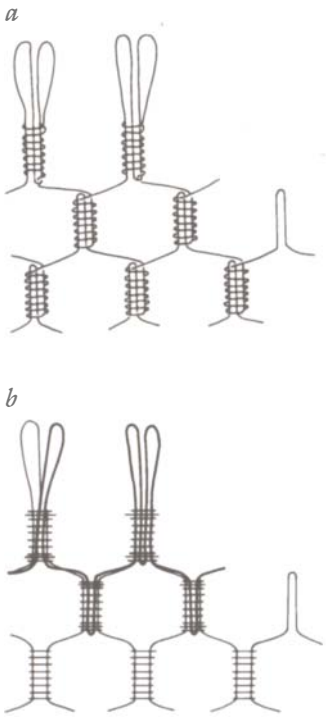



*Figure 5.19. Mechanical mend of Hawaiian* koko *using cordage. (a) Schematic diagram of* koko *knot. (b) Diagram of interior face of knotting showing position and attachment of cord used to reinforce knotting and replace loops.*

**Cord.** Reinforcing cord may be used behind artifact cordage or within narrow hollow elements.

A Hawaiian ***koko*** (a knotted cord sling used to cover and suspend vessels such as gourds) was constructed of knotted and wrapped coconut fiber cord and *olona (Touchardia latifolia*) bast fiber cord. A hemispherical shape was made with successive rows of knots starting from the center. Cord looped through loops on the last row of knots was gathered and bound to form the handle. The handle, loops, and last row of knotting were made of two-ply spun coconut fiber that was very brittle and broken and had been lost from many areas. The *olona* cord used for the rest of the *koko* was in good condition. Since the *koko* and the gourd it contained were to be displayed as used—that is, hanging from the handle—it was necessary to mend and restore the coconut fiber cord in such a way that it would be functional. It was decided to back the first two rows of knotting with a reinforcing cord, extending it to replace lost loops where necessary. In this way, the weight of the gourd and *koko* would be fully carried by the reinforcing cord and the *olona*. So many handle cords were missing that the cord used to replace missing cords would relieve any stress on the original cords. Two-ply cotton cord of the same diameter and spin of the coconut fiber cord was dyed to match its general color tone. The cord was bent and tied to the *koko* with size 50 cotton thread, as illustrated in Figure 5.19. Because two-thirds of the handle binding was replacement of lost binding, most replacement handle cords could be secured by the handle binding. Where original cords were broken outside of the area bound, they were adhered to the replacement cord ends with a poly(vinyl acetate) resin adhesive.

The Maori *piupiu* is a skirt made of *Phormium tenax* leaf tubes. The leaves are scraped in areas and dyed. During drying the leaves curl longitudinally, resulting in a narrow tube with sections of whole leaf in natural tan and sections of exposed leaf fibers dyed black. When old, the tubes are very fragile due to the brittle and weak black fibers; they become fragmented when the black fibers break. A spun cord or strand of raffia dyed black, or black nylon packing cord can be strung through the tube fragments, or through weak tubes. To keep the correct spacing of the tube sections, the tan tubes may need to be packed with cotton wool or tissue paper.

**Fabric.** A whole artifact or section of an artifact may be so weak or fragmented that overall support or protection is necessary. This goal may be achieved by lining, overlaying, or sandwiching the area with fabric. If sheer fabric such as silk crepeline or polyester gauze is used, dyed to the general color tone of the area, artifact design and construction details are still clearly visible and the fabric does not significantly alter the visual appearance of the artifact. As with all mechanical mends, mechanical application of the fabric by stitching should be done only if the artifact construction is open enough to allow passage of needle and thread.

Barton (1986a) sandwiched cloth on a Maori kite—which had been previously consolidated with polyurethane and was now fragile and brittle—between Stabiltex cloth secured with quilting stitches.

Hawaiian dog-tooth leg rattles are constructed of canine teeth pierced through the root and threaded into knotted strands, which are secured side by side with horizontal tacking stitches to form a mat of projecting teeth about 20 cm by

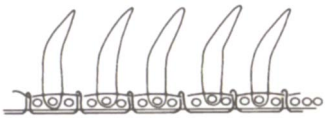


*Figure 5.20. Couching of dog-tooth rattle to backing fabric.*

30 cm in size. The weight of the teeth plus abrasion to the thread results in weak and broken threads with subsequent loss of teeth and general structural insecurity. If damage is not severe, the threads can be repositioned and secured, and the strands secured together, by tying weak threads to adjacent strong ones with size 50 cotton thread. If damage is extensive, this must be followed with further reinforcement to make the rattle strong enough to handle. In the treatment of one rattle, this was done by couching the rattle onto a piece of silk crepeline. The crepeline was secured without tension to a stretcher, and the rattle placed face up over this. A cotton thread was placed vertically, crossing over the strands, between teeth. A second cotton thread was stitched under the crepeline below the strands and over the thread between the strands (Figure 5.20). Rows of couching were placed at 4 cm intervals over the rattle. The crepeline was finally cut from the stretcher, and its edges turned and stitched over the edges of the rattle. This treatment allowed the rattle to be handled and displayed, and still allowed the construction of the rattle to be clearly visible from the reverse side.

A Papua New Guinean bag woven of coarse, brittle fibers was torn, and fiber fragments had become dislodged and lost with movement and handling. The fibers were too coarse to consolidate, and the elements were too thick to allow any but the interior fibers to be held with adhered patches. The torn area was sandwiched between two pieces of silk crepeline stitched with silk thread. The crepeline held the elements and fibers in position, and the stitching and transparency of the crepeline made the mend unobtrusive. As was also true for the treatment of the dog-tooth leg rattle, silk crepeline was chosen instead of polyester, despite the latter's better aging properties, because the sheen of the polyester was obtrusive.

**Plastic.** Severely fragmented three-dimensional artifacts too damaged to support their own weight even if mended may be mechanically secured to a contour plastic shell. Shells molded from acrylic sheet or cast with fiberglass-reinforced polyester resin are thin and clear enough to allow examination of the underside of the artifact. In mending and supporting a severely fragmented basketry hat, for example, Wolf (1977b) drilled holes in a polyester shell through which thread was passed to secure the fragments in place.

## Splints

Splints may be used to join or reinforce broken elements.

### *Internal Splints*

Splints are inserted into the artifact structure to support and join elements. Interna! splints should be used only where there is sufficient space between elements to safely accommodate them.

**Round Splints.** These are used when rigid compound elements (elements made up of a bundle of rigid plant materials such as small stems and roots) are broken and some of the parts are lost. This occurs most frequently in the passive elements of coiled baskets and in reinforced rims. Sections of the outer area of bamboo or straight-grained wood are shaved to the appropriate diameter and cut to the appropriate length. The ends are tapered, and the splint is inserted across the break in the area of loss (Figure 5.21).

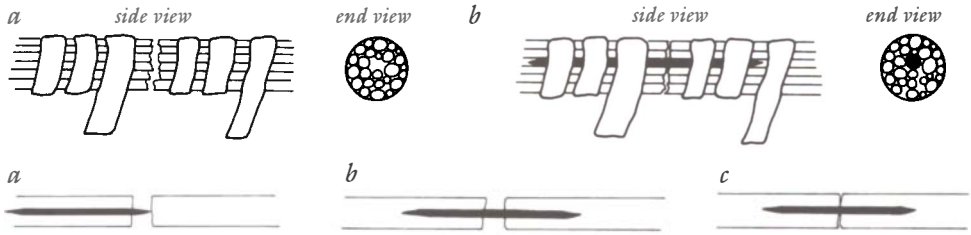



*Figure 5.21. (a) Break, (b) mend using round splint .*




*Figure 5.22. Inserting a splint across a break.*

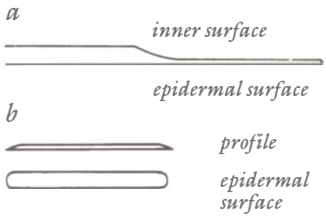



*Figure 5.23. Split bamboo is shaved to the desired thickness (a), then cut to the appropriate length and the corners rounded off (b).*

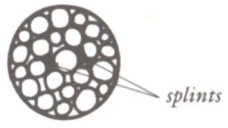



*Figure 5.24. Bamboo splints fit between members of the compound elements.*

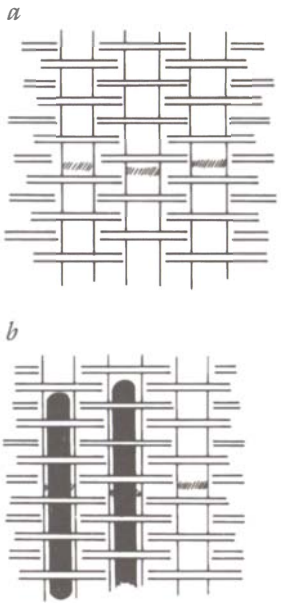



*Figure 5.25. Thin, broad bamboo splints used to reinforce broken elements in interworked element constructions.*

When inserting the splint across the cracks and splits, the butt ends of the join should not be pulled widely apart. As shown in Figure 5.22, the stick is inserted into one side and the broken ends are aligned (a). The stick is then moved across the break with pointed tweezers, so that half of it is inserted in each side of the break (b,c).

**Flat splints.** The hypodermal region of bamboo is very dense and strong. From this region, very fine, paper-thin splints can be made which are strong and flexible. If not grown locally, bamboo can usually be found at hobby and craft shops, and at shops selling cane window and veranda shades and Asian basketry. It is important that bamboo culms or splits contain the epidermis; core splits are not dense enough to make good, thin splints. Rattan epidermal splits are not quite as dense as bamboo, but would be suitable for most splints, if bamboo cannot be found.

To make the splints, the bamboo is split lengthwise to the desired width, and the inner surface of one end is shaved down until the desired thickness is attained (Figure 5.23a). This area is cut off to the desired length and the ends are tapered and rounded (Figure 5.23b).

Very fine (thin and narrow) bamboo splints can sometimes be used to join compound elements when no parts are lost, if there is sufficient space for a splint to be safely inserted. The bamboo splint is made small enough to fit between the members of the compound element (Figure 5.24).

Thin and broad splints can be used to reinforce broken elements in interworked element constructions. The splint is slid under the crossing elements to rest on top of the broken element (Figure 5.25). If possible, this is done on the least visible face of the artifact. This technique can only be used if there is sufficient space under the crossing elements. If the artifact is tightly constructed there may be no room for a splint.

A Micronesian hat band constructed of folded-over grass tufts bound between monocot stem strips was broken across the stem strips in several areas. It was mended with paper-thin bamboo splints slipped behind the stem strips as illustrated in Figure 5.26. The fineness and close proximity of the artifact elements would have made adhered mends difficult and dangerous to apply discreetly and, should the repair need to be removed, adhesive residue could not be safely removed from the fibrous tufts and binding.

Polyester sheet, such as Mylar D, .005" thickness, also makes good flat splints, when a transparent and more flexible splint is desired. The sheet is cut to the appropriate length and width and the ends are rounded. As cut polyester sheet can have somewhat sharp edges, it is advisable to lightly sand the edges with 1200 grit emery paper.

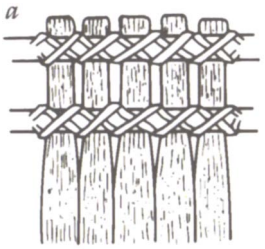


*Figure 5.26. Diagram of mechanical mend of Micronesian hat band using bamboo splints, front (a) and side (b) views.*

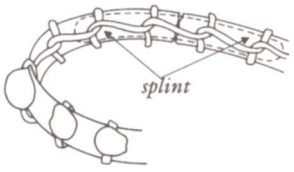



*Figure 5.27. Diagram of mechanical mend of Micronesian wristlet using transparent polyester sheet splint.*

A Micronesian wristlet was constructed of an 8 mm wide strand of banana leaf stalk. Around this, pierced shells were secured with looped cordage. The leaf strand had broken in several places, so that the wristlet would not retain its correct shape and could not be handled safely. Mylar D splints were prepared and slipped between the leaf strand and the cordage on the interior face to reestablish the structural function of the strand (Figure 5.27).

*External Splints*

If there is no room for the splint to be incorporated into the structure, the splint can be placed over the broken area and tied or bound into place. This is especially useful for open constructions and appendages where adhesive joins would not provide sufficient support.

A fine, open-twined Eskimo basket was badly crushed, resulting in many long horizontal breaks across the passive elements. Neither adhesive joins of the broken ends nor adhered sutures across the breaks would have provided sufficient strength to the basket. The basket was conditioned and reshaped over a padded form, and the elements were aligned and provisionally held in place with tied thread from the exterior face. It was then placed right side up in forms which allowed access to both interior and exterior faces of particular wall and base sections. Bamboo splints up to 15 cm long, 1 mm to 1.5 mm wide, and paper-thin were prepared. They were placed over the interior face of the passive elements and bound into place with stitches like those previously illustrated in Figure 5.18, using fine polyester monofilament unravelled from Stabiltex gauze. The mends were not visible on the exterior of the basket, and they gave the basket sufficient strength to be handled and displayed. A padded form was made over which the basket was inverted for storage.

Broken, large, open-weave elements such as found in hexagonal weavework baskets could be mended by binding with adhered paper, but, as the broken elements tend to spring out of shape, a thick, fairly strong glue, like acrylic or vinyl acetate emulsions, is necessary for sufficient strength. Stronger and completely reversible mends can be made by wrapping or whipping a bamboo splint across the interior face of the broken element with cotton thread (see Figure 5.13d and g).

The internal bamboo and rattan framework of a large Melanesian dance mask was repaired with splints of similar materials bound to broken elements with cotton thread and synthetic raffia (Walston, Coote, and Horton-James, 1985).

Broken appendages, such as rattan or wood strips which carry some weight, are almost securely and reversibly mended with bound splints. If the splint and binding thread color match the appendage, and the binding is tidily done, the mends are not visually obtrusive.

**Packing**

Appendages that have been attached by inserting the end into a hole in the artifact body are often dangerously loose or completely free. Those that are free would need to be reinserted and reinforced for display, or if they could be inadvertently separated from the rest of the artifact in storage. Those that are loose and wobbly could cause loosening and loss of material around the hole (see, for example, the tree fern trunk section of the Technology chapter). As the resulting enlargement of the hole is not only undesirable, but also makes the fit of the appendage progressively worse,

the attachment should be reinforced mechanically or with adhesive-putty. (If the appendage is loose enough to be removed and if storage is well organized, the appendage could be stored unattached with the artifact.) If the appendage is inserted in a soft or open fibrous material, such as tree fern trunk, adhesive-putty reinforcement may be more appropriate. If the appendage is inserted in a denser material such as wood, bamboo, rattan, or coconut shell, mechanical reinforcement may be possible. This is usually done by packing. The appendage could be inserted and fine wedges of soft material such as balsa wood or polyethylene foam inserted around it. Or, a circle of cloth of radius slightly shorter than the depth of the hole could be placed around the appendage end before inserting it. The amount of packing should be sufficient to secure the appendage firmly but not tightly, as undue pressure should not be placed on the hole or the appendage end.

### Adhesive and Reinforced Adhesive Mends

Adhesives may be applied in solution or dispersion in a liquid, or may be applied as a solid film to be reactivated by heat or solvent. The choice of application form may depend on the material being joined. A porous, fibrous material may be more successfully joined with reactivated films, as solutions or dispersions penetrate the material too readily, resulting in color saturation and gloss. In other situations, the drying contraction of an adhesive in solution or dispersion may be useful in drawing materials together, as when adhering flaking surface coatings. The choice of application form may also depend on the accessibility of the location of the mend for application, clamping, and so on. For example, heat- and solvent-reactivated films may require only a few minutes of finger pressure to secure the mend, while adhesives in solution or dispersion usually require binding, clamping, or weights.

The specific choice of adhesive used depends on its working, functional, and aging properties. Factors like the adhesive's area of solubility in application and after setting, its glass transition temperature ($T_g$), viscosity in the required concentration and solvent, and its flexibility or rigidity when set are important when determining its suitability in application and function for a particular treatment. Aging properties such as yellowing, embrittlement, and crosslinking will help determine whether a specific adhesive is suitable for use in any conservation treatment.

One approach that can be used to select an adhesive for a particular treatment is to first consider adhesives with the desired functional properties (strength, flexibility, $T_g$, and so on), then, from among those, consider adhesives whose working properties (solubility, viscosity, softening temperatures, and so on) meet the treatment application requirements, and, finally, from among those, consider the ones that have the best aging properties. Another approach is to use a narrow range of adhesives known from testing and experience to have good aging properties, and modify their working properties and the methods of application used to suit the needs of particular treatments. Final selection of the adhesive, its concentration and solvent, and the method of application may require testing on similar materials and mock-ups.

For either of these approaches, it is necessary to be familiar with the properties of adhesive types and chemical families, and with the properties of specific brands and grades of adhesives in those families. Appendix 3 includes a classification of adhesive types and families by setting action, and lists some of the properties that

influence their suitability in application, function, and removability for a particular treatment. The inclusion of adhesive families does not necessarily endorse their use in treatment. Some, like soluble nylon, polyvinyl alcohol, and cellulose nitrate, were used in the past, but have proven through time to have unsuitable aging properties. Others, such as polyurethane and polyester, have never been suitable for use directly on artifacts, but are used in constructing artifact mounts and supports.

The main drawbacks of adhesive mends are that they inevitably cause some permanent alteration of the artifact material, and that it may be difficult or impossible to remove all traces of the adhesive if the mend is removed. Even if an adhesive is used that remains resoluble for many years, the solvent and mechanical action necessary to remove it may be detrimental to the artifact material. One would try to use adhesives with good aging properties and that will remain resoluble for as long as possible. The ease of removing adhesives also depends on the physical nature of the material to which it is applied. Adhesives on dense, smooth material can be more readily and efficiently removed than adhesives on porous, fibrous material. In deciding whether to use mechanical or adhesive mends—and if the latter, which adhesive and method of application to use—the adhesive working properties, functional characteristics, ease of application, and removability must all be considered.

Before commencing any adhesive mends, all materials and equipment necessary for application, clamping or weighting, and clean-up should be gathered and ready to use. For complicated mends, a dry run on the artifact is useful to ensure that all the necessary materials and equipment are at hand, that the artifact is properly positioned, aligned, and supported, and that, if clamping, binding, or weighting is necessary, the system is workable and effective.

**Adhesive Applied in Solution/Dispersion**

Adhesive families commonly used in the treatment of artifacts of plant materials include:

- Starches, and sometimes gelatins, which are dissolved or suspended in water.
- Cellulose ethers, which may be dissolved in a range of solvents. Of the many cellulose ethers made, methylcellulose and carboxymethylcellulose appear from recent testing (Feller and Wilt 1990) to be the most stable; generally these are soluble in water and ethanol, and can be mixed with some other semipolar solvents, though particular brands and grades vary in solubility.
- Acrylic and vinyl acetate resins, which dissolve in a range of nonaqueous solvents.
- Acrylic and vinyl acetate dispersions/emulsions (resin particles held in an aqueous liquid by emulsion or colloidal dispersion) which are applied in water, but are only soluble in nonaqueous solvents after drying. Dispersions vary considerably in resolubility; some become quite insoluble with time. The aging properties of dispersions may not be the same as the aging properties of pure resins of the same polymer composition.

Dissolved or dispersed adhesives may be applied alone, mixed with fillers to form putties, or used to adhere thread, patches, and linings.

*Adhesive Alone*

Adhesive may be used to join delaminated and overlapping material, for example, for delaminating bark (birch bark, paperbark) and barkcloth. A small amount of adhesive is brushed between the delaminating layers, and the layers are then held together with light weights. When layers cannot be lifted apart enough to allow brushing, adhesive may be injected with a small-gauge needle and syringe. Not all delaminating areas need to be joined; relaminating is done primarily to prevent loss or when an object is to be mounted vertically. Paperbark delaminates into so many thin fragments that relamination is often impractical. Flat sheets could be sandwiched between gauze or encapsulated between polyester sheet; however, most paperbark is found in three-dimensional objects, and no good solution to the problem has been developed. For very brittle, delaminating birch bark manuscripts, Agrawal (1984) recommends adhesive lining and lamination (see section on adhesive used to adhere thread, patches, and lining).

