

**CONSERVING WATERLOGGED ROPE:
A REVIEW OF TRADITIONAL METHODS AND EXPERIMENTAL
RESEARCH WITH POLYETHYLENE GLYCOL**

A Thesis

by

JENNIFER RYNELL MCCASKILL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of
MASTER OF ARTS

May 2009

Major Subject: Anthropology

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Approved by:

Chair of Committee,	C. Wayne Smith
Committee Members,	Donny L. Hamilton
	James Rosenheim
Head of Department,	Donny L. Hamilton

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ABSTRACT

Conserving Waterlogged Rope: A Review of Traditional Methods and Experimental
Research with Polyethylene Glycol. (May 2009)

Jennifer Rynell McCaskill, B.A., Texas A&M University

Chair of Advisory Committee: Dr. C. Wayne Smith

The excavation of Sieur de la Salle's ship, *La Belle*, yielded a large amount of waterlogged rope requiring conservation. A history of hemp and rope manufacture is reviewed to assist in the identification of the materials and rope-work recovered from the *La Belle*, as well as to assist in selecting an appropriate conservation treatment.

A summary of several methods used to conserve cordage is presented. Time has shown that not all of these treatment methods have remained viable options, and that continued study and experimentation are needed so that the conservator has the tools to develop an appropriate conservation plan for each artifact.


The majority of *La Belle's* cordage was conserved using the passivation polymers method developed by Dr. C. Wayne Smith and Dr. Donny L. Hamilton, both of Texas A&M University, in conjunction with Dow Corning Corporation, Midland, Michigan. An experiment applying knowledge gleaned from the passivation polymers process to polyethylene glycol (PEG) impregnation was conducted in an attempt to stabilize the PEG within the rope. The results were good; the rope retained some flexibility and appears stable with a slightly darker color than with silicone oil.

For Adrianna, Sadiebug, and Katy...don't ever give up your dreams. I love you.

and

In loving memory of Grandma and Grandpa Grey, we miss you.

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Without the people named below, this project would not have been possible. Donny Hamilton sent me to work at the Conservation Research Laboratory (CRL) at Texas A&M University, so that I could gain the experience I needed in conservation. Dr. C. Wayne Smith provided me with the idea for the PEG experiment, encouraged me to present my research, and watched my successes and failures throughout. Thank you Jim Bruseth, Lillie Thompson, Mo Brown and the staff of the Texas Historical Commission (THC) for the information on the excavation and the permission to work on this project. Thank you also to the Musee National de la Marine  for allowing us the opportunity to work on *La Belle*.

The staff at the CRL was vital to this project. Helen Dewolf, with her vast knowledge, patience, editing ability, and sense of humor, provided invaluable direction, assistance, and a good kick or two when needed. Thank you so much. Jim Jobling's enthusiasm, knowledge, and friendship have been invaluable. John Hamilton, Michael West, and Drew Roberts were always available when I needed an extra hand. The other graduate students working at the CRL also helped in innumerable ways, and deserve thanks. Kimberly Rash, Shanna Daniel, and Rebecca Sager all served time cleaning the rope. Randy Sasaki and Jon Swanson took many of the photographs used in this thesis. Starr Cox and Catherine Sincich also deserve special mention for their input.

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Thank you to the many project donors to the La Salle shipwreck project. Their donations of time, money, and expertise made the recovery of *La Belle* possible. As of October 2008, a full list of the La Salle Shipwreck Project Donors can be found at <http://www.thc.state.tx.us/lasalle/lasbelledonor.shtml>. The CRL receives support, often in the form of supplies, from a number of companies enabling us to carry on our work. As of October 2008, a full list of the CRL's donors can be found at <http://nautarch.tamu.edu/lasalle/sponsors.htm>.

Finally, to my best friend and husband, Bobby McCaskill: thank you for standing by me no matter what. Thank you for being the single parent, the house-husband, and the breadwinner as the occasion demanded. Thank you to my daughters Adrianna, Sadie, and Katy for their patience with Mommy and their enthusiasm for helping me finish. Thank you to Mom, Dad, and Grandma Grey for their support, emotional and financial, even when they thought I was crazy. And thank you my myriad of other family members and friends for their interest in my project and their loving support.

ABBREVIATIONS

APRL	Archaeological Preservation Research Laboratory
CMAC	Center for Maritime Archaeology and Conservation
CRL	Conservation Research Laboratory
DBTDA	dibutyltin diacetate
EDTA	ethylenediaminetetraacetic acid
INA	Institute of Nautical Archaeology
MTMS	methyltrimethoxysilane
PEG	polyethylene glycol
PVA	polyvinyl acetate
PVP	polyvinyl pyrrolidone
PVOH	polyvinyl alcohol
TAMU	Texas A&M University, College Station
TEOS	tetraethoxy silane
THC	Texas Historical Commission

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CHAPTER I

INTRODUCTION

Historical Introduction

In July 1684, the French explorer Rene-Robert Cavalier Sieur de la Salle set out on what would become his final voyage. With the support of King Louis XIV, four ships (*Le Joly*, *Le Saint-Francois*, *L’Aimable*, and *La Belle*) laden with supplies and people set out from New Rochelle, France, in order to establish a colony at the mouth of the Mississippi River. La Salle’s expedition represented a direct challenge to traditional Spanish claims over the Gulf of Mexico (Dunn 1916; Joutel 1998; Minet 1987; Weddle 1991, 2001).

From the outset, the voyage was plagued with difficulties. Personality conflicts among the leaders, a shortage of money, and a broken mast only three days into the journey were merely the first of the problems La Salle would face on his journey. Nevertheless, the expedition continued on to St. Domingue (present-day Haiti), where La Salle lost the store-ship *Le Saint-Francois* to Spanish privateers. After re-provisioning, La Salle’s three remaining ships pressed on toward the Mississippi River. During this leg of the voyage, both *La Belle* and *L’Aimable* sustained damage when a sudden gust of wind drove *La Belle* into the other ship. The accident cost *La Belle* an anchor and 183 m (100 fathoms) of rope, a loss that later would have grave repercussions (Joutel 1998; Weddle 2001).

This thesis follows the journal style of *American Antiquity*.

Approximately 18 months after leaving France, La Salle reached the area in which he believed the Mississippi River lay. La Salle lacked the ability to accurately determine longitude, a technology which lay a century in the future (Sobel 1995). This inability, combined with inaccurate latitudes obtained on an earlier expedition by La Salle from a broken compass and an astrolabe which he suspected was faulty led La Salle to declare that the Mississippi emptied into the Gulf southwest of its true location (Bruseth and Turner 2005:22; Weddle 1991, 2001). Despite La Salle's conviction that he was in the right location, the inaccurate latitudinal readings and incorrect assumptions about the gulf currents led him hundreds of kilometers off course. Instead of the Mississippi River, La Salle had reached the coast of what would later become Texas (Minet 1987; Weddle 1991, 2001).

During an attempt to enter Matagorda Bay, La Salle lost his supply ship, *L'Aimable*, when she ran aground in February of 1685. The 163 t (180 ton) ship, *L'Aimable*, was carrying the forge, most of the cannonballs, and many of the trade goods and stores needed for the colonization attempt. Some provisions were rescued in the days before she disappeared under water, but the loss of a second ship was devastating. Having completed her escort assignment; the 36-gun man-of-war, *Le Joly*, eventually returned to France. The captain reluctantly left La Salle and his colonists behind. Returning to France on *Le Joly* were the crew of *L'Aimable* and 120 colonists who had become disillusioned with both La Salle and the survival chances for the colony. The fourth, and last remaining ship, *La Belle*, stayed with La Salle and the remaining colonists (Bruseth and Turner 2005:27; Joutel 1998; Minet 1987; Weddle 1991, 2001).

Believing he was situated on a branch of the Mississippi, La Salle established his colony a short distance up Garcita Creek, which emptied into Matagorda Bay. Upon returning from an exploratory journey to seek the mouth of the Mississippi River, La Salle was greeted with news of *La Belle's* disappearance. Anchor troubles had continued to plague the little ship, with the crew at one point employing a cannon as an anchor during a squall. No match for the winter storms of the Gulf of Mexico, *La Belle* dragged her one remaining anchor and ran aground near the inlet connecting the bay to the Gulf in February of 1686. *La Belle* slowly sank into the sand and silt, taking most of her contents with her. The loss of *La Belle* left the struggling colony without a means of returning to the Caribbean islands for vital supplies (Joutel 1998; Weddle 2001).

Faced with the loss of his last ship and her stores, La Salle and a small party of men set out to seek aid from New France in Canada (Joutel 1998; Weddle 1991, 2001). La Salle never made it out of Texas, and he met his ultimate fate at the hands of his own men. He was murdered near present day Navasota, Texas (Foster 1998; Weddle 2001). A handful of party members survived to reach Canada and went on to France, abandoning the little colony to disaster.

Several years of searching fruitlessly for the rumored French colony paid off when a Spanish search party found the wreckage of *La Belle* in 1687. The party failed to locate the settlement and its few survivors (Dunn 1916; Enríquez Barroto 1987:171-172; Weddle 1987:129-147, 2001). The remaining colonists struggled on until the winter of 1688, when the native Karankawa people massacred the settlement (Weddle 1987:215, 1991). Of the 23 remaining colonists, only five children survived. Taken in and cared for

by the women of the tribe, the children were eventually discovered by the Spanish (Bell 1987:239-242; Weddle 1987:209-224, 1991, 2001). An estimated 300 people left France with the expedition and approximately 160 stayed with La Salle when *Le Joly* returned to France. In all, fewer than 20 survived La Salle's colonizing fiasco (Weddle 2001). Meanwhile, the little ship *Belle* disappeared under the waters of Matagorda Bay, to lie buried in the sandy silt for more than three centuries.

Focus

More than a million artifacts were recovered during the excavation of *La Belle* by the Texas Historical Commission (THC). The artifacts included trade goods, personal items, armaments, ship supplies, rigging, and other necessities for establishing a settlement. Among the recovered artifacts were several hundred meters of rope of varying lengths and diameters. Some are associated with rigging and some coiled in the hull, as if still awaiting use.

Although not as immediately attention-getting as the cannon, engraved pewter cup, or nocturnal; without cordage, the colonization attempt could not have taken place. Rope was used for everything from holding up a pair of pants to hoisting sail and casting anchor. Several accounts taken from the journals of Joutel and Enríquez Barroto make mention of cordage specifically (Enríquez Barroto 1987:171-172; Joutel 1998: 140). *La Belle* lost an anchor and 183 m (100 fathoms) of rope during the voyage. *L'Aimable* was mentioned as being short of cordage, and after she was wrecked a portion of her cordage was salvaged and buried in casks to preserve it for later retrieval (Joutel 1998). After *La*

Belle ran aground, the survivors buried a cache of recovered ship's supplies, including cordage (Joutel 1998:140). When the Spanish discovered and explored the wreck of *La Belle*, they salvaged a quantity of cordage and divided it between their vessels (Enríquez Barroto 1987:171-172).