Adhesive alone may be used to secure overlapping elements in interworked element constructions—at holes and breaks, for broken element fragments in danger of loss, and loose binding or lashing ends. Usually a small drop of thick adhesive is placed under the free element end where it overlaps other elements or the underlying support. The free end is then held down by binding, clamps, or weights until the adhesive is dry. Care must be taken that the drop is small enough that adhesive does not ooze out around the element edges. With thin, open fibrous elements, such as hibiscus inner bark strands, penetration of the adhesive into the element easily results in gloss and color saturation. A very concentrated, high viscosity adhesive is necessary to prevent this; alternatively, a heat or solvent reactivated adhesive film may be used.

Adhesive only is also used to join broken material (butt or scarf joins) where the two break surfaces meet closely over a substantial percentage of their surfaces and are strong and wide enough to allow a secure join (for example, resin, putties and cements, wood, bamboo, rattan, gourds, and some seed shells). The method works best for fairly rigid materials with edges that are strong or that can be consolidated to make them strong. It is not appropriate for most open fibrous and interworked constructions: the area of the join is usually too small to make a secure join; the material is often weak and brittle at the break and cannot withstand stress at the join; with stress, further breakage and fragmenting of material occurs. Such joins should be reinforced with threads or patches, or mended mechanically.

*Adhesive Putty*

Adhesive with a filler is used, usually on butt joins, where some material at the break edges is missing and must be filled during joining to make a strong join.

In joining baskets, paper pulp mixed into resins, emulsions, and pastes has been used (respectively by Kronkright 1981, Hartley 1978, and Thomsen 1981, for example). Element ends at breaks are often weak or fragmented and further breakage of the ends so joined can easily occur with even small flexing of the basket. Such joins should be reinforced with adhered threads or patches.

In joining more rigid materials (such as wood, bamboo, rattan, gourd, coconut shell, and so on) fillers such as paper pulp, sawdust, glass, and phenolic micro-

spheres and microballoons, as well as fumed silica have been used. These are mixed into pastes, resins, and emulsions.

Adhesive putty is also used to reinforce the attachment of loose appendages inserted into the artifact. Where the artifact main body material is soft or coarsely fibrous, the use of adhesive putty may be safer than mechanical reinforcement. For a tree fern trunk figure with arm and leg appendages, for example, the holes in the main body had been enlarged by loss of adventitious root fragments. After consolidation of the roots around the hole with 3% w/v Methocel A15C in water and ethanol, the hole was lined with a putty made of 8% Methocel A15C and medium-to-fine sawdust. Enough putty was used that, when the appendage end was inserted, the putty was pushed up around the end to a level about a centimeter below the object surface.

Generally, and especially with large fill areas, one would try to use as high a filler-to-adhesive ratio as possible in the particular circumstances so as to reduce the contraction of the putty during drying.

### Adhesive Used to Adhere Thread, Patches, and Lining

Where join edges are small and/or brittle and fibrous, joining with thread and patches provides strength and support. Thread and patches allow greater joining surface area and, very importantly, allow the join to be carried onto stronger, more coherent material beyond the break line. Patches also supply support over areas where holes and losses have reduced the strength or stability of an artifact. When the entire artifact is badly damaged or weak, complete lining or laminating rather than a number of patches may be called for.

#### *Thread*

Thread is used to reinforce joins on fine interworked element constructions, such as textiles and fine basketry and matting. The break is aligned and a thread saturated with adhesive is placed across the break line. The thread is worked into the recesses where elements cross, so as to gain the most area of contact between thread and artifact, and also to make the thread unobtrusive. Thread is also useful for joining or reinforcing fine, freely hanging cordage and thread. The thread is wound around spun cordage following the same direction and angle of twist. Thread is a bit more difficult to apply to plaited cordage, but the same principle of following the movement of the cordage fibers should be applied as much as possible. Repair thread is laid longitudinally along fine threads and straight strands of fibers.

A starch-paste adhesive works best as it dries matte and is much easier to manipulate than threads saturated with resins in nonaqueous solvents. Cellulose ether pastes could also be used, but their adhesion seems to be slightly weaker than starch paste. Threads used are loosely spun cotton thread, such as single-ply embroidery floss and twisted strands of Japanese paper (Odegaard and Harvey 1982). A narrow strip, about 5 cm, of long-fiber Japanese paper, such as Usamino, is teased away from a paper sheet (teasing is used to avoid the short fiber fragments obtained with cutting); for fine threads a strip only a couple of millimeters wide is needed. The strip is then rolled between finger and thumb to make a spun thread. (Refer to Appendix 1 for Kronkright's detailed discussion of suture mends using twisted paper.)

If the broken area does not sit in proper alignment, it must be blocked, weighted, clamped, or otherwise held in alignment with the break, and a couple of centimeters on either side of it exposed. When ready to apply, the thread is soaked in fairly thick starch paste (about the consistency of yoghurt) until saturated, lifted with fine-pointed tweezers, and either touched on a blotter or pulled across the edge of a watch glass to remove excess adhesive. It is then laid in position and tamped into place with a blunt needle or narrow-ended dental packing tool.

Normally, threads would be adhered on the least visible face of the artifact. Some joins may require threads on both faces of the break. The threads are visually unobtrusive if obtained or dyed a color which blends in with that of the artifact. Embroidery floss can be purchased in a variety of colors. It is useful to have available a supply of dyed Japanese paper (see Appendix 4) in a range of colors. The threads are so narrow that inpainting after mending is difficult without getting paint on the object itself.

*Patches*

Patches are most frequently used on interworked fiber constructions such as barkcloth, basketry, matting, and textiles, on flat artifact materials such as leaves, bark, and split monocot stems, and on other materials where the join edges are small and the joined material bears weight or stress.

Patches should be large enough to cover the damaged area and to extend over onto the adjacent undamaged or sound fibers. In this way, strong fibers help to support and to carry any stress on the damaged fibers. In interworked element constructions, the amount which extends over onto sound fibers depends on the size or width of the elements, and on the type of construction. For example, a patch over a horizontal split in a close-twined basket should extend over at least several rows of sound fibers, as the rows immediately over and under the split easily slide off the vertical passive elements if tension is placed on the broken area.

Patch materials used include long-fiber paper, spunbonded filament sheets, gauze, and plant materials. Long-fiber paper is most frequently used as it conforms well to artifact shapes and textures, can be torn or cut to any shape without fraying or loss of strength, and has a matte, subtle texture. The feathered edges obtained with water cutting allow a gentle transition between patched and unpatched areas. Machine-made papers are usually fairly short-fibered and unsuitable; some, such as L-tissue and lens tissue, are long-fibered and thin enough not to obscure detail under the patch, although they tend to have fairly low wet strength. They are useful when translucent patches that do not obscure important detail are needed, such as on the face of palm leaf manuscripts. Hand-made Japanese papers offer a range of fiber length, density (basis weight = $gm/m^2$), thickness, and wet strength. Medium-density papers, such as Usamino and some Seikishus, are suitable for leaves, barks, and many basketry and beaten inner bark artifacts. Thin, low-density papers, such as Bib Tengujo, are useful for very fine constructions and where patches which are thin enough not to obscure surface detail are needed. Silk crepeline and polyester gauze are sometimes useful, as they also allow surface detail to be visible, but, because of their open weave, are more suitable for use with heat and solvent reactivated adhesives. Spunbonded filament sheets, such as nylon gossamer, are sometimes used in a manner similar to Japanese paper; however, they are more difficult to adhere,

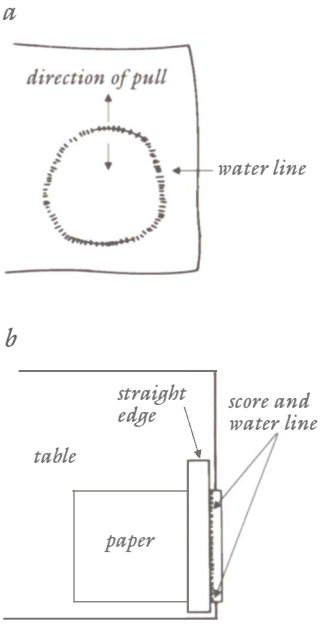



*Figure 5.28. Water cutting Japanese paper in (a) irregularly shaped patches and (b) strips.*

do not conform as well to artifact shape and texture, and must be cut to shape. Plant materials such as bamboo and rattan splints are sometimes used where more rigid patches are desirable, such as across breaks in composite artifact frameworks or in appendages. Although these are usually held mechanically, they may be adhered in place. Raffia strands have also been used in a manner similar to Japanese paper strips.

Resins in nonaqueous solvents are occasionally used to adhere patches, but they are not matte upon drying, are difficult to apply, and do not allow manipulation of patches as well as aqueous adhesives. In most cases, natural-fiber patches are adhered with starch or cellulose ether paste (see Clapp 1979 and Appendix 1). When greater strength is needed because of stress on the patched area, because the artifact surface is very smooth and dense, or because a synthetic-fiber patch is used, emulsions may be mixed with the paste. Up to 40% by volume of the adhesive can be emulsion without imparting gloss, and still allow the patch to be removed with swabs lightly dampened with water (although some nonaqueous solvent may be necessary to remove remaining fibers of the paper patch feathered edges). As most patches are applied to fibrous, porous materials, it may be best to avoid the use of purely emulsion adhesives if possible, as potentially poor resolubility could make future removal of a patch difficult.

For regularly shaped patches (strips, squares, and so on), the size can be measured and the patch material cut or water cut. For irregularly shaped patches, the shape must be taken directly from the artifact. Translucent patch materials can be placed over the area to be patched and the patch material marked with a soft pencil just beyond the cutting line or, if water cutting is used, with water dots stippled by brush at the cutting line. Light tables are useful in making the damaged area more visible. Transparent plastic sheet (such as .002" or .005" thick polyester film) is useful for making patch patterns or templates. The plastic sheet is laid over the area to be patched and the patch outline is drawn in using a pen with ink formulated for permanency on plastic (if the ink used does run with water, the sheet can be turned upside down for watermarking).

To water cut irregular shapes, a thin line of water is brushed along the outline of the shape. With the thumb and forefingers of each hand on either side of the water line, the patch is gently pulled from the paper. The pull should be exerted perpendicular to the water line so that the feathered edge does not tangle, as shown in Figure 5.28a. Water cut strips should be made across the grain of the paper so that the strongest direction of the paper crosses the break. The Japanese paper is placed on a smooth table top so that the edge extends just over the edge of the table. A straight-edge is placed parallel to the edge of the paper with the desired width of the strip exposed (Figure 5.28b). With a bone folder, the paper is scored along the straight-edge, then a thin water line is brushed along the straight-edge and the line is scored again. The water lining and scoring are repeated, as necessary, until the paper is fully wetted just along the line. Still holding the straight-edge firmly in place, the paper strip is pulled away. Starting from the top end, the thumb and forefinger are moved down the strip, tearing so that the pull is always exerted perpendicular to the water line.

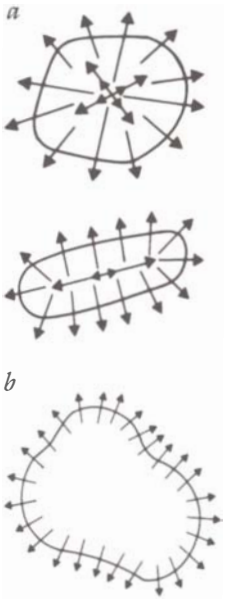



*Figure 5.29. Direction of strokes for pasting (a) an entire patch, and (b) edges only.*

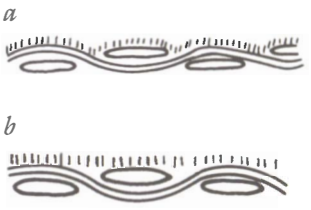



*Figure 5.30. (a) The patch should conform to the object's texture, not (b) rest on the surface.*

During drying, the patch is covered on both sides, first with a release paper, such as spunbonded polyester sheet or silicone-coated paper, and then with blotting paper. It is then bound, clamped, or weighted until dry. The binding, clamping, and weighting system should be fully planned before patches are applied. Flat artifacts can be patched on a flat surface and weighted with sand, lead shot, or steel ballbearing bags, or with glass plates. Curved surfaces should be supported with sand bags or padded styrofoam blocks and weighted with sand, lead shot, or steel ballbearing bags. No weight should be put on contoured surfaces that are not fully supported underneath. Free-standing or hanging elements should be supported with heavy blotter held behind them during application and then clamped with binding or very-light-weight clamps. Binding is particularly useful with rounded or irregularly shaped elements. Clamps must be of weight appropriate to the element and its position. Examples of clamps, roughly in order of decreasing weight, include: aluminum G-clamps, clothes pins, plastic F-clamps, magnets, alligator clips with the teeth filed off, toy miniature clothes pins, bent plastic-tip hair pins, and aluminum spring hair clips. Besides the weight of the clamp, the force applied by spring clamps should be considered and adjusted if necessary.

Starch or cellulose ether paste is usually used to adhere paper patches to an artifact. The paste is diluted with water to the appropriate consistency. It should be strong enough to firmly hold the patch. If the paste is stronger than necessary, it is difficult to remove the patch, and it will contract considerably on drying, pulling and stressing the artifact's fibers. The amount of dilution depends on the strength of the stock batch of paste, the texture of the object surface, and the amount of stress on the join. Smooth epidermal surfaces require a stronger paste than fibrous or porous surfaces. With practice, the appropriate consistency can be accurately estimated. If unsure, a test can be made with a small patch on an undamaged area of the object. As a rough guide, starch diluted to the consistency of cream may be necessary for small patches on smooth epidermal surfaces, while starch paste diluted to the consistency of skim milk is appropriate for more fibrous elements, and to the consistency of white tea for thin beaten fiber sheets.

The paste is brushed onto the side of the paper that will be in contact with the object. The paper should be pasted out on a piece of heavy blotter paper; the blotter absorbs much of the moisture from the paste, reducing the moisture introduced to the artifact material. Using a soft hair brush, the paste is brushed onto the paper, covering all areas of the paper which will be in contact with the object. If the whole patch is to be pasted, paste should be applied to the center first, then brushed out to the edges (Figure 5.29a,b). In this way the feathered edges are not tangled, and the paper is not creased as it expands with the moisture from the paste. If only the edges of the patch are to be pasted, paste should be applied in outward strokes (Figure 5.29c).

When fully pasted, the patch is lifted up by the end or the edge with tweezers. It is air floated to its position on the object and tamped into place with a clean dry brush. The patch should conform to the texture of the object so that it is fully in contact with the object's fibers (Figure 5.30). This ensures maximum strength and also makes the patch visually subtle. A smooth patch on a rough surface will be

very obvious; a patch that conforms to the surface texture will visually blend into the object.

Tamping with a stiff bristle brush is necessary to push the paper into the low areas of a textured surface. An oil painting brush whose width is not greater than that of the elements is used, held perpendicular to the object and tamped with quick short strokes. Tamping should start at the center of the patch so that the paper can be pushed into place, not stretched and ripped into place, as would occur if it were tamped from the edges inward.

Pasting out with paste and emulsion mixtures and application of adhesive to spunbonded filament sheets and gauze are done in a similar manner. Care is needed to not pull threads from gauze edges and to keep the threads aligned during application. Synthetic fiber patches to be adhered with acrylic or vinyl acetate resins in solution are more easily glued out on plastic sheet than on blotter paper.

Barkcloth patches recorded in the literature were made using Japanese paper and starch or ellulose ether paste (see, for example, Firnhaber 1979, Munro 1984, Bakken and Aarmo 1981, and Turchan 1986). However, Erhardt and Firnhaber (1987) reported that starch and cellulose ether paste did not adhere well to oiled tapa. They found that mixtures of acrylic emulsion and cellulose ether paste adhered well and could be removed with mechanical action and solvent. The use of single layers of contemporary tapa (barkcloth) instead of Japanese paper has been suggested by Wolf and Fullman (1980) and Wolf (1983a); however, it should be borne in mind that tapa patches to reinforce thin spots and holes during production has been a technique used by many Polynesian tapa makers. The weight of paper used should be appropriate to the thickness and degree of beating of the barkcloth. Even with very fine patching paper though, patches do make thin barkcloth a bit stiffer. The drape and fall of hung fine-weight barkcloth may be affected by patches. Severely torn decorated barkcloth may be most accurately aligned from the front. To hold the alignment while the barkcloth is turned over for patching (or lining), small cut-paper "Bandaids" can be placed at intervals across tears using very dilute paste. These are removed after patching in the same way that most pasted paper patches are removed, by rolling a lightly dampened swab over the "Bandaid" until the paper is moistened, then lifting the "Bandaid" with tweezers. Cut paper is used to avoid having to pick off fibers that may be left from the feathered edges of water cut strips.

Patches on basketry and matting recorded in the literature are similar to those on barkcloth. Thomsen (1976) recommends torn Japanese paper adhered with starch paste and tamped onto the basket surface. Hartley (1978) recommends Japanese paper patches adhered with poly(vinyl acetate) emulsion. She suggests that the glue be applied to the basket, the paper laid in position and tamped in, and then more glue applied until sufficient to saturate the paper when dry. This method of application would seem to involve the use of more glue than is necessary, with the resulting need for the application of more solvent to remove the patch. Excessive quantities of emulsion glue can result in surface fiber loss with the contraction of the glue on drying and aging. Norton (1984a) repaired fine pandanus matting with water-cut Japanese paper patches adhered with starch paste. Fenn (1980) repaired splint baskets with chiffon or Japanese paper adhered across the back of broken

splints with low-molecular-weight poly(vinyl acetate) resin in acetone, amylacetate, and toluene. Mends were clamped by placing magnets on either side of the patch. Other mends recorded in the literature involved the use of materials and techniques to restore as well as mend baskets and are discussed in the restoration section.

Adhered patch mends to birch bark are recorded by Agrawal (1984) and Gilberg and Grant (1986). Agrawal reinforced weak and delaminating bark layers by introducing paper adhered with paste between layers. Gilberg and Grant recommend the repair of splits in birch bark using Japanese paper patches adhered with Acryloid B-72 or a poly(vinyl acetate) emulsion.

Torn palm leaf manuscripts were mended by Agrawal (1984) using tissue or silk gauze adhered with an acrylic rubber adhesive. Cracks and tears in monocot leaves have been successfully mended elsewhere using water-cut paper patches adhered with starch paste. A patch across both surfaces of broken leaves is usually necessary to prevent bending at the break. Dicot leaves with downy lower epidermises, such as fig leaf, may require pretreatment with ethanol/water to assist penetration of the paste to the epidermal surface.

*Lining*

Lining (securing a support fabric or paper to the reverse face of an artifact material), and laminating (securing a support fabric or paper to both faces of an artifact material), may be necessary when the material is so badly degraded or damaged that it can no longer serve its structural function, or when handling or display would not otherwise be possible.

Paper-and-paste lining of barkcloth is done using methods based on those used for lining in paper conservation. The lining paper and the paste used should be as thin as effectively possible to reduce stiffening of the lined barkcloth. When the use of more than one sheet of Japanese paper is necessary to line the barkcloth, the paper should be measured and water cut so that only the feathered edges of adjacent sheets overlap. To aid in transfer and placement of the lining paper, it is useful to paste out each paper on .005" thick polyester sheet and transfer it to the barkcloth on the sheet. The sheet with the pasted paper is laid paste side down on the barkcloth, lightly rubbed down, then gently peeled away. Light tamping with a broad brush ensures full contact between the lining and the barkcloth. As for patching with paper and paste, both faces should be covered with a release sheet of spunbonded polyester web and blotter. The lined barkcloth should be weighted with papermakers' felts and light glass plates until dry. A couple of changes of blotter is recommended to hasten drying. The lining of barkcloth recorded in the conservation literature includes the use of Tengujo and rice or wheat starch paste by Turchan (1986). Wolf and Fullman (l980) and Wolf (1983a) recommend lining Fijian barkcloth with a single sheet of new Fijian barkcloth adhered with wheat-starch or methylcellulose paste.

Lamination of broken and degraded monocot leaves used as archival documents and as structurally important components of an artifact is recorded in the conservation literature. Crowley (1969) laminated palm leaf manuscripts by brushing the leaf with acrylic rubber and laying tissue over the surface. This procedure was then repeated on the other side of the leaf. The amount of adhesive used was enough to saturate the tissue. Agrawal (1975,1984) laminated broken palm leaves

with silk net or chiffon and starch paste. Horton-James and Townley (1978) laminated degraded pandanus leaves, which formed the structurally important framework covering of a mythical animal from New Britain, with 8% by weight poly(vinyl butyral) in 60/40 acetone/toluene and process nylon laminating tissue. One side of the leaf was painted with the solution and allowed to dry. The tissue was laid on the leaf and painted with the solution. The leaf was immediately put in a press until dry. The process was repeated on the other side of each leaf. The technique allowed enough penetration of the adhesive to consolidate as well as laminate the leaves. It was noted later (Walston, Coote, and Horton-James 1985) that, if a similar treatment were done now, Paraloid B-72 would be used because of its superior aging qualities.

Birch bark manuscripts were laminated by Agrawal (1984) with silk chiffon and paste.

Bird and Dimitrijevic (1964) reinforced weak and broken warp threads on warped backstrap looms using net and Bordon's 1361-4B emulsion adhesive. When the warps were aligned, the net was placed behind them and the adhesive was stippled through the net behind the warp threads. Only small quantities of adhesive were necessary to tack the threads in place.

### Adhesive Reactivated by Heat or Solvent

Adhesive is applied dry and reactivated in situ by the application of heat or solvent. Reactivated adhesive is used for the same types of mends as adhesive applied in solution or dispersion. Adhesives used are the synthetic resins or emulsions that form flexible films and which have either a low $T_g$, so that the heat necessary for reactivation is low, or the property of softening with solvent to become tacky very quickly. Reactivated adhesives have the advantages of limited penetration of adhesive into the artifact material and ease of use, and, as those used are not water-based, of not affecting moisture-sensitive materials. Generally, mends are made with adhesive films or tissue-reinforced adhesive films, or are made with adhesive-coated thread, paper, or gauze.

#### *Preparation of Films and Coated Substrates*

In most cases, films and coated substrates are made on a flexible release sheet. The films can be stored on this sheet, and cut and peeled off as needed. As the adhesives used have a low glass transition temperature, dust and dirt easily become stuck to their surface. The films should be rolled up and covered to protect them from dust. Release sheets used include polyester sheet, polyethylene sheet, silicone-coated paper, and Teflon sheet.

Some adhesive films, such as BEVA 371, can be purchased ready-made. Films can be made using portable machines designed to produce large sheets of uniform thickness (see, for example, Walston, Horton-James, and Zounis 1987), by casting sheets, or by simply brushing out adhesive to the desired thickness on a release sheet. In a laboratory workshop at Symposium '86, Howatt-Krahn (1986) cast small sheets by pouring adhesive in a shallow well made of glass slides. For brushing, dilute solutions or dispersions are brushed out on the release sheet; up to four coats are applied until the desired thickness is reached. Adhesive film may be reinforced with fine paper, such as L-tissue, to make handling easier when larger areas of film

are needed. The reinforcing tissue is laid out on the release sheet and the first coat brushed over this from the center out to the edges. One to two coats are applied over this to build an adhesive coating covering both sides of the reinforcing sheet.

For cast sheets using Acryloid B-72, Howatt-Krahn recommends a solution of 35 parts Acryloid B-72, 35 parts acetone, 35 parts toluene, 5 parts butanol, and 5 parts cellosolve. This solution can also be brushed out on release sheet. Hinman (1983) found that Mowilith DM4 and Primal AC33 brushed out most evenly if diluted to 3 parts emulsion and 1 part water, and that resins brushed out most evenly if diluted to 10% to 15% solids for BEVA 371, and 20% solids for Paraloid B-72.

Substrates, such as cotton and polyester thread, L-tissue and light-to-medium-weight Japanese paper, spunbonded nylon gossamer, and silk and polyester gauze, can be coated by dipping, brushing, or spraying. Coated threads are made by dipping the thread in dilute adhesive and laying it on release sheet to dry. This creates a greater concentration of the adhesive on the side next to the release sheet. Drummond (1986) found that dipping polyester thread unravelled from Stabiltex in 4% solids BEVA 371 produced sufficient adhesive for bonding with heat reactivation. For patches and lining, paper and gauze should be coated on one side. The paper or gauze may be laid on release sheet and one coat of dilute (5% to 20% solids) solutions or dispersions brushed on from the center outward; the adhesive concentrates on the side next to the release sheet. Squeezing may be used to produce an even, thin coating. As it is difficult to keep gauze threads aligned during brushing, it is easiest to staple or tape the gauze to a stretcher that is laid face down over the release sheet for brushing. For spraying, 10% to 15% solids solutions are sprayed onto one side of paper taped to a board or gauze attached to a stretcher. Himmelstein and Applebaum (1977) applied ten coats of sprayed PVA AYAA and AYAC 10% solution in toluene and ethanol on stretched silk crepeline to prepare a heat reactivated lining for a textile. They found that spraying resulted in a more flexible lining than brushing.

*Reactivation of Adhesive*

The adhesive film or coated substrate is placed in position and reactivated with heat or solvent. The method of reactivation chosen may be based on personal preference, or dictated by the thickness or sensitivity to heat or solvent of the artifact material, or by the location of the mend. Film mends under thick elements, such as cordage and pandanus and palm leaves, may be best reactivated by solvent as the thickness of the material through which the heat must pass to reactivate the adhesive would require a long exposure to heat. Film mends under, and coated substrate mends on, fibrous materials such as fine barkcloth and hibiscus inner bark strands are best reactivated by heat, as the application of even small quantities of solvent may draw the adhesive around the fibers, resulting in some gloss and color saturation.

In both types of reactivation, the adhesive film or coated substrate is placed in position, reactivated, and held in place until cool or until solvent has evaporated. The time necessary for this process is quite short and binding, clamping, or weighting are not usually necessary.

Heat may be applied with flat irons, variable tip tacking irons, or temperature- and velocity-controlled hot air blowers. A release sheet such as silicone-coated paper should be placed between the iron and the element or adhesive-coated sub-

strate. When using irons, pressure sufficient to ensure contact is applied during ironing. When using hot air blowers, finger pressure is needed. Linings on large, flat objects such as some textiles, barkcloth, and matting may be applied using hot table vacuum envelopes under the lowest possible effective vacuum pressure. The temperature used depends on the softening temperature of the particular adhesive used. Generally, BEVA 371 seems to require the lowest temperature of adhesives used, with reactivation sufficient for tack occurring between 60 °C and 65 °C. Hinman (1983) found that reactivation temperature for adhesive films applied under raffia and hibiscus inner bark strands varied with film thickness, but required 60 °C for BEVA 371 films and reinforced films 0.6 mm to 1.0 mm thick, 70 °C for Primal AC33 films 0.4 mm to 0.5 mm thick, 50 °C to 80 °C for Mowilith DM4 films 0.4 mm to 0.7 mm thick, 95 °C to 100 °C for films of equal parts PVA AYAC and AYAA, and that films of Paraloid B-72 did not attain sufficient bond at temperatures up to 100 °C. Horton-James and Townley (1978), however, used an iron at 80 °C to adhere a lining of Stabiltex coated with Paraloid B-72. Himmelstein and Applebaum (1977) found that a lining of silk crepeline coated with equal parts of PVA AYAC and AYAA ironed from the object face required 79 °C to 85 °C.

Solvent is applied by pipette or by brush. To reactivate very small film areas, such as those used in mending fine cordage or elements, or to attach coated threads, only minute quantities of solvent are needed and capillary tubes or micropipettes graduated to 0.01 ml are used. The use of too much solvent in these cases results in bond failure because of complete dissolution and spread of the adhesive. Solvent for larger film areas and patches can be applied by brush tip or flat brush. Although their use has not been recorded or observed, the use of local vapor chambers followed by finger pressure or weights is applicable. Solvents selected should be those that reactivate the adhesive quickly and have a rapid evaporation rate.

*Mending with Reactivated Adhesive*

Adhesive film and adhesive-coated substrates are used in mends similar to those discussed for adhesive in solution or dispersion.

**Film and Reinforced Film.** When securing overlapping elements, such as weaving and plaiting elements at the edges of holes and breaks, and broken ends of wrapping and binding elements, and when securing delaminated layers of bark and barkcloth, the use of reactivated film allows greater control over the spread and penetration of the adhesive than does adhesive in solution or dispersion. A piece of film slightly smaller than the area to be secured is placed under the loose element or layer and reactivated.

Australian Aboriginal *mimi* figures are constructed of bent and crossed sticks that are wrapped with flat, thin fibrous plant strands. Breakage of the wrapping elements through abrasion at bends allows the wrapping to unwind. These have been aligned and secured by tacking the broken ends with 2 $mm^2$ pieces of Mowilith DM4 reactivated by heat from a narrow tip tacking iron. Plaited coconut-fiber cordage decoratively and tightly wrapped around Melanesian spears breaks and unravels easily. Securing broken cordage with acetone reactivated Paraloid B-72 film pieces about 1 mm by 2 mm in size resulted in visually acceptable mends, whereas it was difficult to apply the adhesive in solution in quantities small enough not to show around the edge of the cordage.

Agrawal (1975) recommends the use of reinforced film to encase sheets of plant material. Birch bark was laminated between cellulose acetate sheets reactivated by brushing with acetone. Later, Agrawal (1984), recommends laminating with chiffon gauze and flour paste. However, reactivated cellulose acetate sheet is still recommended for laminating palm leaf manuscripts.

**Adhesive-Coated Thread.** Reactivation of adhesive-coated thread can be used to join or reinforce fine fibers in textiles and open-worked constructions, in cordage, and in open, fibrous sheets such as palm leaf petiole remains and very fine barkcloth. Because of the small quantity and surface area of adhesive necessary, reactivated adhesive is sometimes easier to manipulate and involves less penetration and spread of adhesive than the use of adhesive in solution or dispersion.

**Adhesive-Coated Patches and Linings.** Reactivated adhesive patches and linings are commonly used in painting and textile conservation and are used to some extent in paper conservation. Reference to the literature in those fields is useful for materials and techniques used and their advantages and disadvantages.

Firnhaber (1979) examined heat-reactivated lining material and adhesive for barkcloth. She found that Stabiltex made a more flexible lining material than nylon net. Of the various dilutions of Mowilith DMC2, Vinamul 6815, and Vinamul 6525 she tried, 30% Vinamul 6525 was the most successful. Munroe (1984) lined barkcloth with nylon laminating tissue and heat-set polyamide resin. She notes that the lining could be pulled off with minimal effort, and the adhesive was soluble in alcohol. Horton-James and Townley (1978) lined a Balinese barkcloth calendar with Stabiltex coated with three brushed coats of Paraloid B-72, ironed on at 80 °C. The barkcloth of a Marquesean figure constructed of painted barkcloth wrapped around carved wood was very brittle in some areas and had losses, particularly over protruding areas and edges. Lining was necessary to allow the figure to be handled without further damage to the barkcloth and to visually integrate the barkcloth. The barkcloth could not be removed from the figure, so lining was done by slipping silicone release paper and acrylic-emulsion-coated L-tissue under the barkcloth and reactivating it by lightly brushing acetone through the barkcloth. Contact between the lining and the barkcloth during drying was made with finger pressure. Solvent reactivation was chosen over heat reactivation as the rough texture of the wood would have made the use of tacking irons awkward and less safe than finger pressure, and a temperature-controlled hot air blower was not available.

Selick (1987) repaired splits on the obverse face of painted birch bark scrolls with dyed silk crepeline coated with a poly(vinyl acetate) emulsion, Vinnapas EP1 Dispersion, reactivated with ethanol applied by brush. Weight was applied for about one minute after reactivation. The treatment allowed easier manipulation of the splits, covered less surface area, and was more transparent than paper patches adhered with paste.

The use of different adhesives and substrate materials on interworked element constructions are represented by treatments by Gowers (1968), Pomerantz (1975–1976), and Himmelstein and Applebaum (1977). Gowers patched and lined a twined cedar-bark blanket by ironing on nylon net coated with Vinamul 6515, a poly(vinyl acetate) emulsion. Before lining, patches over breaks were reinforced with

stitching across the breaks. Pomerantz used polyamide web on 65/35 polycotton voile, ironed from the back through damp cloth to line a painted, woven cedar-bark mat. Himmelstein and Applebaum lined a textile with silk crepeline coated with ten sprayed coats of equal parts PVA AYAC and AYAA, 10% solution in toluene and ethanol, ironed from the front at 110 °C to 120 °C.

*Reversing Adhesive Mends*

One must assume that any mend may eventually need to be removed. The conservator must consider the methods necessary to remove a mend as well as those used to apply it when deciding what mending techniques, if any, are appropriate.

Assuming that the adhesive used remains resoluble or sensitive to heat, the reversibility of any adhered mend depends on the physical and chemical characteristics of the artifact material, the location of the mend, the amount of adhesive used, and the presence and type of support material. Adhesive on a smooth epidermal surface is much easier and safer to remove than adhesive on a porous or fibrous surface. Adhesive residue removal can usually be accomplished on smooth surfaces by rolling or wiping with solvent-dampened swabs. Complete removal of adhesive residue on porous or fibrous material is probably not possible without immersion in solvent. As this is usually neither feasible nor worth the potential alteration to the material, it should be assumed that some adhesive residue will have to remain. The more adhesive present, the more mechanical action and solvent or heat will be necessary to remove it. The amount of adhesive used should be the minimum necessary to achieve a sufficiently strong bond. Adhesive with a reinforcing tissue or cloth, and adhesive on a support thread, paper, or cloth are generally easier to remove than adhesive alone, as much of the adhesive can be lifted with the reinforcing or support material.

Generally, thread, paper, and cloth attached with starch or methylcellulose paste can be removed by lightly moistening the support until the paste is softened, and then lifting the support material from the artifact. If possible, adhesive can be removed by rolling or wiping with damp swabs.

Reversal of heat and solvent reactivated adhesive mends may in some cases be accomplished by peeling away the support material. In most cases, the adhesive is reactivated again by applying heat, solvent, or solvent vapor, and then the support material or the adhered artifact material is peeled away. Especially on fibrous surfaces, some adhesive is inevitably left on the artifact material. Gresson (1988) found that heat reactivated adhesive residue on barkcloth was more effectively and safely removed by heat mopping than by solvent rolling, blotting, or flow-through. Heat mopping involves laying an absorbent material over the residue, softening the adhesive with a tacking iron, and immediately lifting it. The process is repeated until no further adhesive residue responds to mopping. Absorbent material such as disposable synthetic fiber household cleaning cloths (for example Chux, Handy Wipes, or Quick Wipes) were found to be more effective in heat mopping than paper and woven cloth. Complete removal of all adhesive residue was not possible; some microscopic particles still remained embedded in fibers.

## Restoration

Restoration involves the replacement of losses for aesthetic reasons; the intention should be restoration sufficient to restore the visual integrity of the artifact. Sometimes, losses are replaced to make the object structurally stable. If this is done in a manner which attempts to simulate the original appearance of the object, it is considered restoration.

### Principles

Restoration should be attempted only if there is sufficient evidence of the appearance and structure of the original. This evidence is strongest if it exists on the original. For example, a partially lost basket rim can be restored based on the existing portions of the rim and on attachment holes and discoloration patterns on the wall supporting the lost rim, as long as evidence indicates that no variations in the rim occurred in the area of loss. Photographic and other documentary evidence of earlier conditions of the basket are also used. If the rim was totally lost, and no documentary record of its construction existed, replacement would have to be based primarily on other similar baskets and documentation in the literature, supported by any attachment holes and discoloration patterns in the basket wall. This type of reconstruction, which assumes that the basket followed the pattern and structure of similar baskets and had no individual variation or idiosyncrasies, would not generally be acceptable. Rose (1985) cites several examples of incorrect restoration where the restorer did not account for traditional or individual construction and design variations. Generally, only losses known to be postcollection losses should be considered for restoration. An apparent loss on an artifact could well be the result of precollection use or adaptation.

Restoration should be subtle enough to blend into the object visually, but should be obvious upon examination. The aim of restoration is to make the object visually whole, not to deceive the viewer.

As far as possible, one would try to use stable restoration materials that would not cause degradation of artifact materials and would be reversible without damage to the artifact. The behavior of restoration materials must also be considered. For example, the density and movement of a filler in a fluctuating relative humidity environment must be compatible with the density and movement of the artifact materials.

### Fills

Losses in artifacts may require filling or replacement for structural reasons. When such fills are made to simulate the original, they may be considered restoration as well as mending. Some losses may not structurally endanger the artifact if it is dead storage, but may leave existing portions or elements exposed and in danger of loss if the artifact is frequently handled for study, documentation, or loan, making filling desirable. Other losses are filled or replaced for visual reasons. Where losses disrupt the original form or design of the artifact, its aesthetic integrity may be harmed.

When choosing fill materials, factors such as the visual appearance, applicability, removability, and compatibility with the artifact must be considered. Fills

may be left exposed or may be inpainted. Either way, the appearance and texture of the fills are important in making them visually sympathetic with the artifact. A pigmented soft wax fill, for example, may be ideal for recreating the depth and sheen of a lacquered surface, but would be inappropriate for filling rattan core where a matte fibrous fill is needed. Where fill materials of the desired appearance do not meet the structural and behavioral demands of the fill, compound fills can be used. Applicability refers to the requirements of the conservator and the artifact in application of the fill. The texture, viscosity, and fineness of fill materials must be such that the conservator can manipulate them to most safely get them into place and work them to the required texture or finish, and that this can be done in a way likely to cause the least danger of contamination and disfigurement of the artifact. For example, when filling a narrow loss in a porous material, fills such as the commercial putties may be difficult to apply without getting their fine white filler embedded in the loss surfaces and in the artifact surface just next to the fill. Putties made of thick paste and fine paper pulp or sawdust can be more easily applied by packing in small beads, and any fibers that may get on the artifact surface can be picked off.

Removability involves considerations such as limiting the contamination of the artifact through the use of solid fills or putty fills of a high enough viscosity that they do not penetrate into the artifact material, and determining whether they can be removed mechanically or whether solvent removal will be necessary. Isolating the fill material from the artifact can aid removal and also helps prevent contamination. This is sometimes done by applying a varnish to the surfaces of the loss, or by laying an isolating paper or cloth over the loss surfaces. A fill must be compatible with the artifact material to avoid damage to the artifact. For example, a stiff fill material on barkcloth could lead to breakage and loss of the barkcloth fibers surrounding the fill when the barkcloth is flexed during handling. Plant materials respond to changes in moisture content by expanding and contracting. If a dense, nonelastic material is used to fill artifacts—especially materials like wood and bamboo—damage to the artifact upon expansion can occur, and damage to the fill upon contraction may occur, requiring its removal and application of a new fill.

A wide variety of fill materials have been used to meet the requirements of the type of lost material, the location and extent of loss, applicability, and removability. Solid materials used include: polyethylene foam, wax, paper sheet and strips, cloth, cordage, wood veneer, balsa wood, rattan, and bamboo. Putties are formulated using binders of starch and methylcellulose paste, resins such as Paraloid B-72 and silicone rubber, and fillers of paper fiber, sawdust, fumed silica, and phenolic and glass microballoons and microspheres. Commercial putties such as Liquitex Acrylic Modelling Paste and various grades of Polyfilla are also used.

## Inpainting

Inpainting is done on fill and mend materials to make them blend with the color tones of the artifact. Some restoration and mend materials, such as paper, cloth, and plant materials may be colored by dyeing or staining prior to application to avoid the difficulty of applying paint to the fill or mend without also contaminating the artifact with paint. As far as possible, stable pigments and media are used to avoid future removal and repainting should color alteration occur.

Dry pigments mixed with resin and paste media, and commercially prepared inks, watercolor, and acrylic paints have been used. Color density is controlled by pigment and medium concentration and number of coats. Inpaint texture may be controlled by the surface texture of the fill and/or by the type of medium, the use of matting agents, and pigment and medium concentration. For example, thick, dense matte paint can be achieved by stippling on thick methylcellulose paste with high pigment concentration. Acrylic resin, such as Paraloid B-72, can make a translucent highly glossy inpaint if used with a high resin, low pigment concentration, or it can make a translucent matte inpaint if used with a high resin, low pigment, high matting agent (such as fumed silica) concentration, or it can make an opaque matte inpaint if a high pigment concentration is used.

Depending on the circumstances, inpainting may be applied to match the general color tone of the area surrounding the loss, or may be blended, stippled, and streaked to match subtle color variations. Should it be decided to inpaint design elements where disruption of the design is distracting under display, this should only be done for those elements of design which can be clearly deduced from the existing design (for example, inpainting a design element that has been interrupted by a small fill).