Although cordage is an important part of any historical sea voyage, the published record regarding the conservation of archaeological cordage is sparse. In an attempt to remedy the lack of information, the remainder of this thesis focuses on a brief history of rope and the available methods for conserving waterlogged cordage, particularly those methods used on the rope recovered from *La Belle*.

Excavation

In 1995, State Marine Archaeologist Barto Arnold led a team of researchers in an effort to locate La Salle's ship *La Belle* (Figure 1). Based on locations described in historical documents, the team used magnetometer surveys to search for and investigate anomalies along the southern shore of Matagorda Bay. Possible wreck sites with a signature consistent with *La Belle* were placed at the top of a list of sites to be explored (Bruseth and Turner 2005; THC 1996). A bronze cannon was discovered on the first day of diving on the first anomaly. The cannon was carefully freed from the site over the course of several days and examined upon being brought up. Decorations on the cannon bear the name Le Comte de Vermandois, the Grand Admiral of France between the years 1669 and 1683. All cannon cast in the royal foundries during his tenancy were marked

with his title (Keith et al. 1997; Foster 1998). Here was solid evidence that this wreck was indeed that of *La Belle*, ending a search that had begun in 1978.

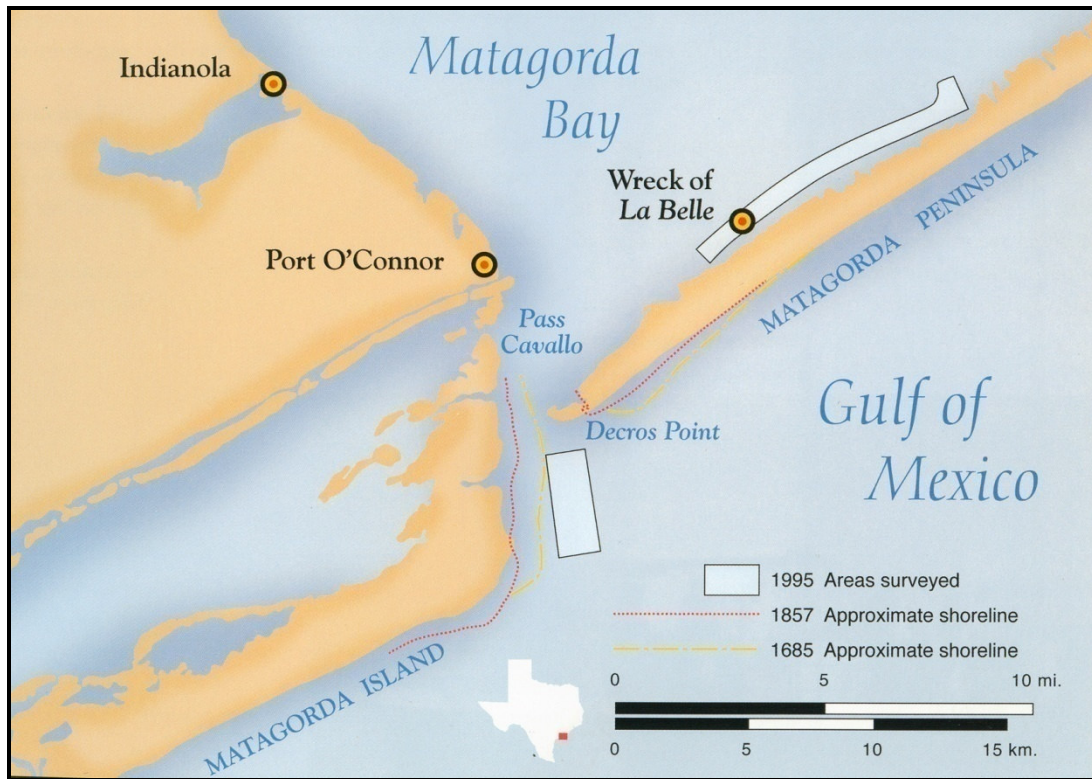


Figure 1. Location of *La Belle*. Image from Bruseth and Turner (2005) (By permission of the Texas Historical Commission).

After some deliberation, the decision was made to completely excavate *La Belle*. The poor visibility of Texas coastal waters, the shallow depth of the site (3.6 m), and the soft dense mud covering *La Belle* led to the decision to attempt the use of a coffer dam to expedite the recovery of the wreck. A coffer dam constructed from two rings of interlocking steel sheet pilings was erected, and the 20 ft gap between the rings was filled with gravel for reinforcement. The water was then pumped out of the coffer dam,

creating a relatively dry site surrounded by the murky waters of Matagorda Bay (Bruseth and Turner 2005; Roberts 1997).

Under the direction of Barto Arnold, and later, Dr. Jim Bruseth, the THC completely excavated the site (41MG86) during one long field season in 1996 and 1997. The covering of silt created an anaerobic environment around the wreck, preventing the total decay that would be expected in the warm Gulf waters. The anaerobic environment preserved approximately 40 percent of the hull and more than one million associated artifacts (Bruseth and Turner 2005; Locke 1999; Grieco 2003). These recovered artifacts and the ship's hull were moved to the Conservation Research Laboratory (CRL), director Donny L. Hamilton, at Texas A&M University. The CRL is part of the Center for Maritime Archaeology and Conservation (CMAC), and was contracted to conserve the ship and all of her associated artifacts.

Cordage ranging from a plaited, or braided, cord less than a centimeter in diameter to anchor cable more than 9 cm in diameter was recovered from the ship. Although cordage was distributed throughout the ship, the largest quantity came from a coil of anchor cable located in the bow. During excavation and recovery the cordage was encased in hardware cloth, or mesh, with coils kept intact when possible or cut into manageable lengths if not. The rope was then placed on pallets and transported to the CRL where it was stored in vats of fresh water until it could undergo the conservation process. The fresh water served to remove the soluble salts and to keep the artifact wet, an important factor when conserving waterlogged artifacts.

CHAPTER II

THE HISTORY OF ROPE MANUFACTURE

History

The origins of rope manufacture are lost through the extreme passage of time, although hominids probably employed cordage as early as the Lower Paleolithic (Bednarik 1997:28). Excavations of Gravettian sites have produced impressions of fiber cordage in clay fragments dating to approximately 26,000 B.C.E. (Pringle 1997; Soffer, et al. 1998). Recent discoveries at Mersa Gawasis in Safaga, Egypt, have yielded archaeological evidence tying the use of cordage to seafaring as early as 3500 B.C.E (Egypt State Information Service 2007). The use of natural fiber cordage has been a vital part of man's history for millennia. Even today we utilize cordage, comprised of metal or synthetic materials, for activities such as constructing suspension bridges, climbing mountains, and drilling for petroleum.

Perhaps nowhere is man's reliance on cordage as evident as in seafaring. Outfitting a ship requires miles of cordage for standing rigging, running rigging, anchor cables, securing cargo and innumerable other jobs. Ubiquitous in seafaring, fiber cordage is not indestructible and has to be replaced on a fairly regular basis due to degradation through sun, water, and friction. Strong, durable materials were needed to craft rope that could endure the rigors of a sea voyage.

Materials

Material as diverse as leather, seaweed, and papyrus has been utilized throughout history to manufacture strong, durable rope. Of these materials, a few stand out as being the most suitable for the manufacture of cordage. Two materials, in particular, left indelible marks in the history of maritime cordage production- hemp and abaca.



Figure 2. *Cannabis sativa*. Drawn by J. McCaskill.

The term hemp has been generically applied to many different fibers with similar properties. In this paper, hemp refers specifically to the bast fiber known as “common” or “true” hemp, *Cannabis sativa* (Figure 2). Man’s use of hemp has a long history, but

cultivation is thought to have begun in Central Asia or China more than 4000 years ago (Abel 1980; Berger 1969; Dempsey 1975; Kirby 1963; Weindling 1947). Hemp spread throughout the world, and became widely distributed in Europe by the sixteenth century (Dempsey 1975:50). Hemp dominated the cordage industry until the early nineteenth century when abaca fiber captured the market. In seventeenth-century France, *Cannabis sativa* was the material of choice for cordage production. Thus, the preparation of hemp is discussed in detail in this report.

Hemp is a strong, durable bast, or stem, fiber lacking the flexibility and elasticity found in flax and abaca. It is stronger when wet and does not rot easily in water. The fibers are hygroscopic, swelling and becoming stiff when soaked (Berger 1969; Dempsey 1975; Gibson 1996; Matthews 1913:416-425; Smith 1990; Švédová 1990). An annual plant, hemp is sown from seed and grows between 2 m and 5 m in height. Hemp is dioecious, producing both male and female plants, with the male being less woody and thus preferred for fiber production. Different types of hemp, soil conditions, and retting methods also affect the quality of fibers produced (Dempsey 1975; Dodge 1897; Kirby 1963; Weindling 1947).

The bast fibers are extracted from the plant stems through retting, a process that softens the gums and pectin which connect the woody core to the bast fibers bundles and hold the bundles themselves together. The softening of the pectin and lignin allows the fibers to be separated from the woody core (Abel 1980; Boyce 1912; Dempsey 1975; Kirby 1963; Matthews 1913:416-425; Weindling 1947). Retting can be done in several ways, but cold-water retting and dew retting, are commonly employed. Cold-water

retting is preferred for quality fibers and produces long, pale-colored and elastic fibers. The stems are cut, bundled, and dried for several days, then beaten to remove the leaves and seeds. The bundles are immersed in either stagnant retting ponds or slow running water for one to two weeks (Figure 3a). The bundles are then allowed to dry by setting them into shocks, and may be processed further or stored for later re-retting (Boyce 1912; Dempsey 1975; Dodge 1897; Kirby 1963; Weindling 1947). Dew, or grass, retting is carried out by spreading the cut stems evenly across a field to weather under the elements. The stems are turned several times over the course of three to six weeks to ensure even retting. With dew retting, there is always a danger of mold. Fibers produced using this method are gray, shorter, less elastic, and weaker than those produced by water retting (Berger 1969; Dempsey 1975; Dodge 1897; Kirby 1963; Weindling 1947).



Figure 3. Depiction of the hemp preparation process: (a.) weighing the bundles of hemp for water retting, (b.) scutching the hemp, (c.) drawing the hemp through a set of hackle pins, (d.) the bundles of hemp fibers. Image after H. L. Duhamel du Monceau (1769).

Once the stalks are retted and dried, they are broken and scutched. Breaking in the seventeenth century involved crushing the stalks by hand or through the use of a simple tool composed of a long wooden block hinged on one side to a heavy, wooden, wedge-shaped blade that could be repeatedly dropped onto the hemp stalks as they were pulled through (Figure 3b). Remaining debris is removed through scutching, or beating the fibers with a wooden club called a scutcher, and then by drawing the fibers through a set of hackle pins (Figure 3c). Long fibers obtained during the separation process are known as line and the short fibers as tow (Dempsey 1975, Kirby 1963, Weindling 1947). The fibers are then bundled in preparation for shipping (Figure 3d).

A simplified account of hemp fiber preparation from an early nineteenth-century survey of Lisieux, Normandy, is translated below by Flaningham (1949:71). Lisieux, France, produced 33,000 kg of hemp during the year of the survey (Flaningham 1949). The retting process was not industrialized, and we can assume that the process had not changed significantly in the 130 years between La Salle's voyage and the survey account.

When hemp is harvested in the field, the seed is obtained by beating the hemp with the hands or with pieces of wood while on a bench or framework. Later the head of the plant, from which the seed is obtained, is cut off. The hemp is tied in small bundles about the size of an average man's thigh and then 10 or 12 of these bundles are bound together similar to bundles of straw. One fastens 10 or 12 of these large bundles together, and they are deposited in a retting pond, which is a

pool of stagnant water. The hemp bundles are covered and loaded down with stones in order to make them completely submerged in the water. The bundles remain thus for 12 to 15 days. They are removed only when it is apparent that the hemp cortex is rotten and that the hemp fiber can be detached with ease. The bundles of stalks are broken up into their original position. Each separate bundle is removed by its top; one works around the fibers from the base; and then each is laid out on the ground. One selects a flat terrain exposed to the sun; the action of the air, and more especially the sun, helps to complete the retting process by detaching the fiber and cortex. One removes the strongest fibers; the inferior ones are broken up into a kind of mush. The hemp fiber, which is thus removed by particles, are kept together by the following process: a handful of fiber or cortex is held by the left hand against a plank some 3 ½ feet in length, the hemp descends along the side of the plank and with the right hand or with a piece of wood of average size one beats the hemp, and finally it is carded with a comb in order to clean it [translation by Flaningham 1949:71].

Abaca (*Musa textilis*), or Manila hemp, is the fiber extracted from the abaca plant, a native of the Philippines. Related to the banana, abaca is composed of 12 to 30 overlapping stalks which form a pseudo stem approximately 4 to 8 m high. It is the pseudo stem which is harvested for fiber, and the leaf blades are discarded. Fibers extracted from these stalks may be up to 3 m in length. They are composed of large bundles of single fiber cells, which can be separated by soaking in an alkaline bath during processing. Abaca may be propagated through seed, suckers, or rhizomes. It

grows best in fertile, well-drained soil in a hot, humid climate with year-round rainfall. Rapid processing is necessary to ensure high quality fiber. It is typically carried out in the field, where the fiber is stripped from the inner and outer stalks within 24 hours of cutting. The stalks are kept separate. Outer stalks produce coarser material more useful for cordage, while the inner stalks produce fiber more suitable for paper production. After stripping, the fibers are hung on poles to dry, and then beaten to separate the individual fibers (Berger 1969, Dodge 1897, Kirby 1963, Matthews 1913:416-425, Weindling 1947).

Europeans were made aware of abaca with the discovery of the Philippines in the sixteenth or seventeenth century (Tyson 1966; Weindling 1947). It was not until the early nineteenth century that abaca was produced for commercial fiber (Dodge 1897; Weindling 1947). Abaca quickly replaced hemp as the premier fiber for marine use due to its superior properties. Abaca fibers are lightweight and exhibit high longitudinal strength, both of which are advantageous in sea-faring (Berger 1969; Dodge 1897; Kirby 1963; Matthews 1913:435-438; Weindling, 1947). Abaca is also more elastic, capable of stretching up to thirty percent under a load (Gibson 1996). Natural oils provide abaca fibers with resistance to deterioration by humidity, fresh, and salt water and eliminate the need for tarring to prevent rot (Gibson 1996; Smith 1990; Berger 1969; Kirby 1963; Matthews 1913:435-438; Weindling 1947).

Although hemp and abaca represent the majority of pre-industrial and industrial European cordage-making for centuries, a number of other materials have been utilized with varying degrees of success. Western cultures have historically employed several

other fibers on a smaller scale, including flax, linden, and esparto grass. Flax (*Linum usitatissimum*) is one of the oldest textile fibers known to man, found on nearly every farm for centuries in Europe (Berger 1969; Dempsey 1975; Dodge 1897; Weindling 1947). When used for cordage, flax produces extremely high quality rope, as it is soft, limp, and flexible without being elastic and is extremely strong and durable (Gibson 1996; Smith 1990; Weindling 1947). Flax was never widely utilized as cordage, being more important as a textile fiber. Cotton (*Gossypium spp.*) has been known to man for at least 3000 years (Dodge 1897; Matthews 1913:184). However, cotton is a poor choice for rigging, as it is not strong, chafes easily, and has a tendency to become unworkable once wet. Cotton is also extremely soft and tends to unravel when cut, making it difficult to splice (Gibson 1996; Smith 1990). Lime bast is the fiber of the linden tree (*Tilia cordata*) and has been in use since the Mesolithic. Lime produces a coarse rope that is pliable and lightweight, but not as strong as hemp, and has low water absorption, elasticity, and durability (Dodge 1897; Myking et al. 2005). Esparto grass is the term applied to two separate, but similar wild grasses: *Stipa tenacissima*, known also as alfa, Spanish grass, halfa, sparte, and sea reed and *Lygeum spartum*, known also as false alfa, sennoc and albardine. Both plants are native to North Africa, southern Spain, and Portugal, and *S. tenacissima* has been cultivated in both Spain and southern France. Esparto grass thrives in the dry, sandy areas along the Sahara and in the Mediterranean steppes. It grows in tufts, and propagates naturally through seed and artificially through rhizomes and seed. Once pulled, the grasses may be dried or retted in sea water and beaten to improve suppleness prior to being used (Dodge 1897; Kirby 1963).

From the late eighteenth to the nineteenth centuries, several natural fibers besides abaca were introduced to the Western world industrially. Sunn hemp (*Crotalaria juncea*) was introduced to Europe circa 1791 or 1792 by the East India Company, although the fiber is identified in Sanskrit texts as *sana* as early as 400 B.C. (Dempsey 1975; Dodge 1897; Matthews 1913; Weindling 1947). A native of New Zealand, *Phormium tenax* was brought to the attention of Europeans by Captain Cook in the eighteenth century, although it was not traded commercially until the mid-nineteenth century (Dodge 1897; Kirby 1963; Matthews 1913; Weindling 1947). Coir (*Cocos nucifera*), or coconut fiber, has never been used to produce cordage industrially, but sources indicate that ropes made from the fiber are strong, elastic, and flexible, although they differ on the durability of coir (Dodge 1897; Gibson 1996; Kirby 1963; Matthews 1913). Sisal (*Agave sisalana*) and henequen (*Agave fourcroydes*) are both strong, durable fibers introduced into the world market during the nineteenth century (Berger 1969; Dodge 1897; Kirby 1963; Matthews 1913; Tyson 1966). Although the fibers swell and become slippery when wet, the Mayans utilized henequen for centuries and Spanish conquistadors used the fiber to create cordage for their ships (Gibson 1996; Kirby 1963; Smith 1990; Weindling 1947). Jute (*Corchorus capsularis*) was introduced to the western world from India in the nineteenth century, but has never been a major cordage fiber due to its relative weakness and perishability (Dempsey 1975; Dodge 1897; Gibson 1996; Matthews 1913; Weindling 1947). More recently, synthetic fibers such as nylon have usurped the natural fibers as the materials of choice for rope-making.

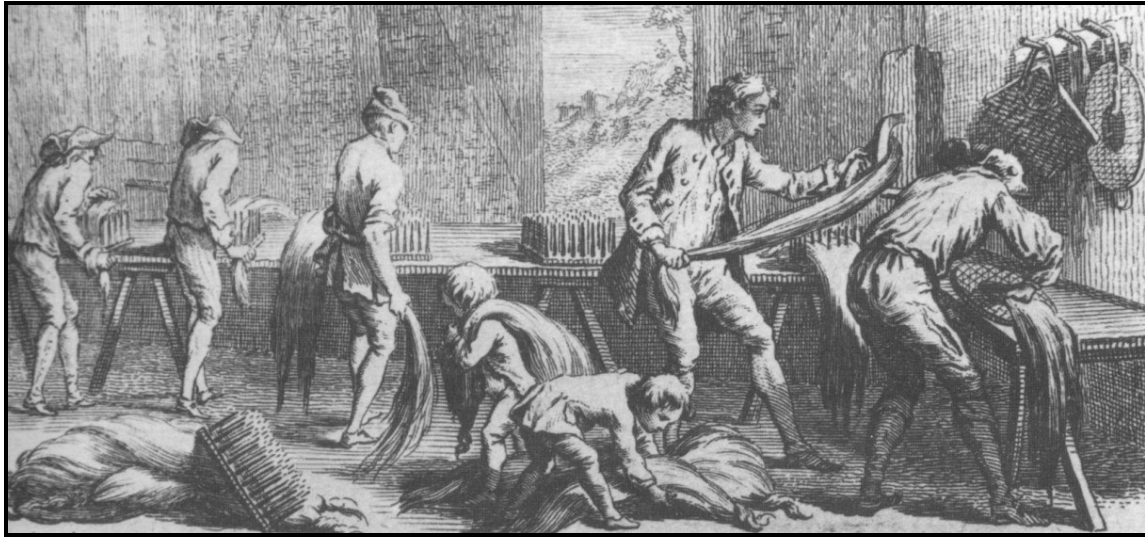
Rope-making

Figure 4. Hackling and smoothing the hemp fiber in preparation for spinning. Image after H. L. Duhamel Du Monceau (1769).

Hemp was the fiber of choice in seventeenth-century France, and was used in the manufacture of *La Belle's* rope. Thus, hemp is the focus of this discussion of rope making. After the hemp fibers were prepared, they were shipped to the rope manufacturers. The cordage industry created rope in areas known as ropewalks, often located conveniently near the shipyards for which so much of their product was created (Seymour 1984). These ropewalks were the same length as the rope to be created because the technology to coil ropes as they were produced was still more than two centuries in the future (Vindheim 2002). Once the fibers arrived at the ropewalks, further hackling removed any remaining tow and dirt and straightened the fibers (Figure 4)

(Dickinson 1943; Dodds and Moore 1984; Plymouth Cordage Company 1916; Seymour 1984; Tyson 1966).