Occasionally, inpainting on original artifact material may be requested. For example, where fresh abrasion has removed original surface coating or patination, exposing disfiguringly bright fresh material, or where paint has been lost by flaking in areas which disfigure the design, retouching these areas may be considered if the artifact were to be put on display. If it is decided that inpainting is desirable and appropriate, the materials used should be removable without distubing the original material, and efforts should be made to isolate the original material to prevent penetration of new stains and pigments. Sometimes, it is possible to lay-in an isolating sheet of fine tissue or cloth. In thin areas of loss, however, only an isolating varnish is possible. This begs the issue to the extent that an isolating varnish also penetrates into the original material, but this at least may be less detrimental to the artifact than the penetration of colored matter.

## Replacement of Design Elements

For display purposes, loss of some design elements may be considered disfiguring, or may be felt to distort the maker's original visual concept. For example, the shells and seeds pressed into clay putty, wax, or resin relief are frequently dislodged and lost. Where the type and location of seed and shell are obvious from the impression in the relief, replacement of lost elements presents few ethical difficulties, if it is clear that the losses occurred after collection and were not losses that were tolerated by the artifact makers and users. Each replacement piece should be marked in some way that will clearly indicate upon examination of the artifact that it is a replacement.

## Reconstruction

Reconstruction of lost appendages, decorative elements, or sections of artifacts is sometimes requested by artifact owners or caretakers, especially for artifacts displayed publicly or privately as "art objects" whose primary function or value to the

owner is their visual impact. The argument that lost portions or elements distort the intended visual impact of the artifact is a valid one. However, the argument that no reconstruction of lost material can be entirely accurate and that the reconstruction could itself distort the visual impact and documentary evidence of the artifact is also valid. Certainly, for research collections, there are very few arguments for, and many strong ones against, reconstruction. In other circumstances, decisions must be based on the uniqueness, current use, and history of the artifact; the function, construction, uniqueness, and extent of the missing portion; the possibility of alternative presentation of the artifact (such as accompanying photographs of other complete artifacts of that type); and the likelihood of documentation of the reconstruction remaining with the artifact.

## Restoration on Artifact Types or Materials

Fills in basketry recorded in the conservation literature include the use of similar interworked plant materials and paper strips, and the use of molded paper pulp putty. Govier (1980) filled losses in a closely twined hat using rattan strips adhered with a poly(vinyl acetate) adhesive to replace vertical elements, and interworked dyed paper strips adhered with a cellulose nitrate adhesive to replace the active horizonal elements. Fenn (1980) used wood trim strips (wood veneer on a paper backing) to replace lost splints in woven splint baskets. Hartley (1978) recommends the use of thick Japanese paper strips coated with a poly(vinyl acetate) emulsion to replace lost elements. The strips were interworked in the manner of the original, adhered to the basket with a poly(vinyl acetate) emulsion, and inpainted with acrylic emulsion paint. Thomsen (1981) filled losses in a twined basket with molded fibers. A silicone rubber (RTV silicone/2) mold was taken from a sound area of the basket. Prior to taking the mold, basket fibers were protected with a coating of microcrystalline wax in Stoddard Solvent. A sheet of cotton fibers mixed with an acrylic resin (Pliantex) was cast in the mold and, when dry, was trimmed to fit the area of loss, aligning the sheet to match the texture of the adjacent original. It was attached with methylcellulose paste and inpainted with acrylic paints.

Grant and Barclay (1986) demonstrated the use of metal foil to take molds of basketry for filling. Lead/tin 60/40 solder sheets were rolled to make them thin. The thin sheet was placed over a strong area similar in texture to the area of loss, and rubbed and impressed with fingers and blunt instruments to conform with the basket surface texture. The sheet was then gently straightened if curved, and laid onto wet plaster of paris, which when set, provided a rigid backing. A thin film of paper pulp mixed with methylcellulose paste was laid in the mold and the sandwich placed in a screw press to dry. A second cast was made, creating two sheets which, when placed back to back, made a fill with the basketry texture on both sides. These were trimmed to fit the area of loss, adhered in place, and inpainted.

Fills in barkcloth are not often required. As it is a relatively thin sheet, dyed patches or lining usually provide a sufficiently similar surface that can be inpainted if necessary. For thick barkcloth, thick Japanese paper infills can be used if necessary. The thick paper is water cut to the desired shape such that the feathered edges only overlap the barkcloth. These edge fibers are pasted out and the fill laid in place. If the barkcloth is not lined, the fill is secured with thin paper strips pasted over the

join. If it is lined, the lining is usually sufficient to secure the fill. Green (1986a) recommended handcast paper pulp fills for losses in thick barkcloth, especially for small losses in areas decorated with a resinous paint. A pulp slurry was made by blending blotter paper or Japanese paper in water using an electric blender. Wheat and rice starch paste were mixed with the slurry (these were found superior to methylcellulose paste as they could be worked drier), which was then spread out on drying screens to dry to a wet putty consistency. Putty made using blotter-paper fibers matched the texture of coarse barkcloth well, while the longer Japanese paper fibers were best for fine, thin barkcloth. Silicone release paper was placed under the barkcloth, and the fill putty applied with a spatula. The area was covered with blotter and weighted until dry. Color tones were matched by tinting the pulp or by painting the fill.

Palm leaf manuscripts frequently have losses around edges and around the holes used for binding them together. These losses can be filled using the thick Japanese paper infill method described for thick barkcloth. Dyed paper is laminated to achieve the correct thickness, and the fill is secured with strips of translucent paper, like L-tissue, around the join. Crowley (1969) made fills of paper-backed wood veneer sheet cut to shape and secured. Agrawal (1984) filled tiny holes with a pulp putty of Japanese paper fibers and methylcellulose paste. For large fills and holes, thick Japanese paper was cut slightly larger than the hole size. The edge of the hole in the leaf was roughened, adhesive was applied to the leaf, and the fill was inserted with a 2 mm overlap. Alternatively, other palm leaves were cut to shape slightly larger than the loss, both the old and the new leaf edges were beveled, and the fill adhered in place with a poly(vinyl acetate) emulsion. The mutilation of the original leaf and the use of palm leaf for fills do not seem justifiable when other methods and materials are satisfactory.

Fills used for rigid artifact materials such as wood, bamboo, palm wood, gourds, and so on, are variable depending on the characteristics and properties of the particular material and on the location and function of the area of loss. Putties and commercial fillers are frequently used. A putty of methylcellulose and sawdust (about 8% w/v methylcellulose filled to saturation with sawdust) has been used to fill losses in wood and other stem material. Termite damage often results in an unsupported thin skin of surface wood, as well as surface losses. Small pellets of the putty are packed into the loss in stages, allowing a layer several millimeters thick to dry before applying the next. The putty provides support for the skin while also adhering it. For interior areas, large sawdust is used and balsa wood chips are inserted in the applied putty to reduce shrinkage. Fine sawdust is used for the final surface layer so that very little, if any, sanding is necessary. Projecting losses are modeled in a similar manner. The putty is also useful for securing loose fibrovascular bundles of degraded palm wood. Carved balsa wood is a useful fill material, as it is easily shaped and has a lower density than many solid materials. Patterson (1978) used BJK (AJK) dough to fill losses in gourds used for musical instrument sound boxes. The considerable shrinkage that occurs with the original Institute of Archaeology (University of London) formulation can be circumvented by allowing small areas to dry before applying the next, or by using sawdust or phenolic microballoons in place of the original jute flock and kaolin filler. Reeve (1987) filled losses in the clay putty relief

of a Papua New Guinea orator's stool with plaster of paris made with 95/5 water/poly(vinyl acetate) emulsion, with pigment and other broken clay fragments added to achieve the desired color and texture. Losses were first lined with nylon gossamer to aid fill removal. Paraloid B-72 filled with fumed silica, microballoons, and so on, is a versatile fill. Hatchfield (1986) discusses the formulation and application of Acryloid B-72 and glass microsphere putty. The putty has wide application because of its light weight and good aging properties. The putty must be quite stiff to prevent absorption of the resin into porous materials resulting in darkening of the material.

Barclay and Grattan (1987) recommend a compound fill of polyethylene foam and silicone rubber filled with microballoons for cracks in soft and hard wood. The top 3 mm to 4 mm of the crack are sealed with ethyl or methylcellulose paste to prevent penetration of the fill into the wood. The crack is filled to within 3 mm to 4 mm of the surface with the polyethylene foam. Silicone rubber 734 RTV or 738 RTV is mixed with phenolic microballoons or glass bubbles in a proportion of 3 to 1 or 2.5 to 1 and applied to the top portion of the crack. Pigments may be added to the fill, and the fill may be carved or sanded when cured. The fill's elasticity and low modulus of compression would also make it suitable to fill cracks in other highly moisture responsive materials like bamboo.

## Conclusion

The primary concern of conservators responsible for artifacts is to stabilize and prevent them from being subjected to further damage. Some aspects of conservation treatments, such as cleaning to remove damaging dirt and restorations, and mending to prevent further structural damage, are designed to remove harmful factors. However, the greatest impact a conservator can have on artifacts' stability concerns not the treatment of specific artifacts, but the development of a safe physical, chemical, biological, and human environment for the whole collection. Collection care and preventive conservation have been discussed in this chapter only briefly, not because they do not deserve in-depth discussion, but because they have already been discussed in detail in the conservation literature. This literature should be studied for information on light, relative humidity, atmospheric pollutants, pest management, storage and display methods and design, handling, transport, and so on.

Conservation treatment procedures have been discussed with the intent of examining their purpose and the implications of the procedures on artifact stability and integrity. Specific materials and techniques are presented either to review past and current treatment or to serve as examples. With increasing knowledge and awareness of artifact significance and of artifact materials' composition and properties, a better understanding of the damage or alteration that can be done unintentionally to an artifact in the course of treatment continues to develop. It is evident that caution and reserve are called for in the treatment and care of collections, and that even greater energies must be devoted to the compilation and determination of the information necessary to understand the behavior and interaction of artifact and conservation materials.

# References


**Agrawal, O.P.**

1975 Conservation in South and South-East Asia. *Museum* XXVII (4), 155–212.

1979 *Termites: A major problem in museums.* Rome: ICCROM.

1981 Problems of preservation of palm-leaf manuscripts. *ICOM Committee for Conservation Preprints*, 6th Triennial Meeting, Ottawa, (81/14/17):1–7.

1984 *Conservation of manuscripts and paintings of South-East Asia.* London: Butterworths.

**Agrawal, O.P. and S.K. Bhatia**

1981 Investigations for preservation of birch bark manuscripts. *ICOM Committee for Conservation Preprints*, 6th Triennial Meeting. Ottawa, (81/14/18):1–4.

**Agrawal, O.P. and S. Dhawan**

1984 Studies on fungal resistance of birch-bark. *ICOM Committee for Conservation Preprints*, 7th Triennial Meeting. Copenhagen, (84/25):1–3.

**Agrawal, O.P., C.B. Gupta, and D.G. Suryavanshi**

1984 Conservation and study of the properties of birch-bark. *ICOM Committee for Conservation Preprints*, 7th Triennial Meeting. Copenhagen, (84/14):1–4.

**Allington, C.**

1986 The consolidation of cellulosic fibre materials. In *Abstracts of papers presented at Symposium 86: The care of ethnological materials.* Ottawa: Canadian Conservation Institute, 55–56.

**Ames, M.M.**

1977 Visible storage and public documentation. *Curator* 20(1):65–79.

1985 De-schooling the museum: a proposal to increase access to museums and their resources. *Museum* XXXVII(1):25–31.

**Bakken, A.**

1987 Museums in the third world: conservation in developing countries. *Ethnographic Conservation Newsletter* (ICOM Committee for Conservation working group on ethnographic materials) 3:1–3.

**Bakken, A. and K. Aarmo**

1978 A report on the treatment of museum materials made of plant fibres. *ICOM Committee for Conservation Preprints*, 5th Triennial Meeting. Zagreb, (78/3/2):1–4.

1981 A report on the treatment of barkcloth. *ICOM Committee for Conservation Preprints*, 6th Triennial Meeting. Ottawa, (81/3/4):1–4.

**Barclay, R. and D. Grattan**

1987 A silicone rubber/microballoon mixture for gap filling in wooden objects. *ICOM Committee for Conservation Preprints*, 8th Triennial Meeting. Sydney, 183–188.

**Barkman, L.-E.**

1984 Storage at the new Ethnographical Museum in Stockholm. *ICOM Committee for Conservation Preprints*, 7th Triennial Meeting. Copenhagen, (84/3):3–6.

1986 What is the true nature of the object? *Ethnographic Conservation Newsletter* (ICOM Committee for Conservation working group on ethnographic materials) 2.

**Barton, G.**

1986 Conservation of a Maori kite. *Abstracts of papers presented at Symposium 86: The care of ethnological materials.* Ottawa: Canadian Conservation Institute, 53–54.

1986 *Ultrasonic cleaning tests in aqueous solutions on Maori cloak materials.* Auckland: Conservation Department, Auckland Institute and Museum.

**Barton, G., and S. Weik**

1987 An investigation into the ultrasonic cleaning of New Zealand Maori cloak materials. *ICOM Committee for Conservation Preprints*, 8th Triennial Meeting. Sydney, 189–194.

**Baxi, S.J.**

1974 Climate and museum architecture in the tropics. In *Conservation in the tropics.* O.P. Agrawal, ed. New Delhi: International Centre for Conservation, 69–73.

**Baynes-Cope, A.D.**

1982 Infestations and collections. In *The care of ethnographic material*, occasional paper No.1, D.L. Jones, ed. Ipswich: Ipswich Museum, 22–25.

**Bhowmik, S.**

1974 Design of a museum building and preservation. In *Conservation in the tropics.* O.P. Agrawal, ed. New Delhi: International Centre for Conservation, 74–80.

**Bird, J.B. and M. Dimitrijevic**

1964 The care and conservation of ethnological and archeological backstrap looms. *Curator* 7(2):98–120.

**Blackshaw, S.M.**

1982 The testing of display materials. In *The care of ethnographic material*, Ipswich Museum Occasional Paper No.1, D.L. Jones, ed. Ipswich: Ipswich Museum, 40–45.

**Blackshaw, S.M. and Y.D. Daniels**

1979 The testing of materials for use in storage and display in museums. *The Conservator* 3:16–19.

**Boustead, W.**

1966 Conservation of Australian Aboriginal bark paintings with a note on the restoration of a New Ireland wood carving. *Studies in Conservation* 11(4):197–204.

**Byrne, R.O.**

1984 An Easter Island effigy figure display case. *ICOM Committee for Conservation Preprints*, 7th Triennial Meeting. Copenhagen, (84/17):9–10.

**Cameron, D.F.**

1982 Museums and public access: The Glenbow approach. *The International Journal of Museum Management and Curatorship* 1(3):177–196.

1983a Care of basketry. *CCI Notes* 6/2. Ottawa: Canadian Conservation Institute.

1983b Labelling museum textiles. *CCI Notes* 13/8. Ottawa: Canadian Conservation Institute.

**Carson, V.**

1985 Caring for a feather cloak. In *Conservation of cultural property*, No. 1. Wellington: Interim Committee for the Conservation of Cultural Property.

**Chesna McNeil, K., J.G. Johnson, D.J. Joyce, and R. Blazina-Joyce**

1986 Mounting ethnographic garments. *Curator* 29(4):279–294.

**Christensen, G.**

1985 The deterioration of New Zealand flax. Otago University research project. In *Conservation of cultural property*, No. 1. Wellington: Interim Committee for the Conservation of Cultural Property.

**Clapp, A.F.**

1979 *Curatorial care of works of art on paper.* Oberlin, OH: Intermuseum Conservation Laboratory.

**Clark, L. and N. Burmingham**

1986 Backing bark paintings using expanding polyurethane foam. Written account of procedure held at the Conservation Laboratory, Museum and Art Gallery of the Northern Territory, Darwin: Northern Territory, Australia.

**Clavir, M.**

1976 A preliminary study on the deacidification of basketry. Conservation Research Project, Art Conservation Programme, Kingston, Ontario: Queen's University.

**Clavir, M., E. Shane, and E. Johnson**

1986 A discussion on the use of museum artifacts by their original owners. *Abstracts of papers presented at Symposium 86: The care of ethnological materials.* Ottawa: Canadian Conservation Institute, 25–26.

**Conservation Analytical Laboratory**

n/d Conservation information sheets. Washington, D.C.: Conservation Analytical Laboratory, Smithsonian Institution.

**Cornu, E. and J. Heuman**

1982 The conservation of two mounted pearl shells from New Guinea. *AIC Preprints.* American Institute for Conservation 10th Annual Meeting, 63–70.

**Cranstone, B.A.L.**

1958 Ethnography. In *Handbook for curators.* Part C, Section 4. London: The Museums Association.

**Creamer, H.**

1976 The involvement of the Aboriginal people in the conservation of their sites and culture. *Proceedings of the National Seminar on the Conservation of Cultural Material.* C. Pearson and G.L. Pretty, eds. Perth: Institute for the Conservation of Cultural Materials, 66–68.

**Crowley, A.S.**

1969 Repair and conservation of palm-leaf manuscripts. *Restaurator* 1(2):105–114.

**Daniels, V.D.**

1982 Labelling ethnographic material. In *The care of ethnographic material*, Ipswich Museum Occasional Paper No. 1, D.L. Jones, ed. Ipswich: Ipswich Museum, 46–48.

**Drummond, G.**

1986 The mending of insect damaged feather vanes. Degree Conservation Project, Conservation of Cultural Materials Training Program. Canberra, Australia: Canberra College of Advanced Education.

1987 Case studies: Support systems for fragile ethnographic objects. *Ethnographic Conservation Newsletter* (ICOM Committee for Conservation working group on ethnographic materials) 4:20–23.

**Edet, A.S.**

1985 An investigation of methods and materials used in the repair of ethnographic objects made of vegetable fibres/basket-work and matting. Degree Dissertation in Conservation, Department of Archaeological Conservation and Materials Science. London: University of London, Institute of Archaeology.

**Erhardt, D.**

1983 Removal of silicone adhesive. *Journal AIC* 22(2):100.

**Erhardt, D. and N. Firnhaber**

1987 The analysis and identification of oils in Hawaiian oiled tapa. In *Recent advances in the conservation and analysis of artifacts.* London: University of London, Institute of Archaeology, Summer School Press, 223–227.

**Feigl, F. and V. Anger**

1966 *Spot tests in organic analysis.* London: Elsevier.

**Feller, R. and M. Wilt**

1990 *Evaluation of Cellulose Ethers for Conservation.* Los Angeles: The Getty Conservation Institute.

**Fenn, J.**

1980 The conservation of splint baskets. *Ontario Museum Association Quarterly* 9(3):2122.

**Firnhaber, N.**

1979 A report on the conservation of bark cloth. Degree Dissertation in Conservation, Department of Archaeological Conservation and Materials Science. London: University of London, Institute of Archaeology.

1986 Hawaiian oiled and 'Mamaki Tapa': Investigation and conservation. *Abstracts of papers presented at Symposium 86: The care of ethnological materials.* Ottawa: Canadian Conservation Institute, 49–50.

**Florian, M.-L.E.**

1977 Plant material used in some ethnological artifacts: Structure, fabrication and deterioration related to conservation treatment. *AIC Preprints.* American Institute for Conservation 5th Annual Meeting, 51–55.

1987 The effect on artifact materials of the fumigant ethylene oxide and freezing used in insect control. *ICOM Committee for Conservation Preprints*, Vol. I. 8th Triennial Meeting. Sydney, 199–208.

**Force, R.W.**

1975 Museum collections: Access, use and control. *Curator* 18(4):249–255.

**Ford, M., K. Head, and B. Kertesz**

1985 The transport of Aboriginal artefacts: A packing and stabilization problem. *ICCM Bulletin* 11(3)111–122.

**Freed, S.E.**

1981 Research pitfalls as a result of the restoration of museum specimens. In *The research potential of anthropological museum collections.* A.M. Cantwell, J.B. Griffin, and N.A. Rothschold, eds. Annals of the New York Academy of Sciences No. 376. New York: New York Academy of Sciences, 229–245.

**Gardon, J.L. and J.P. Teas**

1976 Solubility parameters. In *Characterization of coatings: Physical techniques*, part II, R.R. Myers and J.S. Long, eds. New York: Marcel Dekker, 413–471.

**Gilberg, M.**

1986 Plasticization and forming of misshapen birch-bark artifacts using solvent vapours. *Studies in Conservation* 31(4):177–184.

**Gilberg, M. and R.L. Barclay**

1987 A mounting system for birch bark scrolls. *Ethnographic Conservation Newsletter* (ICOM Committee for Conservation Working Group on Ethnographic Materials) 3:10–12.