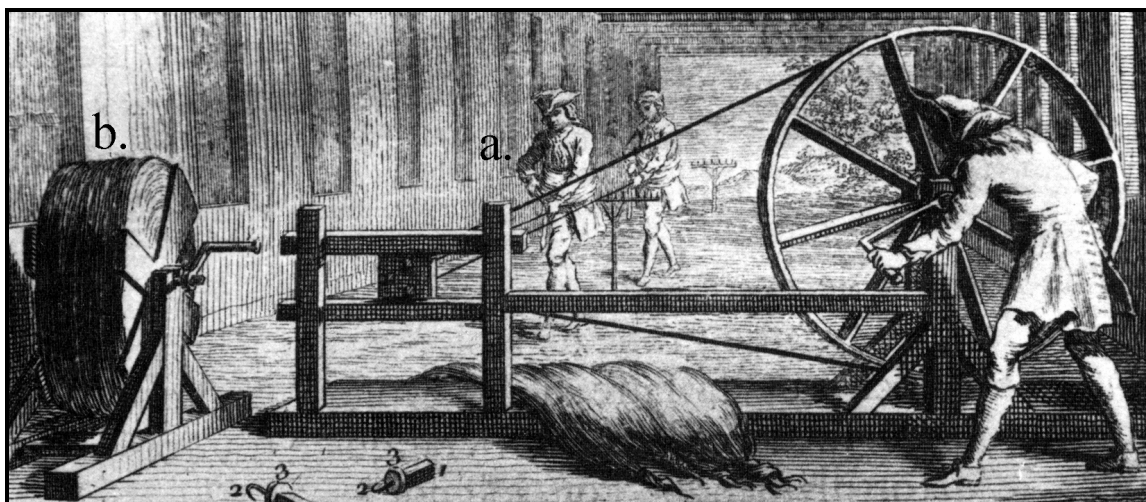


Figure 5. Spinning the hemp fibers into yarn: (a.) spinners spinning the yarns, (b.) reel of yarn. Image after H. L. Duhamel du Monceau (1769).

The first step in the creation of any type of cordage was the spinning of the yarns. Originally, yarn-spinning would have been carried out by hand or by the use of a distaff and spindle, but by the seventeenth-century technology had advanced somewhat. A spinner wound about 18 kg (40 pounds) of hemp fiber around his waist, both sets of ends in front. The spinner then attached one end of the fibers to the spinning hook or whirl, and walked backwards paying out the fibers while another person spun the hook (Figure 5a). This process caused the hemp fibers to interlock into a z-twisted yarn, following the natural twist of the hemp fiber (Beeton 1883; Dickinson 1943; Dodds and Moore 1984; Plymouth Cordage Company 1916; Seymour 1984; Tyson 1966; Weindling 1947). While the spinner walked backward, the fibers were fed with the right hand while the

left hand held a rough cloth or flannel with which to smooth them. As the yarn was spun it was laid across a series of suspended hooks to prevent it sagging. After a length of yarn was spun, it was wound onto a reel by an assistant, while the spinner kept the yarn from untwisting as it was reeled (Figure 5b) (Dickinson 1943; Dodds and Moore 1984; Plymouth Cordage Company 1916; Seymour 1984; Tyson 1966). An experienced spinner could spin 305 m (1000 feet) of yarn in 12 minutes (Dickinson 1943; Tyson 1966).

Prior to spinning the yarns into rope, the yarns were warped. Warping consisted of stretching the yarns between posts placed periodically along the ropewalk. They were stretched until the yarns reached the same length and bore the same amount of load (Dickinson 1943; Hopkins 1998; Tyson 1966). While warping the yarns, a further slight twist would be given to them (Beeton 1883; Hopkins 1998).

Hemp rope was often tarred to waterproof it and prevent rot. The tarring process could be carried out either on the yarns or on already laid rope. When tarring took place prior to laying, the bundles of parallel yarns were pulled through pine tar heated in large kettles (Beeton 1883; Dickinson 1943; Dodds and Moore 1984; Hopkins 1998; Tyson 1966; Vindheim 2002). The yarns were then compressed by a grip to ensure that the tar penetrated throughout (Tyson 1966). Finished rope was tarred by drawing the length through a heated vat of tar. Excess tar might be removed by pulling the yarns through a hole in a board surrounded by oakum. The amount of tar allowed to remain in the yarns was based upon intended use (Dickinson 1943, Tyson 1966). Although effective as a

waterproofing method, tarring the yarns reduced the tensile strength of the rope to only 75 percent of white, or untarred rope (Dickinson 1943; Tyson 1966).

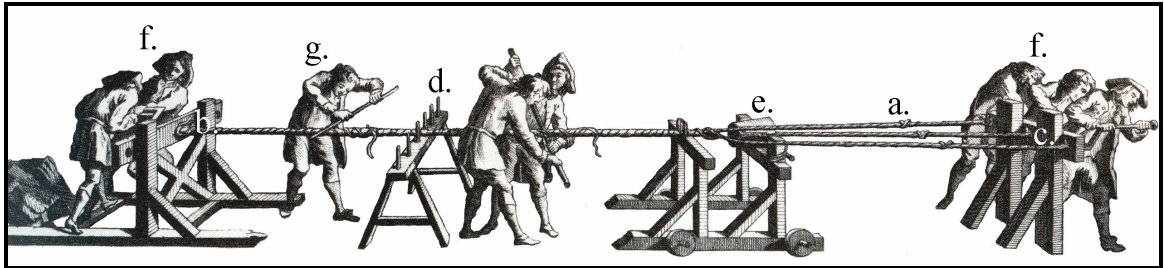


Figure 6. Laying a rope: (a.) strands, (b.) forelock bolt attached to sledge, (c.) whirrs, (d.) skirder, (e.) lay-top on top-cart, (f.) winders, (g.) woolder. Image after H. L. Duhamel du Monceau (1769).

After the yarns were spun, they were formed into strands (Figure 6a) and the strands laid into ropes. A rope was begun by twisting a number of yarns onto a single hook or forelock bolt mounted on a sledge (Figure 6b) at one end of what would be the rope, and dividing these yarns among several contiguous hooks, known as whirrs (Figure 6c), at the opposite end. The whirrs were positioned on a table wheel, a device which would spin the hooks at the same time using a pulley system, or each hook might be cranked separately by hand. The second method may have been employed more often for larger ropes. These whirrs were cranked to form the yarns into strands, which were supported along the length by skirders (Figure 6d). A lay-top (Figure 6e) was used to ensure evenness of twist and to prevent the individual stands from tangling. The lay-top was formed with grooves corresponding to the number of strands in the rope being laid. As the whirrs were spun the yarns would contract. Once the yarns had contracted about a quarter of their length, they had reached the limit of their ability to be twisted without

kinking. At this point, the strands were formed, and the laying of the cordage began (Dickinson 1943; Dodds and Moore 1984; Seymour 1984; Tyson 1966).

The winder or winders (Figure 6f) would continue to spin the whirls, while a layer would begin to walk along the ropewalk with the lay-top. This forced the single hook to spin, the tension causing the strands to twist together in the opposite direction of the strands as the layer walked towards the whirls. This method would have created a soft- or medium-laid rope. The addition of an assistant cranking the single hook, while the layer walked more slowly, would have resulted in a hard-laid rope. In heavier cordage, the lay-top was sometimes supported on a top-cart with wheels (Figure 6e), and the stretching and laying of a particularly thick cable may have taken as many as 70-80 men. After the rope was laid, the woolder (Figure 6g) would follow ensuring that the rope was pulled into shape. Once the rope was fully laid, the ends would be removed from the forelock hook and the whirls then whipped with twine to prevent fraying (Dickinson 1943; Dodds and Moore 1984; Seymour 1984; Tyson 1966).

This process for creating cordage remained static for centuries. An image from the Mandelsches Portrait Buch in the fourteenth century depicts the yarn-making process, which remained essentially unchanged five centuries later (Dickinson 1943, Tyson 1966). Major advances in cordage manufacture didn't begin to take place until the eighteenth century with inventions such as the cordelier, water power, and better fiber extraction methods (Dickinson 1943; Tyson 1966; Weindling 1947).

Seventeenth-century France was still a century or more away from many of these advanced technologies. Lacking an automated process, fibers were spun by hand into

yarns as discussed above. These hemp fibers exhibit a natural z-twist (Figure 7; Figure 8a) used to help form the yarns (Figure 8b). Strands are formed in the opposite direction, or s-twist (Figures 7 and 8c). Hawasers are laid in a z-twist (Figure 8d), then cables closed in the opposite direction yet again (Figure 8e). This reversal of the twist between each stage of rope manufacture is what prevents the rope from immediately unraveling upon completion (Dickinson 1943; Kirby 1913; Plymouth Cordage Company 1916; Smith 1990; Tyson 1966).

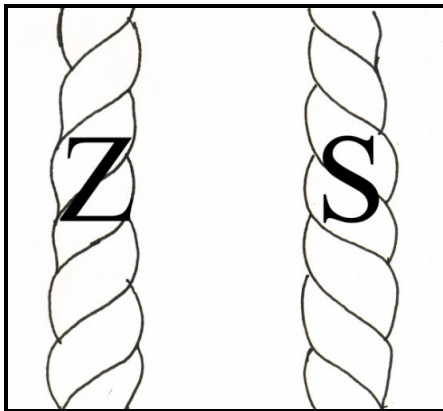


Figure 7. Twist patterns: z-twist and s-twist. Drawn by J. McCaskill.

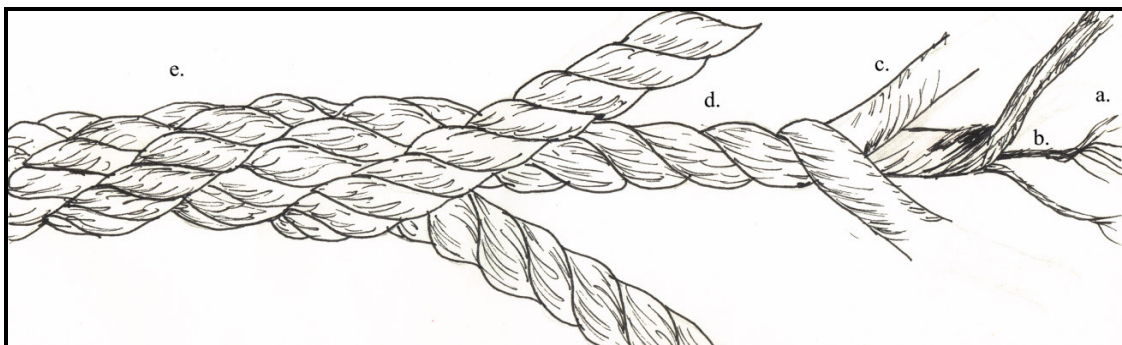


Figure 8. Diagram of an s-twisted cable: (a.) z-twisted fiber, (b.) z-twisted yarn, (c.) s-twisted strand, (d.) z-twisted hawser, (e.) s-twisted cable. Drawn by J. McCaskill.

These twisting patterns formed the basis for the types of ropes available to the seventeenth-century sailor. The yarns themselves, when sold without laying into cordage are known as binder twine. Strands or cords of two or more yarns formed with an s-twist might be sold as wrapping twine or marline (Gibson 1996; Smith 1990; Weindling 1947). Three or more strands laid together, usually in a z-twist, form a rope that is hawser-laid. A shroud-laid rope is composed of four strands laid in a z-twist around a core, which is usually of a slightly smaller size than the four strands. A cable-laid line is formed by three z-twist hawsers being closed together with an s-twist lay (Anderson 1994; Gibson 1996; Weindling 1947).

CHAPTER III
THE HISTORY OF ROPE IN EUROPE AND A DISCUSSION OF THE ROPE
FROM LA BELLE

“Til Revel og Riga din reise henfalt, Din Hør og din Hamp at annamme”

(University of Oslo 2001:Side 236)

“To Revel and Riga your Voyage did go Your Hemp and your Flax to acquire”

[translation by Vindheim (2002:94)]

Europe

Sixteenth- and seventeenth-century Europe was the scene of a mass race to colonize the world. The New World, the East and West Indies, Africa, and Asia all promised wealth and glory to the intrepid, but these promises could not be fulfilled without transportation. Transport to these far places required ships, and these ships required massive amounts of resources, including hemp.

Hemp and flax held a place of undeniable importance on the farm for centuries. These materials supplied the fiber needed for clothing and cordage for the family (Bourde 1953; Hopcroft 2003; Jacquart 1974; Thirsk 1997; Weindling 1947). Local customs reflected the importance of hemp to European farmers. In France, farmers would light bonfires and the locals would dance around them, leaping the flames. The higher leaps and flames, the higher the hemp crop was expected to grow. French farmers hoisted their trouser legs as high as possible while sowing hemp seed to encourage the

hemp to grow to the height to which he raised his pants (Abel 1980). In Great Britain, remnants of the importance of hemp agriculture may be seen in the still extant place names of Hemphill and Hempland.

In this age of discovery, demand for rope far exceeded the supply of hemp produced by most countries. The shortage prompted several monarchs to pass laws regarding the mandatory growth of hemp to supply the needs of the ships. In 1533 King Henry VIII of England decreed that a fine would be levied against any farmer not growing .10 ha (.25 acre) of hemp per every 24.28 ha (60 acres) of arable land. Later, his daughter, Queen Elizabeth I upheld his decree, both monarchs meeting with little success (Abel 1980; Thirsk 1997). King Christian IV of Norway demanded that his Danish farmers grow hemp for his navy, going so far as to supply seeds himself. King Christian V went a step further with the Danish Law of 1683, decreeing that: “Every farmer who holds a full farm, and does not sow a bushel of hemp seed, and he, who holds half a farm, half a bushel, should by his lord be charged and punished as an obstinate and reluctant servant, unless he proves that he has no suitable soil therefore” (Vindheim 2002:94). Theft of cordage was a serious offense; in one instance, thirteen people stood trial for the theft of a single cable. To prevent the theft of cordage in England, colored yarn was spun into each length of government cordage, with each manufactory using a different color. The colored yarn was termed Rogue’s yarn, and was used to identify any manufactories short-changing the Crown (Tyson 1966).

In spite of law and custom, many countries were still not able to meet the demand for hemp. The economic incentives for growing hemp were not enough to

overcome the need to grow foodstuffs for survival, and the penalties were not sufficient to sway the farmers from growing crops that would be worth far more at market (Abel 1980; MacDonald 1936; Thirsk 1997). Much of the hemp necessary for outfitting the ships of Britain and Europe in the seventeenth century was imported from the Baltic (Abel 1980; Bosher 1993; Davis 1956; Vindheim 2002). Reliance on imports caused supply problems during times of war and blockade, and the New World was looked to, with little success, as an alternate supply (MacDonald 1936).

France

Like Richelieu before him, the finance minister Jean-Baptiste Colbert was dedicated to bringing wealth back to France by encouraging self-sufficiency (Clough and Moodie 1965; Cole 1939:I:9, 17, 102, 144). He wrote in 1659 that he expected all resources needed to construct ships could be supplied by France without relying on foreign imports (Oxford Libraries Information Platform 2008). To this end, Colbert instituted policies restricting the imports of foreign goods that could be produced in France, subsidized industries, and encouraged French production of raw materials (Cole 1939:I:415, 427-428). During his tenure as finance minister, Colbert also increased the French navy from a mere 20 or 30 ships in 1661 to 176 ships with a further 68 either under construction or in planning in 1683 (Cole 1939:I:451, 456-457; De Vries 1976). To accomplish his goals, Colbert assisted in the establishment or revitalization of several chief ports at Brest, Rochefort, Toulon, and Marseilles (Cole 1939:I:456-457; De Vries 1976; Symcox 1974). Until Colbert chose these areas for his ports, Brest was a mere

fishing village, Toulon had no importance, Rochefort was a small medieval castle surrounded by hamlets located along a river about 20 km from the sea, and Marseilles was an established port in decline (Cole 1939:I:457; Symcox 1974).

Revitalizing the French navy meant that France, like the rest of Europe, had an insatiable need for hemp. In the early part of the seventeenth century France relied upon Holland for cordage (Cole 1939:II:348). With his policy of self-sufficiency, Colbert successfully spread the cultivation of hemp through France, in the areas of Burgundy, Mâconnais, Bresse, Berry, Auvergne, Brittany, Orléans, Lannion, Bayeux, Champagne, and Dauphiné (Bosher 1993; Boudriot 1986; Cole 1939:I:453, II:348, 524). The various regions of France each had a name for hemp: chenne, chaude, and chenève to name a few. Each region also produced hemp of a different quality. Alsace produced both long, white hemp good for sails and cordage and short, grey dew-retted hemp good only for peasants' clothing. The navy did not want the hemp from Auvergne; as it was short and soft, good quality but filled with tow. Burgundy's hemp was white, but hard and brittle. Hemp from Dauphiné was suitable for the navy, being fine, soft, and 1.5m to almost 2m long. In the regions near Brittany, the quality of hemp became so important any cloth produced in those areas took the name of the particular region or city in which it was produced (Allegret 2006).

Later, as the demand for hemp continued to increase, France looked to the Baltic and to New France to supplement its supply (Abel 1980; Le Mercier 2000; MacDonald 1936; Pilgrim 1975). The first intendant of Canada, Jean Talon, successfully encouraged the settlers of New France to increase the hemp crop by confiscating all of the thread.

The thread could only be purchased from him by paying with hemp (Abel 1980; Chapais 1921).



Figure 9. Joseph Vernet's *Vue du port de Rochefort* (detail). The buildings of *la Corderie Royale* can be seen at the bottom right. Image from Bruseth and Turner (2005) (By permission of the Texas Historical Commission).

As mentioned above, Colbert also encouraged the development of industries to reduce France's dependence upon manufactured goods from foreign markets. One such industry was the manufacture of cordage. Obtaining Colbert's goal of self-sufficiency meant the establishment of several major rope-making manufactories at the chief ports of Toulon, Havre, Brest, Marseille, and Rochefort (Cole 1939:I:453, 457, II:348). These manufactories sold rope at fixed prices to the royal navy, but could set their own prices for any extra cordage (Cole 1939:II:348). The royal manufactory, *la Corderie Royale*,

was the first large building in the arsenal established in Rochefort (Figure 9). Built on marshy ground, the building was constructed upon an oak-log raft foundation. Begun in 1666, more than 2000 workers took part in the building construction. The ropewalk was complete in 1669 and was 374 m long. (Centre International de la Mer 2007, 2008; Gay 1987) The length of the ropewalk allowed for the manufacture of cables 194.4 m (120 fathoms) in length to be produced for outfitting the ships built at the Rochefort shipyard (Boudriot 1993).

The buildings of *la Corderie Royale* still exist as part of a maritime museum representing an important piece of French nautical history (Center International de la Mer 2008). *La Belle* was constructed at the Rochefort ship yard, thus the ropes recovered from her excavation represent the only known surviving seventeenth-century cordage from *la Corderie Royale* (Bruseth and Turner 2005).

La Belle's Cordage

Without cordage, the La Salle expedition would have never left France. As a small ship of approximately 36-41 t (40-45 tons), the rigging of *La Belle* would in no way have taken the 100 t (110 tons) of rope needed to outfit a first-rank French vessel (Bruseth and Turner 2005; Centre International de la Mer 2007). We do not know exactly how *La Belle* was rigged, and cannot precisely state the amount of cordage with which she was endowed. (Jim Jobling, personal communication 2008). However, the amount of cordage needed for rigging and anchor cables would have been extensive, reaching 8 km or more (Glenn Grieco, personal communication 2008). Spare rope for

the ship would probably have been part of the cargo, particularly as it was not known when spare rope would be available for later procurement. When *La Belle* ran aground, she probably was carrying not only her own rigging, anchor cables, and spare ropes; but also supplies for the colony, salvaged rope from *L'Aimable*, and rope for various practical uses such as hoisting buckets or securing cargo and cannon.

The rope recovered during the excavation represents only a fraction of what *La Belle* would have been carrying. Even before her disappearance below the waters of Matagorda Bay, *La Belle* lost a considerable amount of her original cordage. After leaving Haiti, a collision with *L'Aimable* during a storm caused *La Belle* to lose an anchor and 183 m (100 fathoms) of hawser. After *La Belle* ran aground, the survivors buried a cache of salvaged material which included some unknown amount of cordage (Foster 1998). Later, a Spanish search party looking for evidence of the French expedition came across the wreck of *La Belle* and salvaged an unknown amount of rope and 55 m (30 fathoms) of anchor cable for their own use (Enríquez Barroto 1987:171-172). Finally, as she lay submerged in Matagorda Bay, natural decay would have claimed much of *La Belle's* remaining cordage. Still, numerous rope artifacts in varying sizes were recovered from *La Belle*.

The mention of rope in the journals of Joutel and Enríquez Barroto are only remarkable because of how ubiquitous and unremarkable the use of rope was during the seventeenth century. The loss of 183 m (100 fathoms) of hawser in the collision with *L'Aimable* must have been a troubling blow, although it may not have been mentioned if an anchor had not also been lost. However, in later journal entries, Joutel emphasizes the

importance of cordage by mentioning it specifically among the salvaged supplies from both *L'Aimable* and *La Belle* (Foster 1998). Rope salvaged from *L'Aimable* was buried in casks for later retrieval, and, as discussed above, rope was included in the buried cache of salvaged supplies from *La Belle* (Foster 1998). Juan Enríquez Barroto's journal (1987) details the type and quality of rope salvaged from *La Belle*, once again unwittingly emphasizing the importance of a commonplace staple that would not have been readily replaced during the colonization in the New World.