**Gilberg, M. and J. Grant**

1986 The care and preservation of birchbark scrolls in museum collections. *Curator* 29(1):67–80.

**Govier, T.**

1980 Haida hat: Conservation of an 1899 basketry rain hat. (Chapeau Haïda: Restauration d'un chapeau de pluie datant de 1899). *CCI Journal* 4:12–13.

**Gowers, H.J.**

1958 A storage fitting for arrows. *The Museums Journal* 58(1):13–14.

1968 The conservation of a Tlingit blanket. *Studies in Conservation* 13(2):98–101.

**Graham-Bell, M.**

1986 *Preventive conservation: A manual*. Victoria, B.C.: British Columbia Museums Association.

**Grant, J.**

1961 *A laboratory handbook for pulp and paper manufacture*. London: Edward Arnold.

**Grant, J.H.**

1978 The conservation of an Easter Island bird figure. *IIC-CG 4th Annual Conference Abstracts*.

**Grant, J.H. and R.L. Barclay**

1986 The use of metal foil in the conservation of basketry. Laboratory workshop, *Symposium 86: The care of ethnological materials*. Ottawa: Canadian Conservation Institute.

**Grattan, D.W.**

1978 The oxidative degradation of organic materials and its importance in deterioration of artifacts. *Journal IIC-CG* 4(1):17–26.

**Green, S.W.**

1986 Conservation of tapa cloth: filling voids. *Conference notes: New directions in paper conservation, 10th Anniversary Conference*. Oxford: The Institute of Paper Conservation, 84–86.

1986 Conservation of tapa cloth from the Pacific. *AIC Preprints.* American Institute for Conservation 14th Annual Meeting Papers, 17–31.

**Green, T. and S. Hackney**

1984 The evaluation of a packing case for paintings. *ICOM Committee for Conservation Preprints*, Vol.I. 7th Triennial Meeting. Copenhagen, (84/12):1–16.

**Greene, C.S.**

1978 Storage techniques for ethnology collections. *Curator* 21(2):111–128.

**Greene, V.**

1986 Storage renovation at the University Museum, University of Pennsylvania. *AIC Preprints.* American Institute for Conservation 14th Annual Meeting, 32–41.

**Gresson, J.**

1988 The use of heat-seal adhesives in the display of barkcloth. Degree Conservation Project, Conservation of Cultural Materials Training Program. Canberra, Australia: Canberra College of Advanced Education.

**Gyermek, S.A.**

1964 Conservation of ethnological material. *Museum News*, Technical Supplement (4):49–56.

**Hartley, E.**

1978 The care and feeding of baskets. Tacoma, WA: Emily Hartley.

**Hartley, E. and G.H. Grosso**

1981 Adhesives for basketry conservation: Preliminary tests. *ICOM Committee for Conservation Preprints*, 6th Triennial Meeting. Ottawa, (81/3/1):1–10.

**Hatchfield, P.**

1986 Note on a fill material for water sensitive objects. *Journal AIC* 25:93–96.

**Havyatt, V.**

1980 A simple method for storing spears and other long thin objects. *Kalori Quarterly Newsletter* 8.

**Hawthorn, A.**

1976 U.B.C.'s new Museum of Anthropology. *Canadian Geographical Journal* Oct.–Nov.:52–57.

**Hedley, G.**

1980 Solubility parameters and varnish removal: A survey. *The Conservator* 4:12–18.

**Himmelstein, P. and B. Applebaum**

1977 The use of sprayed polyvinyl acetate resin mixtures in mounting textiles. *Journal AIC* 17:37–44.

**Hinman, P.M.**

1983 The preparation and reactivation of polymer films and reinforced polymer films for the repair of plant fibre material. Degree Conservation Project, Conservation of Cultural Materials Training Program. Canberra, Australia: Canberra College of Advanced Education.

**Horton-James, D. and P. Townley**

1978 A consolidation/lamination technique for the treatment of fibrous materials. *ICCM Bulletin* 4(2, 3):60–63.

**Howatt-Krahn, A.**

1983 The accessible storage prototype at Glenbow: The mechanics of conservation. *IIC-CG 9th Annual Conference Abstracts.*

1986 Film for quill repair. Laboratory workshop, *Symposium 86: The care of ethnological materials.* Ottawa: Canadian Conservation Institute.

**Idiens, D.**

1973 New ethnographical storage in the Royal Scottish Museum. *Museums Journal* 73 (2):61–62.

1975 A survey of methods of storage of ethnographical collections. *ICOM Committee for Conservation Preprints.* 4th Triennial Meeting. Venice, (75/3/2):1–6. Institute for the Conservation of Cultural Materials. ICCM Code of Ethics, ICCM Newsletter 19 (June 1986).

**Johnson, E.V. and J.C. Horgan**

1979 Museum collection storage. *Protection of the Cultural Heritage Technical Handbooks for Museums and Monuments* No. 2., Paris: UNESCO.

**Koob, S.P.**

1982 The instability of cellulose nitrate adhesives. *The Conservator* 6:31–34.

**Kronkright, D.P.**

1980 Custom fitted supports for the storage of Native American basketry. *Newsletter of the American Association of Museums Western Regional Conference* (Summer):1–2.

1981 New directions in Native American basketry conservation. *AIC Preprints.* American Institute for Conservation 9th Annual Meeting, 95–108.

1987 Personal communication.

**Lambert, A.M.**

1983 *Storage of textiles and costumes: Guidelines for decision making.* Vancouver: University of British Columbia, Museum of Anthropology.

**Lee, D.J.**
1982 The conservation and storage of large ethnographic specimens. In *The care of ethnographic material.* Ipswich Museum Occasional Paper No. 1, D. L. Jones, ed. Ipswich: Ipswich Museum, 1–12.

**Lee, D.J., L. Bacon, and V. Daniels**
1985 Some conservation problems encountered with turmeric on ethnographic objects. *Studies in Conservation* 30(1):184–188.

**Leechman, J.D.**
1944 Preservation of fiber cordage in ethnological objects. *Museums Journal* 44:112.

**Losche, D. and S. Walston**
1982 Conserving ethnographic collections: Problems of documentation. *Museum* XXXIV(1):34–36.

**MacQueen, M.**
1982 The problems of displaying ethnographic material. In *The care of ethnographic material.* Ipswich Museum Occasional Paper No. 1. D.L. Jones, ed. Ipswich: Ipswich Museum, 29–36.

**Majewski, L.**
1973 On conservation: Care of ethnographic collections. *Museum News* 51(6):8–10.

**Marsh, F.J.**
1980 The repair of Islamic illuminated manuscript leaves and the conservation of palm-leaf manuscripts. In *The conservation of far eastern objects.* Tokyo: Tokyo National Research Institute of Cultural Properties, 3–16.

**McDonald, P.**
1972 A new approach to loan collections: The Australian Museum, Sydney. *Museum* XXlV(4):239–243.

**Mibach, L.**
1981 Traditional conservation practice among the North American Plains Indians: A summary of work in progress. *ICOM Committee for Conservation Preprints*, 6th Triennial Meeting. Ottawa, (81/3/11):1–3.
1986 Body building in the far frozen North or Mannikin construction, artifact supports and environmental packing systems for travelling exhibits at the Provincial Museum of Alberta. *AIC Preprints.* American Institute for Conservation 14th Annual Meeting Papers. Textile Specialty Group Abstracts, 159–160.
1986 The native North American approach to conservation. *Abstracts of papers presented at Symposium 86: The care of ethnological materials.* Ottawa: Canadian Conservation Institute, 29–30.

**Morrison, R.**
1982 *A handbook for paper conservation*, Vol. I. Canberra, Australia: Canberra College of Advanced Education.

**Mulvaney, D.J.**
1977 The preservation of the Aboriginal cultural heritage. In *Conservation in Australia*, S. Walston, ed. Sydney: Institute for the Conservation of Cultural Materials, 17–18.

**Munro, S.N.**
1984 The conservation of a Hawaiian sleeping tapa. *ICOM Committee for Conservation Preprints*, 6th Triennial Meeting. Ottawa, 1981(81/3/3):1–5.

**National Institute for the Conservation of Cultural Property, Inc.**
1984 *A suggested curriculum for training in ethnographic and archaeological conservation.* Washington, D.C.: National Institute for the Conservation of Cultural Property.

**Nicklin, K.**
1983 Traditional preservation methods: Some African practices observed. *Museum* XXXV (2):123–127.

**Niinimaa, G.S.**
1984 Accessible storage and mounting systems for textiles and ethnographic objects. Harpers Ferry Regional Textile Group 7th Annual Symposium. Available on tape cassette from Cassette Recording Co., P.O. Box 20453, Dayton, Ohio 45420.
1986 Mounting systems for ethnographic textiles and objects. *AIC Preprints.* American Institute for Conservation 14th Annual Meeting Papers. Objects Specialty Group Abstracts, 145.

**Norton, R.E.**
1984 Practical manual for the storage and display of textiles: For museums in south-east Asia. *Studies and Documents on the Cultural Heritage*, No. 8. Paris: UNESCO.
1984 The stabilization, mounting and packing of a Tahitian's mourner's costume. *ICCM Bulletin* 10(1):35–53.

**Oak, A. and L. Mibach**
1983 Creative traditions: A humidity-buffering mounting and crate system. *IIC-CG 9th Annual Conference Abstracts.*

**Odegaard, N.**
1986 The care of basketry collections. *Conservation Notes*, No. 16. Austin, TX: Texas Memorial Museum, University of Texas at Austin, 1–4.

**Odegaard, N. and R. Harvey**
1982 Twisted Japanese paper threads. Poster Session, AIC 10th Annual Meeting, Milwaukee.

**Odegaard, N. and D.P. Kronkright**

1984 Giving your baskets a long, healthy life: A basic guide to basketry conservation. *Fiberarts Magazine* 11(1):43–49.

**Patterson, C.**

1978 An approach to the conservation of ethnographical musical instruments. *The Conservator* 2:45–48.

**Pearlstein, E.**

1986 Fatty bloom on wood sculpture from Mali. *Studies in Conservation* 31(2):83–91.

**Pearson, C.**

1987 Vapor-phase deacidification. Personal communication. Canberra, Australia: Canberra College of Advanced Education.

**Peever, M.**

1986 Characterization of alteration to artifacts. *Abstracts of papers presented at Symposium 86: The care of ethnological materials.* Ottawa: Canadian Conservation Institute, 31–32.

1987 Personal communication.

**Petersen, K.S. and A. Sommer-Larsen**

1984 Cleaning of early feather garments from South America and Hawaii. *ICOM Committee for Conservation Preprints*, 7th Triennial Meeting. Copenhagen, (84/3):13–16.

**Phillips, S. and A. Gaulton**

1983 A storage and transportation system for Pukamani poles. *ICCM Bulletin* 9(3,4):93–100.

**Piechota, D.V.**

1986 Packing anthropological collections for transit. *Abstracts of papers presented at Symposium 86: The care of ethnological materials.* Ottawa: Canadian Conservation Institute, 5–6.

**Piechota, D.V. and G. Hansen**

1982 The care of cultural property in transit: a case design for travelling exhibitions. *Technology and Conservation* 7(4):32–46.

**Pomerantz, L.**

1975 The lining treatment of a painted cedar mat. *Bulletin AIC* 16(1):45–56.

**Pouliot, B.**

1986 Research on the conservation of African camwood: A project realized in a small conservation laboratory. *Abstracts of papers presented at Symposium 86: The care of ethnological materials.* Ottawa: Canadian Conservation Institute, 65–66.

**Pretty, G.L.**
1976 The ethnographic collections in the South Australian Museum. *Proceedings of the National Seminar on the Conservation of Cultural Materials*, Perth 1973. C. Pearson and G.L. Pretty, eds. Canberra, Australia: Institute for the Conservation of Cultural Material, 107–119.

**Priestman, K.B.**
1984 Conservation and storage: Ethnological material. *Manual of curatorship.* J.M.A. Thompson, ed. London: Butterworths, 302–307.

**Reeve, B.**
1987 The conservation of an orator's stool from Papua New Guinea. *ICCM Bulletin* 13(3,4):89–106.

**Reeves, P.**
1979 Use of BEVA in the conservation of an interlocked warp and weft Nazca texile. *AIC Preprints.* American Institute for Conservation 7th Annual Meeting, 108–115.

**Renshaw-Beauchamp, R.B.**
1983 The conservation of ethnographic material. *Museum* XXXV(3):194–197.

**Reynolds, B.**
1962 Some ideas on the storage of ethnographic material. *Museums Journal* 62(2):102–109.

**Rose, C.**
1985 Ethical and practical considerations in conserving ethnographic museum objects. *The Ninth International Taniguchi Foundation Symposium: Conservation of ethnographic objects in museums.* Osaka, Japan: National Museum of Ethnology.

**Roussakis, V.**
1986 Storage renovation and mounting techniques for the Andean textile collection at the American Museum of Natural History. Harpers Ferry Regional Textile Group 8th Annual Symposium. Available on tape cassette from Cassette Recording Co., P.O. Box 20453, Dayton, Ohio 45420.

**Rymar, G.I.**
1978 Conservation and restoration of birch-bark manuscripts. *ICOM Committee for Conservation Preprints*, 5th Triennial Meeting. Zagreb, (78/14/17):1–6.

**Satterwait, L. and N. Chadwick**
1978 A storage fitting for spears. *Kalori* (55):27–30.

**Schaffer, E.**
1976 The preservation and restoration of Canadian ethnographic basketry. *Studies in Conservation* 21(3):129–133.

1978 Water soluble plastics in the preservation of artifacts made of cellulosic materials. *ICOM Committee for Conservation Preprints*, 5th Triennial Meeting. Zagreb, (78/3/7):1–16.

**Schur, E.**

1981 Laboratory profile: The Anthropology Conservation Laboratory, Smithsonian Institution. *Technology and Conservation* 6(4):26–35.

**Scott, M.**

1986 Evaluation of solvent systems for the swelling of cured epoxy resins. Degree Conservation Project, Conservation of Cultural Materials. Canberra, Australia: Canberra College of Advanced Education.

**Sease, C.**

1983 Caring for primitive art objects. *Art and Antiquities* Sept.–Oct.:98–104.

1984 Problems in lighting and display: An example from the Metropolitan Museum. *ICOM Committee for Conservation Preprints*, 7th Triennial Meeting. Copenhagen, (18/17):54–55.

**Selick, M.**

1987 Birchbark repair. *Ethnographic Conservation Newsletter* (ICOM Committee for Conservation working group on ethnographic materials) 3:12–13.

**Sitwell, C.**

1983 Technical and practical considerations in the design of packing cases for paintings. *AIC Preprints*, American Institute for Conservation, 11th Annual Meeting Papers, 113–119.

**Slade, S.**

1985 The suitability of threads for use in the conservation of basketry. Degree Conservation Project, Conservation of Cultural Materials Training Program. Canberra, Australia: Canberra College of Advanced Education.

**Smith, M.A., N.M.M. Jones, S.L. Page, and M.P. Dirda**

1984 Pressure sensitive tape and techniques for its removal from paper. *Journal AIC* 23:101–103.

**Smithsonian Institution**

n.d. Basic basketry conservation. Black-and-white videotapes and booklet. Washington, D.C.: Smithsonian Institution.

**Staniforth, S.**

1984 The testing of packing cases for the transport of paintings. *ICOM Committee for Conservation Preprints*, 7th Triennial Meeting, Copenhagen, (84/12):7–16.

**Staniforth, S., ed.**
1985 Packing cases—safer transport for museum objects. United Kingdom Institute for Conservation, one-day meeting, 21 June.

**Storch, P.S.**
1982 The analysis and identification of residues on African objects. M.A. thesis, George Washington University Graduate School of Arts and Sciences. Washington, D.C.: George Washington University.

**Story, K.O.**
1985 *Approaches to pest management in museums.* Conservation Analytical Laboratory. Suitland, MD: Smithsonian Institution.

**Sturtevant, W.C.**
1977 Guide to field collecting of ethnographic specimens. *Smithsonian Information Leaflet* 503. Washington, D.C.: Smithsonian Institution Press.

**Thomsen, F. G.**
1976 Mending baskets. *Conserve O Gram.* Harper's Ferry, WV: National Park Service Harper's Ferry Center.
1981 Repair of a Tlingit basket using molded cotton fibres. *ICOM Committee for Conservation Preprints*, 6th Triennial Meeting, Ottawa, (81/8/2):1–3.

**Thomson, G.**
1978 *The museum environment.* London: Butterworths.

**Tilbrooke, D.R.W.**
1979 The problem of naphthalene in ethnographic collections. *ICCM Bulletin* 4(2,3):75–76.

**Turchan, C.**
1986 Conservation repair techniques for 'Tapa': Conservation and research into special problems of the Bishop Museum Tapa Collection, Phase III. *Abstracts of papers presented at Symposium 86: The care of ethnological materials.* Ottawa: Canadian Conservation Institute, 51–52.

**Tworek, B.**
1985 Restoration of the flexibility of degraded monocot leaves. Degree Conservation Project, Conservation of Cultural Materials Training Program. Canberra, Australia: Canberra College of Advanced Education.
1987 Restoration of flexibility of degraded monocot leaves used in artifacts. *ICCM Bulletin* 13(3,4):63–76.

**Vandyke-Lee, D.J.**
1979 An ethnographic collecting expedition to Papua New Guinea: Field-conservation and laboratory treatment. *The Conservator* 3:43–46.

**Verdu, J., V. Bellenger, and M.O. Kleitz**

1984 Adhesives for the consolidation of textiles. Adhesives and Consolidants. *IIC Paris Congress Papers*, 64–69.

**Vuori, J.**

1984 A method for putting crepeline onto mats. *Textile Conservation Newsletter* (Fall):11–14.

**Walston, S.**

1984 Techniques for minimizing environmental damage to wooden objects moved from Papua New Guinea to Australia with particular reference to seasoning. *ICOM Committee for Conservation Preprints*, 7th Triennial Meeting. Copenhagen, (18/17):56–62.

1988 A mounting system for paintings on bark. *Abstracts of papers presented at Symposium 86: The care of ethnological materials.* Ottawa: Canadian Conservation Institute, 47–48.

**Walston, S., K. Coote, and D. Horton-James**

1985 Ethnographic collections: Case studies in the conservation of moisture-sensitive and fragile materials. *The Ninth International Taniguchi Foundation Symposium: Conservation of ethnographic objects in museums.* Osaka, Japan: National Museum of Ethnology.

**Walston, S., D. Horton-James, and S. Zounis**

1987 Investigation into methods and materials for the adhesion of flaking paint on ethnographic objects: A progress report. *ICOM Committee for Conservation Preprints*, 8th Triennial Meeting. Sydney, 833–841.

**Walston, S. and P. Gill**

1979 Conservation of The Australian Museum's collection of Aboriginal bark paintings. *ICCM Bulletin* 4(2,3):54–59.

**Ward, P.R.**

1978 In support of difficult shapes. *Museum Methods Manual* No. 6, Victoria, BC: British Columbia Provincial Museum.

1982 Poor support: The forgotten factor. *Museum* 34(1):54–56.

**Welsh, E.C.**

1984 Displaying Navajo textiles. *Masterkey* 58(4):26–27.

**Wolf, A.H.**

1980 Open storage for a research collection. *Curator* 23(4):249–254.

**Wolf, S.J.**

1976 Guidelines for travelling exhibits. *Curator* 19(1):226–232.

1977a A survey of basketry cleaning methods. *American Indian Art Magazine* 2(3):24–25.

1977b Caring for your basketry collections. *American Indian Art Magazine* 2(2):18–19.

1982 Hanging Navajo blankets. *Conservation Notes*, No. 1 Austin, TX: Texas Memorial Museum, University of Texas at Austin, 1–4.

1983a Repair and display of Fijian tapa cloth. *Conservation Notes*, No. 5. Austin, TX: Texas Memorial Museum, University of Texas at Austin.

1983b The treatment of Native American sacred objects. Paper presented to the Objects Specialty Group, American Institute for Conservation 11th Annual Meeting. *AIC Newsletter* 8(2):6.

**Wolf, S.J. and P. L. Denton**

1985 Labelling museum specimens. *Conservation Notes*, No. 11. Austin, TX: Texas Memorial Museum, University of Texas at Austin, 1–4.