As an organic artifact composed of simple fibers, cordage does not survive well in an underwater context. The warm coastal waters of Texas are an ideal place for *Teredo navalis*, a small crustacean that burrows into and devours organic materials, further accelerating their decomposition. Only the submersion of *La Belle* into the anaerobic silt in Matagorda Bay prevented the complete loss of the cordage. In spite of environmental factors, more than 200 rope artifacts were recovered from *La Belle*, comprising hundreds of meters of rope. The rope assemblage included rigging elements, anchor cable, and cargo. Much of the cordage was recovered in a fragile and degraded condition, and many of the artifacts are only small fragments of rope or yarns.

When the Spanish discovered *La Belle*, Enríquez Barroto (1987:171) wrote of her cordage: "All her tackle...was very fine, new, and mostly of four strands." Barroto's statement is not reflected in the archaeological record. Although a few pieces of four-strand shroud-laid rope with a central core and four-strand hawser-laid cordage were recovered, nearly all of the recovered rope was three-strand hawser or anchor cable. Many of the rope artifacts recovered from *La Belle* were probably seeing active use as

part of the ship's rigging. These artifacts would have been exposed to the elements for an extended period before the ship was completely submerged. The Spanish party probably left only cordage that was submerged, and thus difficult to recover, or cordage that was degraded beyond usefulness. The Spanish even removed 55 m (30 fathoms) of eight-inch anchor cable for use as yarns (Enríquez Barroto 1987:172). Thus, if Enríquez Barroto's account of the four-strand rope is correct, little was left behind to enter the archaeological record after the Spanish salvage operation.

In spite of the inroads made into *La Belle's* cordage prior to her submersion, cordage was recovered among the rigging. Some was associated with rigging elements such as blocks, deadeyes, or canvas. A discussion on the art of knot-tying and ship's rigging is not within the scope of this paper; however a brief description of the ropework recovered from *La Belle* is discussed below.



Figure 10. Short segment of rope displaying serving and canvas sail or awning attached with marline hitches. Photo by J. McCaskill.

Some of the most common elements seen on ships' ropes are worming, parcelling, and serving. Worming is the use of marline or twine to fill the gaps between

the strands along the lay to make it smooth in preparation for parcelling. Parcelling is the wrapping of rope tightly in canvas, again in the same direction as the lay of the rope. Parcelled rope is then served, or wrapped against the lay with marline or twine. A serving mallet is a special tool which provides enough tension to produce a tight, even result. These steps are taken to waterproof cordage and to help prevent weakening of the rope through chafing. The rope recovered from *La Belle* does not follow this standard pattern; there is no evidence that *La Belle's* cordage was either wormed or parcelled. However, serving was used liberally to protect the surfaces of the ropes from wear (Figure 10). Although parcelling does not appear to have been used, several pieces of rope do have canvas wrapped around them, some over serving. A few of these sections still show evidence of having been marled to the rope with marline hitches placed approximately 2.5 cm apart (Figure 10). These canvas pieces probably represent part of a sail, and the associated ropes may then be identified as bolt ropes (Gibson 1996; Graumont and Hensel 1952; Smith 1971, 1990).

Seizings are lashings wound around ropes meant to be bound together permanently (Figure 11). No identification of seizing type was determined because of the difficulty of tracing the pattern of lashings encrusted with dirt, degraded, and shifted from their original position. Most of the seizings were finished with a series or two of frapping turns (Figure 11). Frapping turns are lashings that cross the seizing perpendicularly to tighten seizings and to prevent slippage. Where needed to prevent the ends of the rope from unraveling and fraying, common whipping appears to have been used on *La Belle's* rope (Gibson 1996; Graumont and Hensel 1952; Smith 1971, 1990).



Figure 11. Heavily tarred rope (3100) exhibiting serving, an eyelet and seizing with two sets of frapping turns. Photo by R. Sasaki.



Figure 12. A cringle awaits final cleaning. The cringle is worked onto a bolt rope attached to canvas with marline hitches. The cringle has a smaller rope hitched around it. An eyelet rests in the bottom left-hand corner. Photo by J. McCaskill.

A number of more intricately worked rope artifacts also survived. In this report, specific identifications are tentative. Fifteen rope artifacts were found in association with

blocks, and four in association with deadeyes. Much of the rope recovered in association with other rigging elements provided further information in the form of knots, splices, and other rope work. At least 25 artifacts showed evidence of splicing: six possible cringles, as many as 14 short splices, some of which are part of block assemblies, and four eye-splices (Figures 12 and 13). Twenty-four complete or partial hitched, worked eyelets were recovered, several in association with bolt ropes and canvas (Figures 11 and 13). These may have been used to attach a canvas awning or windsail to a rope (Anderson 1994; Gibson 1996; Graumont and Hensel 1952; Smith 1971, 1990).



Figure 13. One of the four identifiable eye-splices recovered from *La Belle*. Photo by J. Swanson.

Very few identifiable knots were recovered. These included two hitches (12982 and 13975) (Figure 12), three crown stopper knots seized together in a sheet assemblage (3100) (Figure 14), and an overhand knot with no connected length of cordage (3100). The stopper knots were intended as permanent fixtures to prevent the rope from unreeving, or unraveling. The hitches are simple knots, used to temporarily fasten a line. The overhand knot, or thumb knot is typically a base for other knots, and can be used

alone as a stopper knot or as a replacement for whipping. Several other rope artifacts had partial knots or knots unidentifiable due to concretion or deterioration (Anderson 1994; Gibson 1996; Graumont and Hensel 1952; Smith 1971, 1990).



Figure 14. Two of the three crown knots which are seized together. The ropes are served and heavily tarred. The seizing is frapped. Photo by R. Sasaki.

The bulk of the rope recovered from *La Belle* was a pile of anchor cable stored in the bow (4909) (figure 15). Cut into 2 m sections to facilitate removal, it was later discovered that the pile was made up of three separate coils of cordage. The lengths of the individual ropes have not been determined, as portions of the anchor cable are still in conservation at the writing of this report; however, the combined length is an estimated 300 m to 400 m. The largest rope is a cable of 27 cm (approximately 10 French inches) in circumference (Boudriot 1993). The cable appears to have been soft-laid; however, the loose cabling could also be evidence of the cable having become long-jawed, or over-stretched, after extensive use or the rope may have unwound slightly when the

cable was cut into pieces (Smith 1971). A section exhibiting a three-cable splice and another section which exhibited seizing is evidence that this cable may have seen use. A second, 22 cm (8 French inches) cable was also recovered from the pile of cordage, and may have been a back-up anchor cable (Boudriot 1993). Enríquez Barroto recorded the salvage of 55m (30 fathoms) of eight-inch anchor cable along with the associated anchor, supporting this theory (Enríquez Barroto 1987:172). This cable had a tighter lay than the larger 27cm cable, appropriate to the rigors to which an anchor cable would have been exposed (Rees, 1970). The third rope was an approximately 6 cm circumference rope, probably coiled on top of the other two.



Figure 15. A skeleton sprawls across the anchor cables recovered from *La Belle's* bow. Image from Bruseth and Turner (2005) (By permission of the Texas Historical Commission).



Figure 16. The smallest diameter coil; one of five removed from *La Belle's* hull. Photo by R. Sasaki.

Five coils of medium-laid, three-strand rope were also recovered from the hull. Four were removed intact, and the fifth removed in sections. The smallest of these coils (7717) (Figure 16) has an approximately 3.8 cm circumference, corresponding to a 1.5 inch rope by the old French system of measurement (Boudriot 1993). Two of the coils (6089 and 7266), one of which is cut into sections, have an approximate 5.2 cm (2 French inches) circumference (Boudriot 1993). The two largest of these five coils (3447 and 10790) have a 6.4 cm circumference, or approximately 2.5 French inches (Boudriot 1993). Coil length is subject to speculation, as determining the length would require damaging the fragile rope by uncoiling it. Weighing the rope to determine a proportionate length to weight ratio would not provide accurate results, due to the

unknown quantity of sand and sediments remaining within the coil and weight variation along the length of the rope because of uneven degradation. An estimate of the sectioned coil is limited to field notes indicating an estimated 76 m to 91 m (250 to 300 feet) of rope, as parts of the cordage unraveled into the component yarns (THC, La Salle Shipwreck Investigation Field Notes 1996-1997, Austin, Texas). The coils appear to have been unused, and their purpose can only be speculated upon. The rope may have been intended as replacement for the ship, as supplies for the colony or salvage from *L'Aimable*.



Figure 17. Decorative rope wrapping for an iron handle. The iron handle did not survive. Photo by J. McCaskill.

Several recovered rope artifacts do not appear to be associated with the rigging, the anchor cables, or the coils. These include what used to be an iron handle served with twine and ornamented on one side with a pattern reminiscent of outside Spanish hitching (3419.79) (Figure 17), a small piece of braided matting which may be part of a hat (10133), a short piece of hawser strung with roves (3196.2), and the 17 short lengths of braided cordage manufactured not from hemp, but from the second fiber (Graumont and Hensel 1952; Tom Oertling and Bart Hamiter, personal communication 2004). Two

small jumbles of yarns, which may be tangled balls of marline or spunyard (3312 and 11887) and five other artifacts which included segments of two-strand marline or spunyard (1126, 1617, 7056, ,12099, 12997) were also recovered. The remaining rope artifacts had no identifying features, and may have served any number of purposes. These pieces were composed of short sections of hawser, anchor cable, loose yarns, and strands in varying sizes.

Fiber Analysis

Although ash testing and microscopic analysis were attempted, the identification of the materials in *La Belle's* rope is based primarily upon observation and the historical research discussed above. The vast majority of the recovered cordage was composed of a single fiber type (hemp), with a second fiber type (probably esparto grass) represented by only 17 short lengths of plaited, or braided, cordage.

The first fiber has been identified as hemp (*Cannabis sativa*), an identification corroborated by historical research and physical characteristics. Other common industrial rope fibers, including abaca, jute, sisal, and henequen were eliminated from consideration based on the timing of their introduction as industrial fibers in the European market. Although these fibers were used to manufacture cordage in their native countries for centuries, none were available for industrial use in Europe until the nineteenth century. Other European rope fibers such as linden, flax, and cotton were eliminated based on historical research and comparison of physical characteristics (Berger 1969; Dempsey 1975; Dodge 1897; Kirby 1963; Matthews 1913; Myking et al.

2005; Tyson 1966; Weindling 1947).

A small sample of the anchor cable was subjected to an ash test. The test was inconclusive, as no identifying crystalline structures were observed. The absence of crystalline structures is not surprising, as fiber material is less likely to show identifiable crystalline structures than other parts of the plant. It is also possible that the absence of crystals can be attributed to heat exposure during tarring, decay, or conservation treatments. (Catling and Grayson 1982; Schaffer 1981; The Textile Institute 1985) A drying-twist test was carried out by holding one end of a wet fiber over heat and allowing it to dry. The twist produced was counter-clockwise, or z-twist. The twist direction eliminated flax, ramie, and nettle fibers as options; as these fibers exhibit a natural s-twist (Goodway 1987; Schaffer 1981; The Textile Institute 1985).

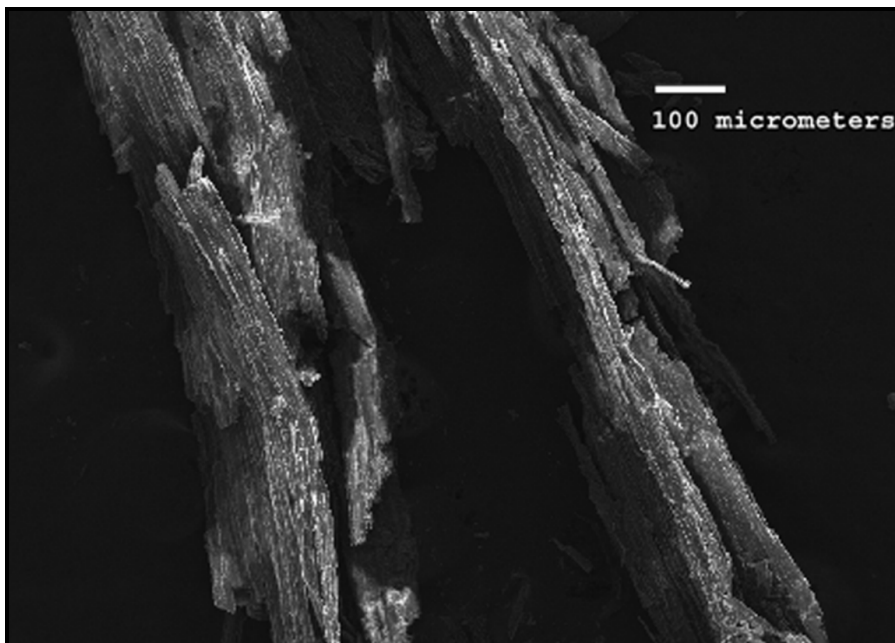


Figure 18. SEM image of *La Belle's* hemp rope, showing the degraded fiber structure. JSM-6400 39 mm working distance at 15 kV 60x magnification. Taken at 1200 dpi, 2 scans. Image by J. McCaskill.



Figure 19. Microscopic image of fibers from *La Belle's* hemp rope. Striations are visible, as is a possible joint (top right). Taken at 400x magnification. Image by J. McCaskill.

Microscopic analysis showed that the cellular structures are in an advanced state of decomposition (Figure 18). After three centuries under water, only the cell wall and an interior layer of lignin were identifiable. Bast fibers are composed of long, usually cylindrical cells which abut to other bast fiber cells above and below. The joints between these cells are often pronounced, and have a larger diameter than the cells (Figure 19). The presence of these joints, characteristic of bast fibers, supports the identification of the fiber as hemp (Catling and Grayson 1982; Middle East Technical University 2008). Cross markings or striations are common and show great variability in many species of

bast fiber. These markings can be short and evenly spaced, extend around the fiber, appear fine, wavy, straight, or doubled (Figure 19) (Catling and Grayson 1982). Both striations and large end joints were identified in *La Belle's* rope fibers, indicating that the rope is composed of a bast fiber, and probably hemp. However, no definitive hemp characteristics were identified through microscopy, and bast fibers from one species of plant often look very similar to those of other species (Catling and Grayson 1982; Goodway 1987; Middle East Technical University 2008; The Textile Institute 1985). The fibers from *La Belle's* rope were extremely degraded, making the microscopic identification of the fiber inconclusive. However, considering the history of rope-making, there is little doubt that the fiber is hemp.



Figure 20. Rope artifact manufactured probably from esparto grass. Photo by R. Sasaki.

The second fiber type (Figure 20) recovered from *La Belle* has been tentatively identified as esparto grass, although this conclusion is based purely upon a visual comparison with a modern object crafted from esparto grass. No positive identification has been made as to which of the two species it might be. The individual fibers are thick, wiry, and appear to hold the shape of the braid when separated from the cordage. Scanning electron microscope images of fiber cross-sections were inconclusive, with no identifying features definitively identified (Figure 21).

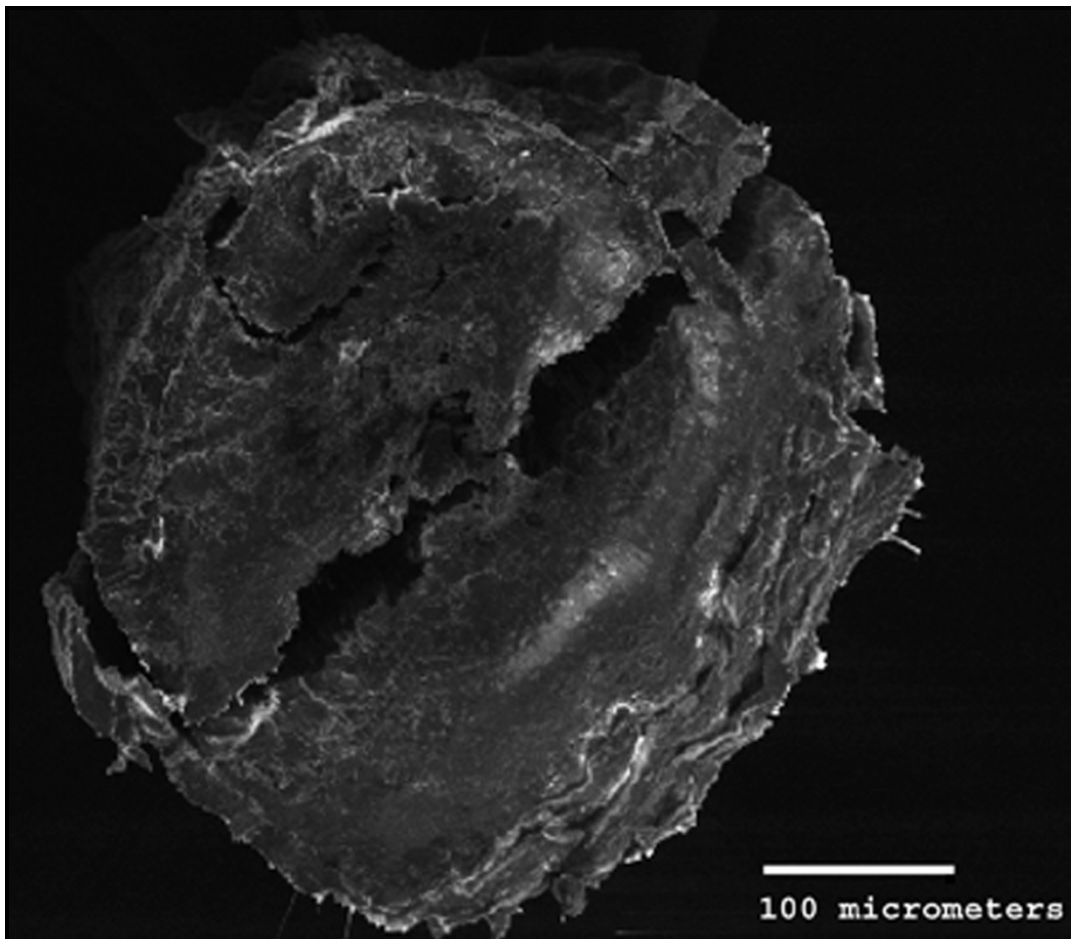


Figure 21. SEM image of a cross-section of *La Belle's* second fiber type, post-treatment. JSM-6400 39 mm working distance at 15 kV 190x magnification. Taken at 1200 dpi, 2 scans. Image by J. McCaskill.

CHAPTER IV

A REVIEW OF CONSERVATION METHODS

The published record with regard to archaeological cordage is sparse considering its ubiquitous character. This lack is due in no small part to the perishable nature of the organic materials from which rope is crafted. The bast fibers used in the manufacture of cordage are composed primarily of cellulose and lignin. Cellulosic materials are susceptible to a number of forms of decay; including thermal, photolytic, biological, oxidation, and hydrolysis (Cardamone 2001; Garside and Wyeth 2006; Mills and White 1987). Through time, these forces act on cellulosic materials; causing the bonds in the polymer chains to break, reform, and cross-link, causing the formation of crystals within the basic structure due to the massing of smaller polymer chains, and causing the breakdown of the cellulosic material into its basic components (Cardamone 2001; Garside and Wyeth 2006; Mills and White 1987). The lowered degree of polymerization brought about by the breakdown of the cellulosic material causes the artifact to become weak and brittle (Garside and Wyeth 2006). When these natural forces of decay are amplified by submersion in a salt-water environment over a long period of time, both the lignin and the cellulose will break down, and the artifact may disappear altogether.

The constant cycle of soaking and drying typical of a sea voyage, the swelling caused by the introduction of the soluble salts, physical stress, fatigue, weakening of the cellulosic materials caused by exposure to sunlight and heat, and microbial action all work to degrade rope during the lifetime of a ship. Exposure to sunlight is eliminated

when a ship sinks below the water. Both fungal and aerobic microbacterial attack may be prevented by the burial of the rope in silt or through other environmental conditions such as darkness or very cold water. The saturation of the fibers with water and salts, and sulfate-reducing anaerobic bacteria action continues to have a detrimental effect on the fibers by releasing hydrogen sulfide. Hydrogen sulfide reacts with the rope fibers to produce thiol compounds (Chen and Jakes 2001). Together these forces work toward the gradual weakening and eventual loss of the artifact (Chen and Jakes 2001). When recovered, these rope artifacts require intervention in the form of a conservation treatment to prevent their total loss.

While the published record regarding archaeological cordage is slim, the record regarding the conservation of cordage is doubly so. Because cordage is typically composed of fibrous vegetable materials, there exists a tendency to categorize cordage and woven fiber textiles together. This classification is not universal, and indeed, Veldmeijer (2005) argues for the categorization of rope as a separate class of artifact. Although cordage is a manufactured fiber product; it is not a flat, or woven, textile. Rather, Veldmeijer (2005:1) points out that cordage is “more than linear strands used for binding and tying;” it also encompasses netting and other artifacts constructed from cordage such as saddles, matting, and some basketry. However, few actual sources detail cordage specifically, and many mention nothing more than the presence of rope in a section about textiles or organics recovered from a site.

Regardless of the classification, waterlogged rope artifacts must undergo some form of conservation to prevent total loss. The choice of a conservation treatment for

waterlogged rope begins with an examination of the rope itself; determining the fiber type, where possible, and evaluating the state of degradation. A good treatment will conserve not only the structure of the rope fibers, but also take into account the cohesion and construction of the rope. A good treatment prevents unraveling, flaking, and shrinkage while preserving the cohesion between the rope elements and maintaining the flexibility of the rope. Ideally, the natural fiber color and texture are maintained. Much of the research into the conservation of cordage has been empirical, employing everything but the kitchen sink in an effort to see what works. In spite of this, many treatments begin similarly, with some form of cleaning and soluble salt removal. Once clean, the water is removed; typically through drying, solvent exchange, or freeze-drying. A pre-treatment with an impregnant or bulking agent may be introduced to prevent the weakened fibers from collapsing and to impart flexibility to the rope fibers. Following the water removal, some form of post-treatment consolidation may be needed to promote cohesion. Finally, the whole is typically stored in an environmentally-controlled environment. Following are brief descriptions of some of the available techniques which have been used to conserve cordage and textiles in the past, collected through a review of the available literature. Not all of these treatments remain viable options, and any long-term problems with a treatment are noted when possible.