**Wolf, S.J. and G. Fullman**

1980 Notes on the treatment of Fijian tapa cloths. *ICCM Bulletin* 6(3,4):58–64.

**Wolf, S.J. and L. Mibach**

1983 Ethical considerations in the conservation of Native American sacred objects. *Journal AIC* 23(1):1–6.

Appendix 1

# Mending Structures with Twisted and Folded Mulberry Paper Strands

*Dale Paul Kronkright*

Several fundamental points made in Chapter 4 about plant material artifacts bear review when considering conservation treatments (see the section on Mechanical Damage in Chapter 4).

First, artifacts are generally fabricated using structural techniques that allow the physical load or stress to be distributed in the manner predetermined by the maker. In use, the structures—and the shapes they create—need to successfully accomplish the intended goals in utility, expression, wear, and economy that the maker valued. When a structure is altered by damage, the relationships between the structural elements change, and all elements undergo stresses for which they were never intended.

Second, repair techniques for damaged structures generally need to be very specific to the structural roles they must play within the artifact. Reading the artifact for structural information and visible evidence of utility in a systematic manner provides the insight necessary to correctly interpret structural intent and begin to plan appropriate repair measures. For example, warps often control much of the weight, strength, and shape in woven structures. Repairing a broken warp should address the need for structural definition that the damaged warp originally provided. A weft provides surface area, transmits loads, hinges, flexes, and binds together woven structures. Repairs to a weft should likewise specifically address these roles in a torn or damaged structure.

Next, it must be remembered that damage cannot be undone. It can be avoided or mitigated, but, in fact, there is no going back. Consequently, the conservator's duty falls clearly into four areas of responsibility. First and foremost, the artifact needs to be protected from new damage or deterioration. Therefore, conservators first seek to preserve those aspects of an artifact's materials and structures that are stable and intact, regardless of what else needs to be done. Existing damage needs to be stabilized by treating either the artifact environment, the artifact itself, or both in order to arrest its development or continuation. After meeting the responsibility to first preserve and stabilize (and, often, in a concerted effort to accomplish both), conservators can seek to correct damaged structures by introducing their materials and techniques in repairs and mends. Finally, they may seek to introduce compensations for losses in the artifact due to deterioration.

These last two are somewhat risky because their success and appropriateness depend largely upon the judgment and skills of the conservator and the materials and techniques at his or her disposal. In any case, the central point is that in any of these instances, damage is not undone. The conservator is dealing with deteriorated materials and structures; the effects of the aging process cannot be reversed as a result of any new treatment. However, appropriate interventions may keep such artifacts from getting any worse.

## Principles

The principles for making structural repairs using twisted fiber strands are essentially those presented earlier in this text regarding all repairs to artifacts made from plant fibers. Here, they can further focus our efforts:

1. Repairs should be made using stable materials.
2. Materials should be removable or reversible.
3. Materials should be chosen from those whose aging characteristics and behaviors are known in practice from aging tests and from professional experience.
4. The method of application and removal or reversal should do no damage nor cause deterioration.
5. Solvents used in treatment should be chosen carefully to cause the least amount of change in the original material.
6. The technique selected should be the one least likely to cause permanent alteration to the structure of the artifact.
7. Mends should be compatible with the strength of the artifact. Ideally, the repair should be strong enough to give the artifact the required support, yet yield to stress before the artifact does.
8. Mends should be visually subtle yet should be visually discernible upon examination of the artifact.
9. Repair materials should be different from those used in the original fabric or in native repairs.

The following techniques and materials are basic methods which may be adapted as needed to best suit the fabrication of the artifact and the nature of the damage.

## Techniques

The fundamental technique was originally developed by Odegaard and Harvey (1982,1984), who recognized that the field was struggling in its efforts to adapt techniques and materials used in fine art and decorative art conservation to the very different, although sometimes analogous, problems of ethnographic basketry.

They note that different basketry structures and types of damage require very specific kinds of support and continuity to ensure stabilization. They point out that, in their experience, most mending techniques described in the literature do not address specific structural needs, do not adhere evenly, and/or are difficult to remove safely.

They propose a technique which (1) attempts to redistribute the stress found at a traumatized area, (2) utilizes the properties of strength, flexibility, and stability found in long-fibered mulberry papers, and (3) is adaptable to a number of adhesive solutions in a manner that minimizes the use of adhesive and maximizes the properties of the paper.

In Odegaard and Harvey's original technique, thin fiber strips are torn from sheets of mulberry fiber paper. The fibers are rolled between clean fingers to a desired diameter and length. The fibers are then drawn through a small pool of adhesive with tweezers. The strand is then applied to the damaged area in a location that allows the paper strand to address the structural deficiency.

The authors found that the choice of adhesive could be varied depending upon the basketry materials and the nature of the trauma. They found that toning and coloring methods could likewise be selected based upon the basketry materials and the adhesive used in the repair. Just as important, the repair strands are so simple and incorporate such economy in materials that they can be removed from the mend using a fine dental explorer and a brush wetted with the adhesive's solvent. The elegance of the repair technique is that it provides structural continuity both physically and aesthetically.

Since that time, ethnographic conservators have been proving just how adaptable the technique is to the variety of mechanical damages found in artifacts made from plant materials.

## Adaptations of the Basic Technique

### Shape and Strength

Working with paper strands allows the conservator to fabricate just about any shape, width, and diameter strand. Likewise, the strength of the repair can be strictly controlled by selecting the combination of paper weight and strand size.

Wet tearing a relatively wide strip and folding in the deckled edges forms a thin, flat strip. Wet tearing a very wide strip and folding over or rolling the paper makes it possible to create strips very similar in appearance and function to fairly sturdy woody tissues.

Extremely fine, strong, and flexible repairs can be made using individual threads from high quality, dye-fast cotton embroidery floss. In this case, the color of the repair strand can frequently be found within the selection of existing floss colors. Care must always be taken to test the floss selected for dye-fastness in whatever solvent is used in the adhesive system in the repair. Because the floss fibers are relatively long, extremely fine strands can be created using even partial sections from individual threads. In each case, the embroidery floss fibers should be rolled prior to use to avoid separation during application. The embroidery floss threads are well suited to repairs of finely woven structures and those where the visual impact of a repair strand size may be critical.

## Techniques in Addressing Complex Structural Problems

Often, the ends of broken plant material elements are misaligned or distorted from years of sitting in a distorted orientation after the initial break or trauma. This condition can make a simple mend with a twisted strand or strip considerably more complex. The conservator must consider if the new, "postdamage" configuration of the structure is now stable, or if it will continue to stress and fatigue remaining undamaged elements in undesirable ways. We must also decide if relaxing and realigning the damaged area is possible without incurring other new damage. In these cases, several variations of the original technique are useful in resolving the technical problems of making a repair.

### Adhering Strand Ends Individually

Where the broken plant material elements are flexible or somewhat plastic but still have a tendency to separate, it is possible to make a repair by adhering one end of the repair strand to one side of the broken element and allowing it to dry completely. One can then position either of the two ends to align properly by using very small weights (such as fishing weights or tiny muslin bags filled with an appropriate amount of shot and wrapped or sewn shut), using #000 stainless steel insect pins, bent in any direction necessary, as levers and wedges between weave elements, or one can use small strips of Parafilm (paraffin labware film which stretches and mechanically adheres to many surfaces, manufactured by American Can Company, Greenwich, CT, 06830), adhering the strand to the opposing element.

### Temporary Strands for Securing Proper Alignment

Likewise, it is quite simple to apply temporary untoned strands, as frequently and in as many locations as needed, to hold a structure in proper alignment. Temporary strands can be applied to both a work face and a nonwork face, after which final toned strands can be placed strategically to be as unobtrusive and as functional as possible. The white, untoned temporary strands can then be easily identified and lifted off by slightly reactivating the solvent.

### Strand Repairs for Very Flexible or Loose Structures

Where original structural connections were loose and/or extremely flexible, twisted strand repairs can be made to accomplish a similar result. In such cases, only the securing ends of repair strands are adhered to the opposing structural elements using the appropriate adhesive. The fiber strand between the two adhered ends receives no adhesive and is therefore, depending upon length and tautness, allowed to flex and move quite freely. This may be very important if that was the original intent of the structure.

### Using Twisted/Folded Strands in Compensations

Because the fundamentals of the technique are so adaptable, excellent compensations can be made for losses in structures which not only provide visual integration for the damaged area, but which also provide structurally functional repairs that are easily applied and removed. Because any type of structural element can be roughly simulated by varying the weight and dimension of the paper used, entire braided,

woven, coiled, or plaited structures can be recreated to the necessary scale simply by copying the original fabrication technique.

A section of replicated work can then be trimmed to the proper size and fitted into the area of loss. Next, normal strand repairs can be made between the newly fabricated fill section and the edges of the loss in the original work. On close examination, there can be no confusion between original repair materials or ethnographic repairs using traditional materials and a new conservation repair using all twisted strand elements, toned as necessary. There is, also, relatively little potential for damaging the piece as there can be when attempting to make a mold of an artifact structure and attaching a fill of cast paper fiber.

## Selection of an Adhesive

Starch pastes are by far the most common adhesives used in securing twisted fiber strand repairs. It is beyond the scope of this paper to attempt to document the various qualities of rice, wheat, corn, or potato starch pastes in all their various recipes, dilutions, preparations, and applications. Clearly, a relatively "dry" or low-moisture cooked starch paste that has high tack, smoothness, and body benefits many repair situations. In the author's experience, the longer the starch is cooked after swelling without burning or boiling, the tackier the starch seems to become. Paper conservators are great sources for surveys regarding starch recipes and the behavior of the various pastes in application. The recipe that follows is provided only as a possible starting point for the multitude of variations and working characteristics that are possible.

The paste is generally used at room temperature and is reworked with a small stainless steel spatula on a glass palette until quite smooth. If the paste contains too much water and does not have enough body to adhere to the spatula, it can be worked again on a piece of acid-free blotter paper to absorb excess water. The strand can be either drawn through the starch to coat the entire length or loaded with a small amount of starch using a small brush or the tip of a dental excavator.

**Starch Paste**

- 4½ parts water
- 1 part starch

Mix 1 part water and 1 part starch and warm slowly, but do not allow to boil. Boil 3½ parts water. As the starch-water mixture starts to congeal, stir in 3½ parts boiling water. Continue to stir, cooking over low heat until thick and translucent and until desired tack is acquired.

If the original material of the artifact is very weak and there is concern that the starch or paper may be so strong that a trauma could damage original material rather than the repair, the strength of the repair can be reduced by incorporating a cellulose ether into the starch paste. The addition of cellulose ethers appears to add some flexibility to the repair and also eases removability with limited moisture.

### Other Adhesives

Occasionally, it will not be possible to use starch paste as a repair adhesive. This situation typically occurs when materials are oily from ethnographic use or from a previous treatment. The repair strand may also need to have one end applied to a material, such as glass, metal, bone, or shell that has limited receptivity to starch paste adhesive. Resins may be considered as adhesives where experience indicates that insects are accustomed to attacking starch repairs. The alternatives generally include solvented cellulose ethers, solvented resins, solvent reactivated resin films, and heat activated resin films. Each of these techniques is described more completely in Chapter 5 (see Adhesive and Reinforced Adhesive Mends).

Choice of resins is frequently determined by their compatibility with the substrate materials, stability of the resin, and its characteristics and behavior in application and in service. One of the most convenient ways of working with a resin to attach a twisted strand repair is by casting a thin film of the resin on silicone mylar and peeling off an appropriately sized piece with tweezers when dry. The film can be reactivated by the touch of a small solvent-loaded brush. Areas where it is difficult to hold the strand in place while activating the resin can be supported by using bent #000 stainless steel insect pins as wedges or by holding the strand in place with a small hair clip or other similar device sprayed with silicone release.

## References Cited

**Odegaard, N., and R.N. Harvey**

1982 The conservation of Native North American basketry: A case study. Paper presented at the AIC 10th Annual Meeting, Milwaukee.

1984 A stabilization technique for mending basketry. Poster presentation, AIC 12th Annual Meeting, Los Angeles.

Appendix 2

# Construction of Storage Boxes and Folders

*Ruth E. Norton*

## Boxes Made with 3 mm Single-Wall, Acid-Free Corrugated Board

Cut the board into a square or rectangle of the dimensions indicated in Figure A.1. On the interior surface, in pencil, draw lines 1, 2, 3, and 4 (Figure A.1). In pencil, draw the additional lines indicated in Figure A.2.

With a utility knife cut completely through the corrugated board along the thick lines indicated in Figure A.3. Discard the four corner pieces. Along the dotted lines indicated in Figure A.4, cut through the upper two layers of the corrugated board, being very careful not to cut the bottom layer (Figure A.5).

Being careful not to damage the bottom layer (Figure A.6), peel off the upper two layers of cardboard in the stippled areas, as shown in Figure A.7, . Score the four edges of the base of the box by firmly pressing a heavy blunt instrument between the double lines drawn in pencil on the board (Figure A.7).

To assemble the box, fold the four walls up along the scored lines. The wall corners should overlap as shown in Figure A.8. Then, fold the peeled-off flap over the adjacent wall and adhere with an acrylic or poly(vinyl) acetate emulsion adhesive. The flaps should be securely adhered; completely cover the inside of the flap with adhesive and press it onto the wall (Figure A.9). Lay the box on its side, with the adhered side on the table and place a weight on the inside. Allow to dry overnight (Figure A.10).

The lid is constructed like the box. The lid sits over the top of the box walls, extending down 5 cm. The interior dimensions of the lid should equal the exterior dimensions of the top of the box. The lid should fit snugly, but not tightly; it should lift off easily without jarring the box.

## Boxes Made with 6 mm Double-Wall, Acid-Free Corrugated Board

Preparation and construction are identical to those for boxes of 3 mm single-wall board, except for the following alterations necessary to accommodate the greater wall thickness: the 4 mm lines (Figure A.2) should be increased to 8 mm to allow

for the thicker walls. Because the 6 mm board is difficult to score by pressing, the upper layer of the board is cut out and the bottom layer of the board is scored (Figure A.11).

## Folders for Small Flat Objects

Folders can be made with acid-free, four-ply mount board or with acid-free corrugated board.

Cut two boards of equal size. The length and width should be 6 cm larger than the dimensions of the object. These boards will be the base and lid of the folder.

Cut strips 3 cm wide for the walls of the folder. These are adhered to the base as shown in Figure A.12. The height of the walls should be just fractionally higher than the height of the object.

Hinge the lid to the top wall using gummed linen tape or an acid-free, medium-weight paper strip adhered with an emulsion adhesive (see Figure A.13).

The object is wrapped in acid-free tissue which sits inside the folder. This provides additional protection from abrasion and allows the object to be lifted easily from the folder. Flap 1 (Figure A.14) is of the same dimensions as the base so that it completely covers the object. Flaps 2, 3, and 4 fold over flap 1. In this way, there are no paper edges over the object to catch on and tear fibers.

*Figure A.1. Draw pencil lines on interior surface at 1, 2, 3, and 4.*

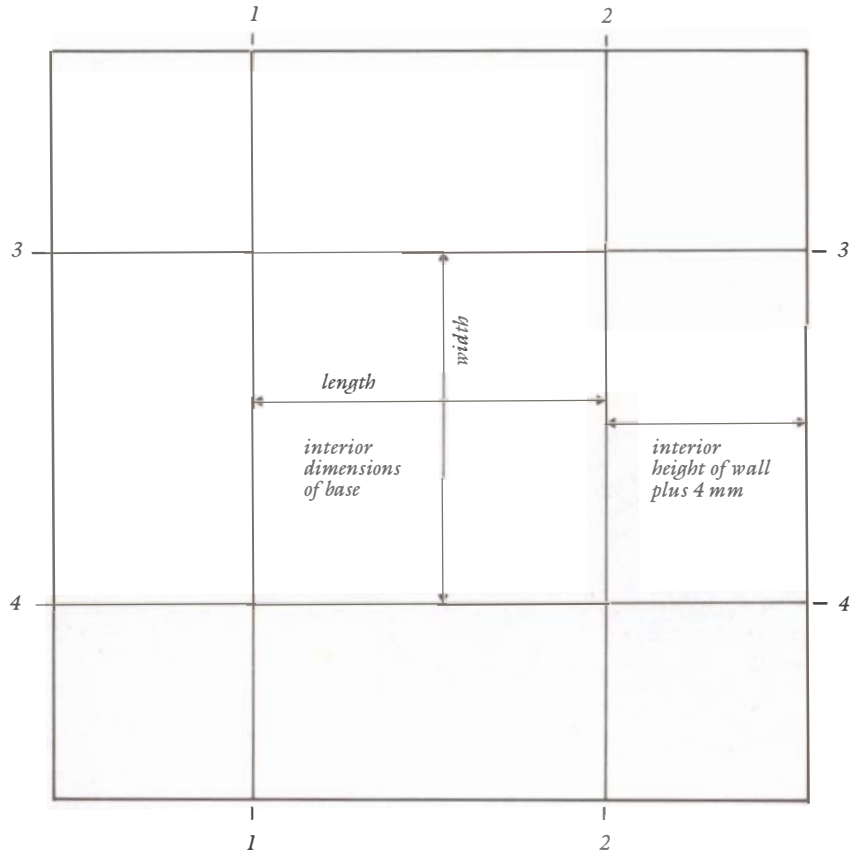



*Figure A.2. Draw additional lines as marked at 1, 2, 3, and 4.*

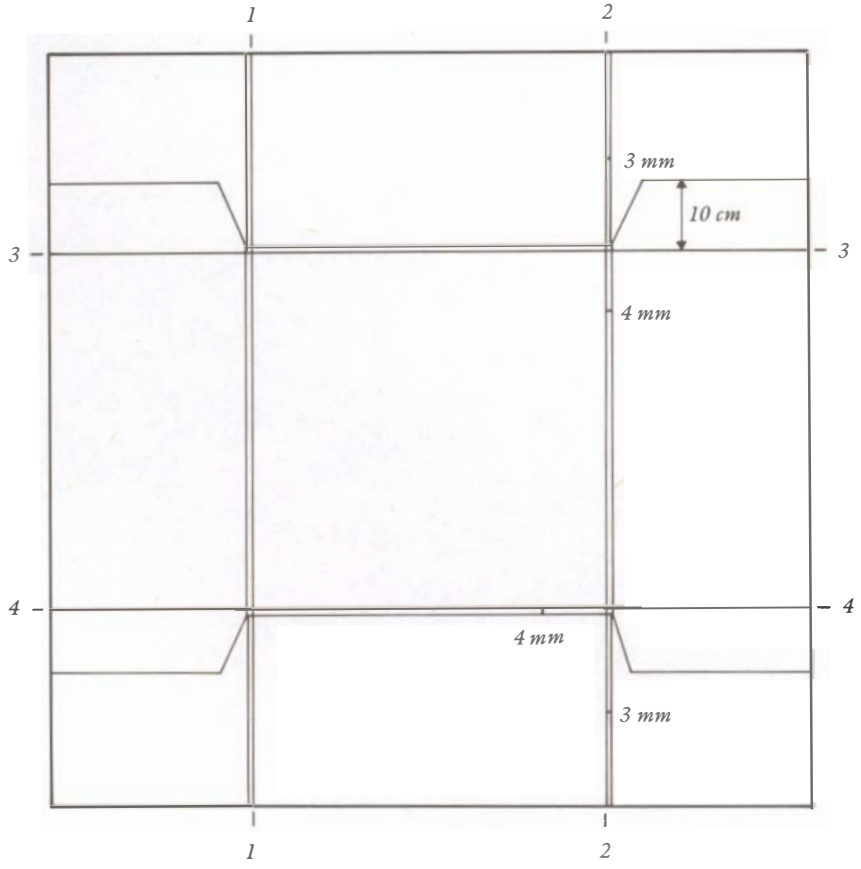


*Figure A.3. Using a utility knife, cut through board along heavy lines and discard the four corner pieces.*

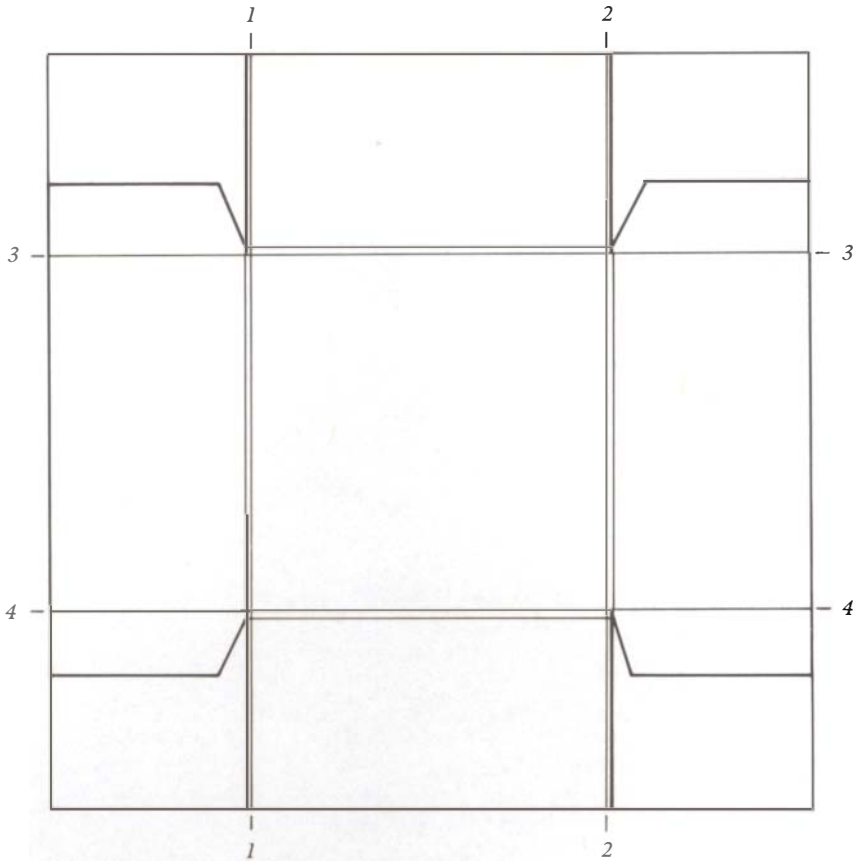



*Figure A.4. Cut through the top two layers of board along the dotted lines at edges of flaps and peel off the upper layer (stippled areas).*

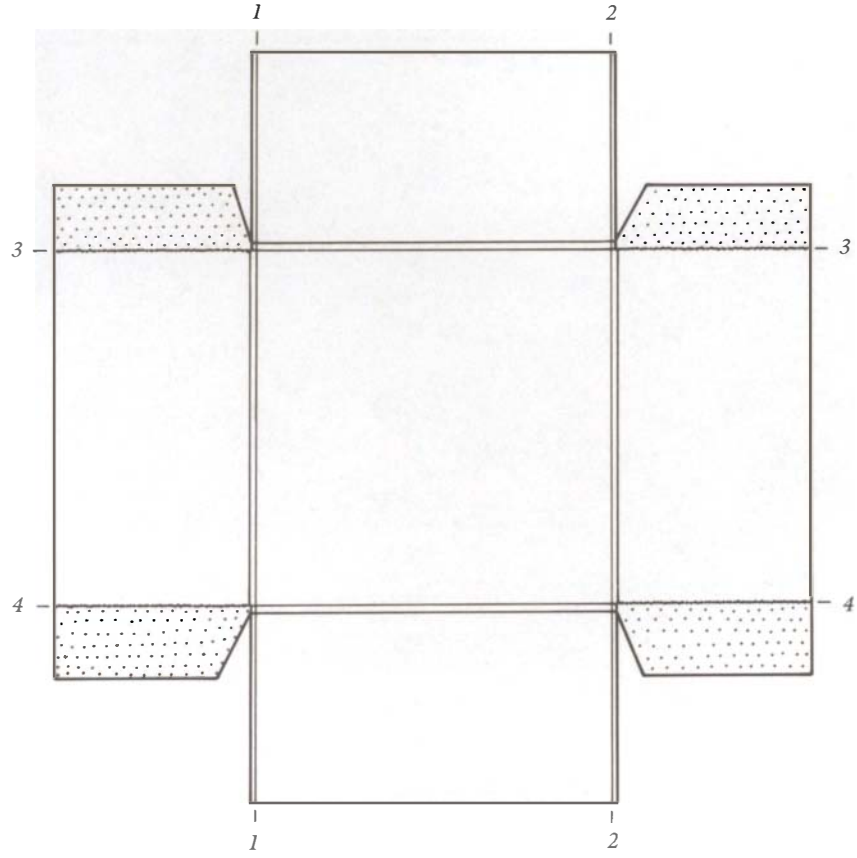


*Figure A.5. Cross section of corrugated board.*

*Figure A.6. Upper layers removed.*

*Figure A.7. Scoring 4 mm board.*

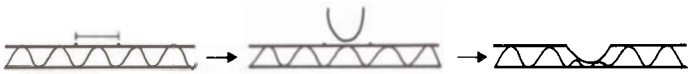


*Figure A.8. Corner joint.*

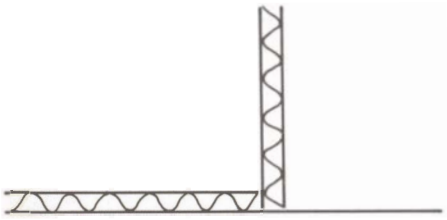


*Figure A.9. Adhering corner joint.*

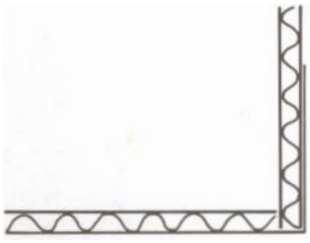


*Figure A.10. Adhered side is weighted and dried overnight.*

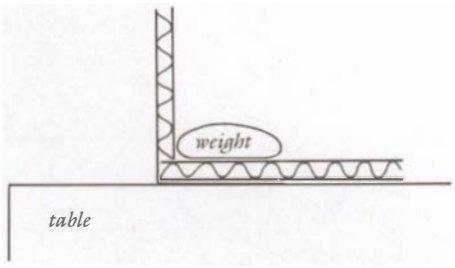



*Figure A.11. Scoring 6 mm board: (a) cut board, (b) remove upper layer , (c) score bottom layer.*

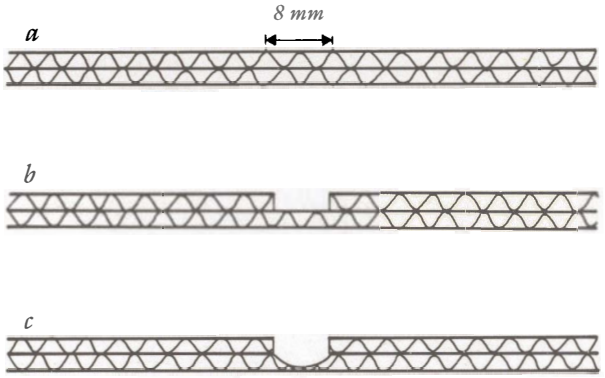


*Figure A.12. Walls and base of folder.*

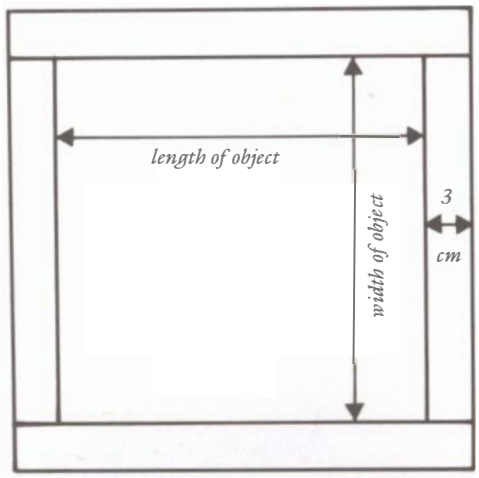



*Figure A.13. Top hinged to folder.*

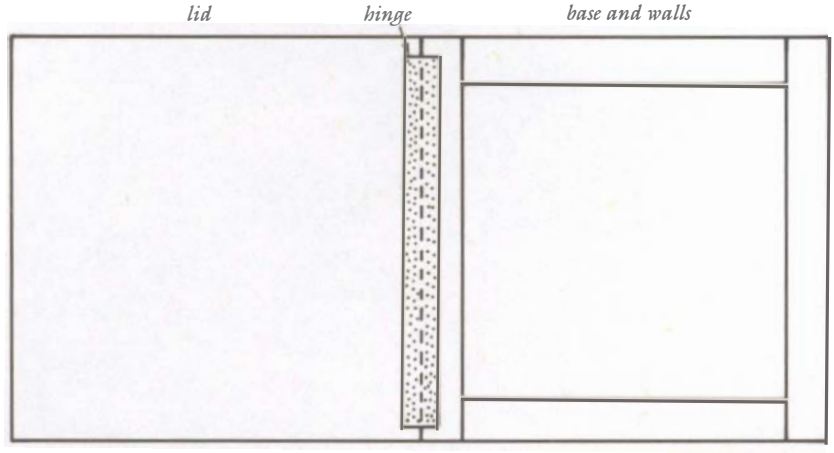
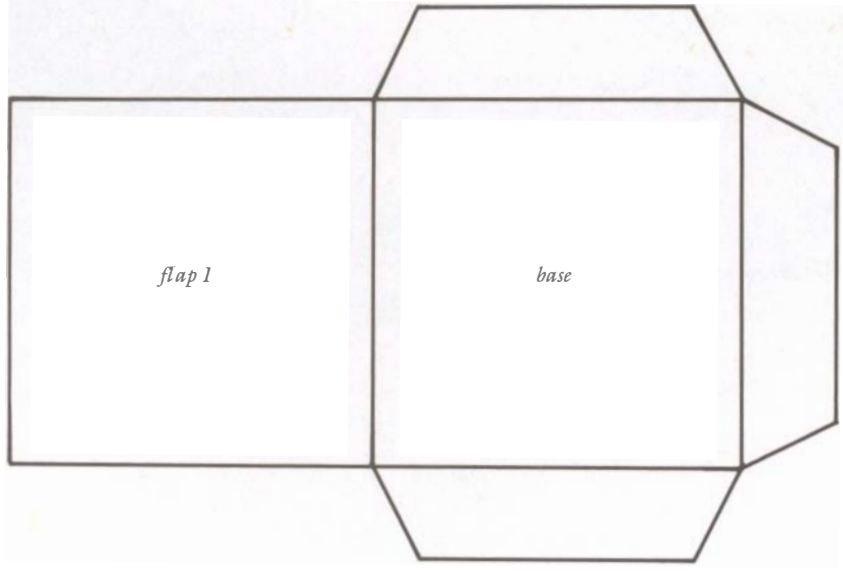



*Figure A.14. Acid-free tissue wrapping for object. Flap 1 should have the same dimensions as the base.*



Appendix 3

# Characteristics of Adhesives

*Ruth E. Norton*

## Classification of Adhesives by Setting Action

| | | | |
|---|---|---|---|
| Temperature Change | Wax | Natural | Carnauba |
| | | | Beeswax |
| | | Synthetic | Paraffin |
| | | | Microcrystalline |
| | | | Polyethylene glycol |
| | Thermoplastic resins | Emulsion and resin film reactivation | Poly(vinyl acetates) |
| | | | Acrylates |
| | | | Polyamides |
| Solvent Loss | Suspended/dissolved in water | | Starch |
| | | | Cellulose ethers |
| | | | Protein |
| | Dissolved in organic solvents | Natural resins | Shellac |
| | | | Dammar |
| | | | Rosin (colophony) |
| | | | Lacquer |
| | | Synthetic resins | Acrylates |
| | | | Vinyl acetates |
| | | | Cellulose nitrate |
| | | | Cyclohexanone |
| | | | Vinyl butyrals |
| | | | Vinyl alcohols |
| | | | Soluble nylon |
| | | | Polyurethane |
| | Synthetic resins suspended in water | Emulsions/colloidal dispersions | Vinyl acetates |
| Temperature Change Plus Solvent Loss | | | Animal glues |
| Chemical Action | | | Epoxy |
| | | | Polyester |
| | | | Cyanoacrylates |
| | | | Silicone rubber |

## Characteristics to Consider When Selecting Adhesives

1. Thermoplastic vs. thermosetting
2. Shrinkage upon setting
3. Penetration
4. Aging properties
    - discoloration
    - shrinkage
    - embrittlement
    - cross-linkage
5. Reversibility
6. Plasticizer

## Technical Data

1. Molecular weight (MW)
2. Particle size
3. Viscosity
4. Solubility
5. pH
6. Glass transition temperature ($T_g$)
7. Minimum film formation temperature (MFT)

## Where to Find Information

1. Manufacturers' technical information data sheets
2. Suppliers' catalogues such as Conservation Materials Ltd. and Frank Joel Ltd.
3. Books, articles, reports by conservators and conservation scientists
4. *The Merck Index* (1976, 9th Edition), Merck & Co. Inc., Rahway, New Jersey, U.S.A.

Appendix 4

# Dyeing Cellulosic Materials With Fiber-Reactive Dyes

*Ruth E. Norton*

Fiber-reactive dyes are often chosen for dyeing paper, cloth, cord, and plant materials because they may be applied in cold water baths, have reasonable light fastness, and are easily reproducible. The dyes are formulated for use on cellulose and some cellulose derivative fibers. They may also be used on silk fibers.

Hot water dyes are difficult to use on very fine papers like L-tissue and fine Japanese paper, especially if these have low wet strength. Vat and disperse dyes in general have better light fastness than fiber-reactive dyes, but the former use hot water baths and the dyeing process of some is complicated enough to make color reproducibility difficult. Selected fiber-reactive dyes have very good light fastness in manufacturers' standard tests, and have proved fast under twenty months' exposure to ambient laboratory light.

Bayer, Sandoz, ICI, Ciba-Geigy, and others manufacture ranges of fiber-reactive dyes. The choice of specific fiber-reactive dyes used at the Canberra College of Advanced Education (CCAE) was based on manufacturers' light-fastness data (Table A.1).

*Table A.1. Fiber-reactive dyes used at the Canberra College of Advanced Education.*

| Color | Dye | Manufacturer |
|---|---|---|
| Red | Levafix Rubine EFB | Bayer |
| | Drimarene Rubinol K5BL | Sandoz |
| Blue | Levafix EFFA | Bayer |
| Yellow | Levafix E2GL | Bayer |
| | Drimarene Yellow K2GL | Sandoz |
| Black | Cibacron F2B | Ciba-Geigy |
| | Levafix Black ERL | Bayer |

Dyed Japanese Usamino paper (mulberry fiber) and unbleached cotton muslin tested shortly after dyeing showed no pH change using cold extraction determination of pH of dyed and undyed material; the pH of dyed raffia and pandanus leaves increased toward neutral, primarily because of the predyeing scouring of the leaves. All dyed material exhibited no crocking, and good fastness in water, ethanol, acetone, and toluene.

A wide range of colors is available in fiber-reactive dyes. To determine the particular dye or mix of dyes and the particular depth of shade necessary to produce the desired color, a dye chart is necessary. Many manufacturers no longer supply dye charts, and it may be necessary to make one's own. At the CCAE, a red, blue, and yellow were chosen which, when two were mixed, created balanced purples, greens, and oranges, and, when all three were mixed, created the broad range of brown tones needed to match the colors found in many artifacts. Black was added to deepen and "dirty" the colors. Using these, dye charts for cotton muslin and Usamino paper were made for dye mix ratio (hue) and depth of shade.

## Dyeing Paper

The paper is soaked in a bath of dye and salt solution for 45 minutes. Alkali solution is then added and the paper is soaked for 70 to 110 minutes. The paper is rinsed in running water for 4 hours and dried on a blotter. During this time, it is kept flat and is transferred to and from the rinsebath on a Mylar sheet.

### Materials

- tap, deionized, or distilled water
- salt: sodium chloride
- alkali: sodium carbonate (soda ash)
- dye
- dye bath tray: shallow, flat-bottom (essential) glass or plastic trays slightly larger than the paper to be dyed
- *hake* brush: wide (at least 3 cm), flat, soft hair brush

### Dye Calculations

The following factors must be determined:

- weight of paper
- depth of shade
- amount of dye
- volume of water
- amount of salt
- amount of alkali
- soaking time

The soaking times and the amounts of salt and alkali differ for particular brands of fiber-reactive dyes. The amounts specified in the following instructions are for Levafix, Drimarene, and Cibacron dyes. Check with the dye manufacturer or the dye supplier for amounts recommended for other brands.

The discussion below uses the following example for purposes of illustration: 0.5 g of paper dyed to a 4% depth of shade; the color is a hue of 2 parts red, 2 parts blue, and 6 parts yellow in a proportion of hue to black of 9:1; a 0.1% stock solution of each dye is used.

### Weight of Paper

Paper may be weighed or the basis weight of the paper may be used.

### Amount of Dye

This is calculated from the depth of shade, weight of paper, and strength of stock solution. Because of the small quantities of dye needed, it is best to prepare stock solutions of the dyes from which the desired quantity of dye solution is taken. (Stock solutions should be made up on the day they are to be used, ideally just before they are needed.) For example, 0.1% stock solution = 0.1 g dye per 100 ml water.

The volume of stock solution needed is determined as follows:

$$\frac{\text{depth of shade}}{100} \times \frac{\text{g paper}}{1} \times \frac{100}{\text{\% stock solution}} = \text{total volume}$$

For example, to dye 0.5 g of paper to a 4% depth of shade using the 0.1% stock solution:

$$\frac{4}{100} \times \frac{0.5}{1} \times \frac{100}{0.1} = 20\ \text{ml stock solution}$$

If mixes of red, blue, yellow, and black are to be used, a 0.1% stock solution of each is made, and the volume of each dye solution is calculated from their proportion in the mix.

To make a 4% depth of shade of hue 2R + 2B + 6Y in a proportion of hue to black of 9:1, for example, it is calculated that 20 ml total of stock solution is needed using the 0.1% stock solutions. For a hue to black proportion of 9:1, 18 ml of hue and 2 ml of black are needed. The 18 ml of hue is made of 2R, 2B, 6Y:

- 18 ml x 0.2 = 3.6 ml red
- 18 ml x 0.2 = 3.6 ml blue
- 18 ml x 0.6 = 10.8 ml yellow

Therefore, the total of 20 ml stock solution is made from:

- 2 ml black stock solution
- 3.6 ml red stock solution
- 3.6 ml blue stock solution
- 10.8 ml yellow stock solution

### Volume of Water

This is calculated based on the weight of paper using a liquor ratio of 70:1 (70 ml water per l g paper). For 0.5 g of paper, for example, 70 x 0.5 = 35 ml water needed. This is the total volume of water to be used in the bath. Of this, about one quarter must be reserved to dissolve the alkali, and some is contributed by the stock solution. Of the 35 ml total water needed, 10 ml is needed to dissolve the alkali, leaving 25 ml for the dye and salt solution. Since 20 ml of stock solution is needed, 5 ml of water is added to these 20 ml to make up the 25 ml of dye and salt solution. The required weight of salt is added to the 25 ml.

**Amount of Salt**

This is calculated based on the volume of water in the proportion of 50 g salt per liter of water.

$$\frac{50\ g}{1000\ ml} \times \text{total ml water} = \text{g salt}$$

In the example given, 35 ml total water is needed, therefore:

$$\frac{50\ g}{1000\ ml} \times 35\ ml = 1.75\ g\ \text{salt needed}$$

**Amount of Alkali**

This is calculated based on the volume of water in the proportion of 20 g alkali per liter of water:

$$\frac{20\ g}{1000\ ml} \times \text{total ml water} = \text{total g alkali needed}$$

For 35 ml total water:

$$\frac{20\ g}{1000\ ml} \times 35\ ml = 0.7\ g\ \text{alkali needed}$$

**Soaking Time**

The amount of time needed for soaking in the bath following addition of alkali is based on the depth of shade:

<1% = 70 minutes
1-5% = 90 minutes
>5% = 110 minutes

## Procedure

1. Weigh out dye, salt, and alkali.
2. Prepare dye stock solutions.
3. Prepare dye and salt solution. Pipette the required volume of dye stock solution into a beaker. Add water to reach the required amount. In the example, a total of 35 ml of water is needed: 10 ml is reserved for dissolving the alkali, 20 ml of stock solution is used, 5 ml of water must be added. Add salt to dye solution and stir or swirl until dissolved.
4. Pour dye and salt solution into a flat tray. Lay paper on the bath (start at one corner and roll paper onto bath to avoid trapping air under paper). Using a *hake* brush, gently brush the surface of paper to fully wet it out and submerge it in the bath. Alternatively, lay paper in tray, pour dye and salt solution over the paper, and immediately brush over paper surface to fully wet out and brush out air trapped under the paper.

5. Paper soaks in the dye and salt solution bath for 45 minutes. Agitate by rocking the solution back and forth over the paper. This should be done as frequently as possible for the first 5 minutes, and at 5-minute intervals after that.
6. Add alkali. Before the 45 minutes are up, dissolve the alkali in the reserved water (dissolves most readily if hot water is used). At the appropriate time, pour the alkali solution over the paper and immediately brush well over the paper surface to distribute and mix the alkali.
7. Paper soaks in the dye, salt, and alkali solution bath for 70, 90, or 110 minutes, depending on the depth of shade desired. Agitate as described in step 5.
8. Rinse. Leaving the paper in the tray, place the tray in a large sink at a 45° angle and gently run water from a hose over the paper until no more color runs out. Transfer the paper to a photo tray or basin and leave in slowly running water for 4 hours.
9. Transfer the paper from the rinse bath to a dry blotter using a sheet of 5 mil Mylar.

For accurate duplication of color, exact measuring and timing is important. The paper must be well brushed immediately upon addition of the dye and salt solution and the alkali solution, and the baths must be agitated to produce even dyeing of the paper. Thorough rinsing is necessary to remove all residual dye, salt, and alkali.

## Dyeing Cloth and Thread

Cloth should be scoured (boiled in soap and water for 30 minutes) or machine washed in soap and hot water prior to dyeing. Fiber-reactive dyes are formulated for dyeing cellulose and cellulose-derivative fibers—cotton, linen, jute, rayon, and so on. Suppliers recommend that silk may be dyed with fiber-reactive dyes, but because the alkali makes the silk harsh, the alkali proportion should be reduced and the rinse should be followed by a final rinse in a mild acid solution.

The wetted cloth is soaked for 10 minutes in a bath of dye and water. Salt is dissolved in water and added to the bath, ⅓ at a time, at 10-minute intervals. Fifteen minutes after the last salt addition, the alkali is dissolved in water and added to the bath, ⅓ at a time, at 10-minute intervals. After the last addition of alkali, the cloth is soaked in the bath a further 50 to 90 minutes, depending on depth of shade. The cloth is thoroughly rinsed and air dried.

The cloth should be lifted from the bath during the addition of the salt and alkali, and should be gently agitated throughout the dyeing procedure, to avoid uneven dyeing. Accurate measurement of materials and strict timing are important to ensure accurate reproduction of color.

### Materials

- tap, deionized, or distilled water
- salt: sodium chloride
- alkali: sodium carbonate (soda ash)
- dye

- cloth
- dye bath container: glass or plastic basin or jar
- stirring rod, plastic glove

## Dyeing Calculations

Determine:

- depth of shade
- amount of dye
- volume of water
- amount of salt
- amount of alkali
- soaking time

The soaking times and the amounts of salt and alkali may differ for particular brands of fiber-reactive dyes. The amounts specified in the following instructions are for Levafix and Drimarene dyes. Check with the dye manufacturer or dye supplier for amounts recommended for other brands of dyes.

**Amount of Dye**

This is calculated from the depth of shade and the weight of cloth.

$$\frac{\text{depth of shade}}{100} \times \frac{\text{g cloth}}{1} = \text{g dye needed}$$

If the amount of dye needed is large enough to weigh accurately it may simply be weighed out and used. If the amount of dye needed is small, it is more accurate to make stock solutions of each dye needed and measure the required volume of stock solution. See discussion of stock solutions in instructions for dyeing paper. The concentrations of stock solutions for cloth are often higher than those for paper (for example, 0.5% or 1.0%).

**Volume of Water**

This is calculated on the weight of cloth using a liquor ratio of 30:1 (30 ml water per 1 g cloth). For example:

$$30 \text{ ml} \times 10 \text{ g cloth} = 300 \text{ ml water needed}$$

This is the total volume of water to be used in the bath. Of this, about ⅔ is used to dissolve the dye, about ⅙ is reserved to dissolve the salt, and about ⅙ is reserved to dissolve the alkali. For example, if the total amount of water required is 300 ml, it would be used in the following proportions:

- 175 ml to dissolve the dye
- 75 ml to dissolve the salt
- 50 ml to dissolve the alkali

If stock solutions of dye are used, the volume of stock solution is included in the amount of water used with the dye, as noted above. See notes on determining the amount of dye and volume of water for dyeing paper.

**Amount of Salt**

This is calculated on the basis of the volume of water in the proportion of 50 g salt per liter water.

$$\frac{50\ g}{1000\ ml} \times \text{ml total water} = \text{g salt}$$

For example, if 300 ml total water is needed:

$$\frac{50\ g}{1000\ ml} \times 300\ \text{ml water} = 15\ \text{g salt}$$

**Amount of Alkali**

This is calculated based on the volume of water in the proportion of 20 g alkali per liter water.

$$\frac{20\ g}{1000\ ml} \times \text{ml total water} = \text{g alkali}$$

For example: 300 ml total water are needed.

$$\frac{20\ g}{1000\ ml} \times 300\ \text{ml water} = 6\ \text{g alkali}$$

**Soaking Time**

The time required for soaking in the bath following the last addition of alkali is based on depth of shade:

<1% = 50 minutes
1–5% = 70 minutes
>5% = 90 minutes

## Procedure

1. Weigh out dye, salt, and alkali.
2. Prepare dye solution by dissolving the dye powder in warm water, or by using stock solutions and water.
3. Wet cloth in tap water and wring out as much water as possible.
4. Immerse wetted cloth in dye solution for 10 minutes. Agitate continuously by moving the cloth with gloved fingers or a stirring rod.
5. Addition of salt. Before the above ten minutes are up, dissolve all the salt in the required volume of hot water. At the appropriate time, lift the cloth above the dye bath, pour in ⅓ of the salt solution, mix well, and lower the cloth back into the bath. Agitate continuously. Repeat twice at 10-minute intervals.

6. Addition of alkali. Alkali is added 15 minutes after the last addition of salt. It is dissolved in the required volume of water and added ⅓ at a time at ten-minute intervals as described for the addition of salt. Agitate continuously.
7. The cloth soaks in the dye, salt and alkali bath for 50, 70, or 90 minutes (depending on depth of shade) after the last addition of alkali. The cloth should be agitated continuously for the first 10 minutes, and at least 5- to 10-minute intervals after that.
8. Rinse. The cloth is rinsed in running tap water until the water runs clear, and is then machine rinsed in hot, then warm water for four rinse cycles (about 45 to 60 minutes).

*Table A.2. Time intervals for addition of salt and alkali to the dye bath, and total dyeing time.*

| Duration | Bath | Total Dyeing Time |
|---|---|---|
| | Cloth into dye solution | 0 minutes |
| 10 minutes later | add ⅓ salt | 10 minutes |
| 10 minutes later | add ⅓ salt | 20 minutes |
| 10 minutes later | add ⅓ salt | 30 minutes |
| 15 minutes later | add ⅓ alkali | 45 minutes |
| 10 minutes later | add ⅓ alkali | 55 minutes |
| 10 minutes later | add ⅓ alkali | 65 minutes |
| 50, 70, or 90 minutes later | remove cloth and rinse | 115, 135, or 155 minutes |

The total dyeing time is most important. For example, if one is a bit late with the second addition of salt, the third addition should still be done 30 minutes after beginning the dyeing process.

## Dyeing Other Plant Materials

Other plant materials to be used in artifact mending and restoration can be dyed with fiber-reactive dyes. Some preparation of the plant materials is necessary. The success of dyeing—degree of penetration of dye and evenness of dye—varies with the density of the material and the presence of an epidermis and extractives like cutin, suberin, and resin.

Bamboo and rattan core will take dye, but the dye is taken primarily in the parenchyma tissue between fibrovascular bundles, not in the bundles themselves. The dye will not penetrate through the epidermis.

Leaves, like pandanus and raffia, should be scoured by boiling in water for 30 minutes before dyeing to augment dye penetration. (Scouring also makes the leaves more supple and raises their pH toward neutral—whether this is of long-term effect and benefit is not known.) Dye does not appear to penetrate well through the leaf epidermis. Of material tested, raffia strips took dye well on the leaf interior side of the strip, but the epidermal side, though evenly dyed, was a paler shade. Pandanus leaves did not dye well with fiber-reactive dyes. Leaf strips took the dye only through the cut ends and sides of the leaf strip and through breaks and scratches in the epidermis, resulting in very uneven dyeing in all but very narrow strips.

# Glossary

*absorption* — Penetration of a substance into the structure of another, such as through capillary action or as radiant energy passing through a material.

*adsorption* — Chemical condensation of gasses, liquids, or dissolved substances on surfaces.

*aerenchyma* — Parenchyma tissue with large intercellular spaces filled with air.

*amorphous* — Without definite crystalline form or structure; loosely or randomly structured at the molecular level.

*amphiphloic siphonostele* — Tube-like stele with phloem both external and internal to the xylem.

*amphivasal vascular bundle* — Concentric vascular bundle in which the xylem surrounds the phloem.

*angstrom* — Unit of length, used in discussing light waves, equal to one tenth of a nanometer, one ten-thousandth of a micron, or one ten-billionth of a meter.

*annual ring* — Growth ring in secondary xylem formed in one growth period.

*axillary bud* — Bud in the axil of a leaf.

*bark* — Nontechnical term for all the tissues outside the vascular cambium.

*bast fiber* — Any extra-xylary fiber such as a phloem fiber.

*birefringence* — Light-refracting ability of crystalline materials.

*bordered pit* — Pit in cell walls of coniferous tracheids in which the secondary wall overarches the pit membrane.

*cambium* — Embryonic tissue that gives rise to secondary tissue.

*carbohydrate* — Molecules containing only hydrogen, oxygen, and carbon atoms in various combinations. A carbohydrate that cannot be hydrolyzed to simpler compounds is called a monosaccharide. A carbohydrate that can be hydrolyzed into two monosaccharide molecules is called a disaccharide. A carbohydrate that can be hydrolyzed into many monosaccharide molecules is called a polysaccharide.

*carbonyl group (C=O)* — Functional group that largely determines the acidity of many aldehydes and ketones and their susceptibility to nucleophilic addition.

*carboxyl group (COOH)* — Functional group made up of a carbonyl group (C=O) and a hydroxyl group (OH) giving carboxylic acids their characteristic properties such as polarity and hydrogen bonding capability.

*cellulose* — Polysaccharide polymer that is the main structural chemical in the plant cell wall.

*chain reaction* — Self-sustaining molecular process in which the products of a reaction directly contribute to the propagation of the process.

*chlorenchyma* — Parenchyma tissue made up of cells which contain chloroplasts.

*chromophore* — Chemical group in a molecule that reflects and absorbs light in the visual spectra, thereby producing color in a compound.

*collagen* — Basic fibrous protein molecule located in the fibers of the dermis of skin and in sinew and other structural tissues in animals.

*collenchyma* — Supporting primary tissue composed of cells with unevenly thickened primary walls rich in hemicellulose.

*companion cell* — Parenchyma cell associated with a sieve tube member.

*compression strength* — Stress required to produce failure in a material when pressing or squeezing to reduce volume.

*coniferous* — Refering to cone-bearing trees, usually with needle-like leaves, such as pine, spruce, cedar, and others.

*cork* — Nontechnical term for outer bark (see *phellem cells*); the cells are waterproofed with suberin.

*cortex* — Primary ground tissue which fills areas between the epidermis and the vascular tissue.

*covalent bond* — Bond formed by the sharing of a pair of outer valence electrons by two atoms.

*cross-field pitting* — Pits on radial walls that join ray parenchyma cells and longitudinal tracheids or vessels.

*cuticle* — Layer of cutin on the outer walls of epidermal cells.

*cutin* — Complex waxy substance excreted on the outer surface of epidermal cells.

*dicotyledon* — Plant with two seed leaves in the embryonic seed, such as hardwood trees, linen, hemp, and others.

*dictyostele* — Stele in which the vascular system is dissected into anastomosing strands with the phloem surrounding the xylem.

*diffuse porous* — A characteristic of hardwood xylem in which the vessels are evenly distributed throughout the annual ring.

*dipole moment* — Some molecules have a permanent dipole moment, or mathematical product of one of the charges of a dipole times the distance separating the two opposite charges. These moments are associated with the transfer of electrical charge within the molecule and are, therefore, closely related to molecular structure and bonding characteristics.

*early wood* — Secondary xylem formed in the first part of a growing period in the annual ring, commonly called spring wood.

*ectophloic siphonostele* — Stele having a pith and one phloem region external to the xylem.

*einstein* — One avogadro number of photons, numerically equal to a mole, or one avogadro number of molecules, ($6.022045 \times 10^{23}$). Kilocalories per einstein is, therefore, abbreviated Kcal/mol.

*elasticity* — Property of a material enabling it to recover from deformation caused by force.

*endodermis* — Innermost layer in the cortex of roots; the cells have connecting protoplasm and suberized walls.

*epidermis* — Outermost layer of cells of the plant body of primary origin.

*epithelial cells* — Compact layer of cells, often secretory in function, covering a free surface or lining of a cavity such as in resin canals.

*extensin* — Protein located in primary cells walls.

*fiber* — An elongated sclerenchyma cell with tapering end and thick walls.

*glucosidic bonds* — Bond in starch and cellulose where one D-glucose unit is linked from its C-1 oxygen atom to the C-4 of the next glucose unit.

*ground tissue* — Fundamental tissue (see *cortex*).

*guard cells* — Pair of cells that surround the stomatal pore and regulate the size of the pore.

*hemicellulose* — Polysaccharide polymer, mainly in the primary cell wall, that can absorb large amounts of water to provide pliability or turgidity in the cell wall.

*heterocellular ray* — Ray in the secondary vascular tissue composed of two cell types.

*homocellular ray* — Ray in the secondary vascular tissue composed of one cell type.

*hydrogen bond* — Bond formed between two molecules in which one contains a slightly acidic hydrogen atom and the other a slightly electron-rich atom in an unshared electron configuration.

*hydrolysis* — A double decomposition reaction wherein water is split into its component hydrogen and hydroxyl ions and where either acids or bases are subsequently formed which react with another compound.

*hypodermis* — A layer or layers of cells beneath the epidermis that differs from the epidermis and underlying cells.

*idioblast* — Cell that differs markedly in shape from the majority of cells in generally uniform tissue.

*ionic bond* — Bond that occurs when outer valence electrons are transferred between two atoms.

*lacuna* — Air space or empty cavity formed by the destruction of specific cells in a tissue, as in aerenchyma or protoxylem.

*late wood* — Secondary xylem formed in the latter part of a growing period in the annual ring, commonly called summer wood.

*lenticel* — Conspicuous apertures on stems, usually over pre-existing stomates.

*lignin* — Amorphous organic mixture of phenolic-like chemicals deposited between the cellulose fibrils in the cell wall.

*lumen* — Central cavity of a cell.

*meristem* — Embryonic tissue that gives rise to primary tissues.

*mesophyll* — Photosynthetic parenchyma of a leaf blade located between the upper and lower epidermis.

*metaxylem* — Primary xylem vessels that form after the protoxylem.

*middle lamella* — Layer of pectin and lignin-rich substances that cement the primary walls of adjacent cells.

*moisture regain* — The ability of a material to adsorb water molecules, measured as a change in weight from the oven-dry state, at a specific pressure, temperature, and relative humidity.

*monocotyledon* — Plant with one seed leaf in the embryonic seed, such as grasses, palms, lilies, rushes, and reeds.

*multiseriate rays* — Secondary vascular tissue rays wider than two cells, as seen in tangential view.

*nanometer* — Unit of measurement, especially of light waves, equal to ten angstroms or one-billionth of a meter.

*parenchyma* — Tissue composed of undifferentiated, irregular-shaped cells each with a nucleated protoplast, that commonly stores metabolic products such as starch or crystals.

*pectic substances* — Group of complex carbohydrates, occurring mainly in the primary cell walls and middle lamella, that can absorb large amounts of water.

*perforation plate* — Part of the end wall of the vessel member cell, which is perforated and joins to other members to make a continuous vessel tube.

*pericycle* — Part of the ground tissue of the stele of roots, located between the phloem and the endodermis.

*periderm* — Protective complex secondary tissue composed of phellem, cork cambium, and phelloderm cells, that replaces the epidermis in stems and roots; commonly called bark.

| | |
|---|---|
| *phellem* | Outer protective secondary tissue of stems and roots, composed of nonliving cells with suberized cell walls, formed from the phellogen (cork cambium); commonly called cork. |
| *phelloderm* | Embryonic cells that give rise to the tissue of the periderm. |
| *phellogen* | Cork cambium giving rise to phellum and phelloderm. |
| *phloem* | Principal photosynthate-conducting tissue of vascular plants. |
| *phytolith* | Needle-shaped crystal located in parenchyma cells. |
| *plasticity* | The ability to retain a shape attained through deformation from an applied stress. |
| *primary tissue* | Plant tissue derived from the meristems of the seed embryo. |
| *procumbent ray cells* | Secondary vascular tissue ray cells that, in radial view, have the longest axis in the radial direction. |
| *protostele* | The simplest type of stele containing a solid column of vascular tissue, with the phloem outside the xylem. |
| *protoxylem* | First-formed vessels of the primary xylem. |
| *ray parenchyma* | Parenchyma cell that makes up the radial rays in secondary vascular tissue. |
| *reticulate* | Netlike. |
| *rhizoid* | A dermal protrusion on the stem, rootlike in appearance but not function. |
| *rhizome* | Underground stem. |
| *rhytidome* | Term for the outer bark, used to designate old layers of periderm. |
| *ring-porous* | A characteristic of hardwood xylem in which the vessels form a well-defined ring at the beginning of the annual ring. |
| *sclariform* | Ladderlike. |
| *sclereid* | Sclerenchyma cell, varied in shape, not elongate, with thick, lignified, laminated, pitted walls. |
| *sclerenchyma fiber* | Elongate cell with thick, lignified, pitted cell wall. |
| *sclerenchyma sheath* | Group of sclerenchyma cells that may partially or completely surround a vascular bundle to give it strength. |
| *secondary tissue* | Tissue produced by the activity of the vascular cambium and the phellogen (cork cambium). |
| *shear strength* | Stress required to produce failure in a material when impressed perpendicularly upon the cross section of the material. |

| | |
|---|---|
| *sieve element* | Individual cell of the sieve tube, commonly called sieve cell or sieve tube member, that is involved in longitudinal conduction of food material in the phloem. |
| *sieve tube* | Series of sieve elements connected end to end, and interconnected through sieve plates, involved in longitudinal conduction of food materials in the phloem. |
| *silica cells* | Cells filled with silica bodies, usually in the epidermis of grasses. |
| *stele* | Column of the plant body comprising the vascular and associated ground tissues. |
| *stellate* | Star-shaped. |
| *stoma (stomate)* | Opening in the epidermis of leaves and stems bordered by two guard cells. |
| *stomatal complex* | Guard cells and associated subsidiary epidermal cells that work together for the opening and closing of the stoma. |
| *strain* | Deformation of a material resulting from stress, measured by change in the dimension in which the deformation occurred. |
| *stress* | Force producing, or tending to produce, deformation in a material. |
| *suberin* | Fatty substance, impermeable to water, deposited in the cell wall of cork and endodermal cells. |
| *subsidiary cell* | Epidermal cell associated with guard cells in the stomatal complex. |
| *tensile strength* | Longitudinal stress required to produce failure in a material. |
| *tracheid* | Tracheary element of the primary or secondary xylem that has tapered ends and does not have perforations joining it end to end with other tracheids. |
| *trichome* | An epidermal cell that is unicellular or multicellular and may take the shape of a hair or scale and may be glandular. |
| *ultimate fibers* | Individual cells that have been separated from their original configuration within the structure of a plant. |
| *uniseriate ray* | Secondary vascular tissue rays that are a single cell in width as seen in tangential view. |
| *vapor pressure* | Pressure exerted when a liquid is in equilibrium with its own vapor, which is a function of the substance and of the temperature. |
| *vascular bundle* | Strandlike part of the vascular system composed of xylem, phloem and, if present, associated sclerenchyma sheath. |
| *vessel* | Tube-like series of vessel member cells used for water transport in xylem of dicots, monocots, and some lower plants. |
| *vessel member* | One of the cells that make up a vessel in the xylem of dicots, monocots, and some lower plants. |
| *xylem* | Principal water-conducting and nutrient-carrying tissue in vascular plants. |

# Index

## A *



## B

# C

# D

# E



# F

# G



# H

# I



# J



# K



# L

# M

# N



# O



# P

# Q



# R

## S

# T

# U



# V

## W



## X

# Y



# Z



* *Page numbers in bold italic type refer to illustrations.*

THE GETTY CONSERVATION INSTITUTE

ISBN 0-89236-160-3