Historical Treatments

With the sheer variety of treatment methods utilized to conserve rope in the past, one might say that conservators have employed every resource at hand, including the

kitchen sink, to produce a stable result. Not all of the methods used stand up to the test of time. As early as 1848 attempts were being made to conserve delicate textiles with shellac. More than a century later, these textiles are crumbling into dust (National Museum of Denmark 2003a).

Conservation methods continued to evolve through the twentieth century. The website for the National Museum at Denmark (2003b) describes a treatment by Rosenberg, in which textiles were impregnated with a solution of tung oil in turpentine. The lacquer-like treatment has penetrated the artifact, matting the individual fibers together. Attempts to remove the treatment with an enzyme merely caused the treatment to penetrate the artifact more deeply, making further removal efforts impossible without damaging the textiles. Another Rosenberg treatment in which India rubber dissolved in chloroform and mixed with two parts of cellulose lacquer is also unsuccessful over time, as the India rubber eventually oxidizes (Rathgen 1926).

Glycerine, used alone or as part of another treatment is still occasionally used in textile treatment today. An early twentieth-century text makes mention of rope being soaked in glycerine alone before being allowed to drain on blotting paper (Rathgen 1926). A project undertaken by Joan Gardner, under the auspices of the Smithsonian Institution advocated the use of an aqueous five to 10 percent glycerine solution to restore the pliability of extremely fragile, pre-Columbian textiles so that they might be unfolded and examined. Water alone was also used; however, the addition of glycerine allowed for an increased working time. The increased working time eliminated repeated drying cycles which would have stressed the material (Gardner 1979).

Soluble nylon received a great deal of use when treating textiles in the mid-twentieth century. Initial results showed a treatment which allowed the artifact to remain flexible and maintain its color with little shrinkage (East Carolina University n.d.; Sease 1981). Time once again disproved the method, soluble nylon eventually loses its flexibility, becoming rigid. Soluble nylon begins to shrink, damaging the surface of the artifact. The matte appearance is lost and the artifact attracts dust, which obscures the surface. Soluble nylon also becomes insoluble nylon, meaning that damage caused by its other attributes cannot be undone without causing further damage to the artifact (National Museum of Denmark 2003b, Sease 1981).

Another common adhesive and consolidant for textiles and cordage was cellulose nitrate. An experiment indicated that while an artificially aged cordage sample treated with cellulose nitrate maintained flexibility, it was subject to shrinkage, color change, and unraveling (East Carolina University n.d.). In addition to these problems, cellulose nitrate is extremely flammable, vulnerable to oxidation and hydrolysis, and is affected by ultraviolet light (Mills and White 1987; Tímár-Balázs and Eastop 1998). As it ages, cellulose nitrate begins to break down, and the evaporating nitrogen dioxide reacts with the oxygen and humidity in the atmosphere to form nitric acid (Tímár-Balázs and Eastop 1998).

Research into potential methods for conserving waterlogged cordage in the 1970s produced polyvinyl pyrrolidone (PVP) as a potential treatment. Used as a cryo-protectant when freeze-drying biological materials, PVP appeared viable. Used alone and in combination with glycerol or polyethylene glycol (PEG) 400, PVP produced good

results and was still found in use in Central European conservation labs in 1996. A PVP treatment was used to conserve the cordage recovered with the “ice-man” discovered in the Alps. In spite of early indications of success, Western Australia has reported that artifacts treated with a PVP and glycerol solution have deteriorated (Peacock and Schofield 1996).

Anecdotal evidence from Tímár-Balázsy and Eastop’s book (1998) discusses other potential problems with treatments commonly employed in the past. One such treatment is the treatment of textiles with polyvinyl alcohol (PVOH). Over time, artifacts treated with PVOH may become brittle and their matrices damaged by sharp edges of the hardened adhesive. Like soluble nylon, removal of PVOH becomes difficult as the linear polymer begins to cross-link, turning into a complex matrix of polymers. The problem with solubility and brittleness over time is a common complaint as consolidants age.

The Rockaway, a PEG and Freeze-drying Method

Katherine Singley presents a monograph discussing the conservation methods used for the artifacts recovered from the scow schooner *Rockaway*, which sank in Lake Michigan in 1891. The project had a limited budget, and conservation was undertaken utilizing the available materials and equipment. It was assumed that the rope recovered from the *Rockaway* was composed of manila, sisal, hemp, or jute; typical of the nineteenth century (Singley 1988:70-73).

Singley chose to freeze the rope for storage. No reason is given, but freezing would have prevented the rope from unraveling before conservation. However, water expands when frozen. The pressure of the expanding water molecules on already weakened cell walls could result in cellular damage. Prior to treatment, the *Rockaway's* rope was encased in netting for protection and the ends tacked down with thread to prevent shifting. Tar and tallow coatings were removed by soaking the rope in acetone or xylene, iron salts were removed by soaking the rope in a one to three percent solution of oxalic acid, five percent solution of disodium EDTA, or a three to five percent solution of ammonium citrate. The rope was then thoroughly rinsed in deionized water. Where necessary, the rope was washed mechanically with the gentle application of a stipple brush and a solution of de-ionized water and Triton-X. Singley recommends the use of an ultrasonic cleaner to remove any entrapped mud. The rope was then rinsed twice and soaked overnight in deionized water (Singley 1988:70-73).

After preparing the rope, it was soaked for six to eight weeks in a five to 10 percent solution of PEG 400, one percent glycerol, two percent methylcellulose and an optional half a percent of Lysol in a covered container at room temperature. The rope was shaped or coiled before placing it into a freeze-dryer in order to “lock” the artifact into the desired shape. Singley suggests that post-treatment surface consolidation can be carried out if needed with an application of five percent PVA in ethanol and acetone (Singley 1988:70-73).

A constant humidity of 55 to 60 percent is necessary due to the continued mobility of the PEG within the artifact (Singley 1988:70-73). No discussion of the

outcome is included in the monograph. The single post-treatment picture is not clear enough to determine the success or failure of the method aesthetically, but the pictured cordage did appear stable. The statement about pre-arranging the rope into position prior to freeze-drying indicates a lack of flexibility in the final result. The need for a post-treatment consolidant implies that the rope may be friable after the freeze-drying treatment. PVA and PEG are not compatible; however, the author did not discuss the result of a post-treatment use of the PVA solution (Donny Hamilton, personal communication 2009). The use of PVA as a consolidant may have darkened the rope (Hawley 1989; Peacock and Schofield 1996).

The Defence, a PEG, Ethulose, and Freeze-drying Method

The recovery of the eighteenth-century American privateer, *Defence*, began in 1975 and produced hemp, silk, and linen textiles. These textiles, including cordage, were treated by the Maine State Museum Regional Conservation Center (Morris and Seifert 1978).

Initially, the metal salts were removed by soaking the artifact in a five percent aqueous solution of oxalic acid for a short period then rinsing it in tap water for a week. Two types of consolidant were first used on the textiles recovered from the *Defence*; Modocol (a solution of ethylhydroxyethyl cellulose and PEG 400) and a second solution of ethulose, PEG 400 and a fungicide (Morris and Seifert 1978; Peacock and Schofield 1996). The results were poor, the textiles being too brittle (Morris and Seifert 1978). Further insight into the use of Modocol was obtained from a paper on the conservation

of rope recovered from Trondheim, Norway. The Trondheim rope treated with Modocol became black, brittle, and displayed surface crystallization over time (Peacock and Schofield 1996).

To combat these treatment problems, a conservation method was developed for the rope and textiles from the *Defence*. The textiles were encased in net then pretreated in an aqueous solution of one percent ethulose and five percent PEG 400 prior to being frozen to negative 18° C. The freezing process was interrupted before the rope was completely frozen; the netting removed and the yarns of the rope separated to reduce matting. The artifact was then completely frozen, preventing cellular collapse and placed into a vacuum freeze-dryer with gradual reductions in pressure to 100 microns. Artifacts were removed from the freeze-dryer once ice ceased deposition on the condenser. In the event that a delicate textile needed reinforcement, it was sewn to nylon net and mounted on unbleached muslin (Morris and Seifert 1978).

No further discussion of the condition of the artifacts from the *Defence* is carried out within the paper. The authors do state that different conservation methods may be needed for different types of sites, as environmental conditions vary from site to site (Morris and Seifert 1978). The only images of a cordage artifact included in the report were of a ball of wadding. The individual yarns are clearly visible. Although there is a degree of matting, it is not severe, indicating that arranging the cordage before it was fully frozen was successful. No definitive statement can be made as to the success of the treatment; as the color, flexibility, and overall stability of the cordage is not discussed in

the report. However, having to arrange the yarns prior to the completion of the process implies that the result is inflexible, friable, or both.

The Frankfurter Method

Initially, the National Museum Conservation Laboratories in Brede, Denmark, used a typical PEG and freeze-drying treatment. Rope was first cleaned with water to remove soil and EDTA to remove iron salts. The rope was placed on a support of foam rubber on masonite, encased in a layer of foam rubber, and sewn around the edges of the rope to prevent shifting. The rope was then impregnated with an aqueous solution of PEG 200 to 600 and two percent methylcellulose for two weeks, before being wrapped in a plastic sheet and frozen to negative 27° C. Once frozen, the plastic sheet was removed and the rope was freeze-dried (Koefoed et al. 1993).

The method was determined to have several flaws. The placement of the rope in its package was considered time-consuming and labor intensive. The masonite did not provide a tight support. It was necessary to keep the package wet during preparation to prevent cellular collapse, but the wet or impregnated foam rubber was heavy and could damage or compress the rope (Koefoed et al. 1993).

The laboratory developed two new methods to counter some of these drawbacks. The first, known as the “Frankurter method,” begins in a similar manner to the original treatment. The rope is cleaned with water, taking care not to remove the tar. Iron salts are cleaned off once the rope has been packed in its support with a 0.1 M solution of EDTA or a 0.1 to 0.5 M solution of acetic acid. This step is followed by another water

rinse. After packing the rope in a perforated polypropylene sheet fastened to masonite, it is placed into a plastic bag “frankfurter” made exactly to size. The package was filled with water, and then sealed. The package is frozen to negative 27° C then removed and placed on 3 cm of insulating material in a vacuum tank, making sure the Masonite is underneath the rope. The rope is then freeze-dried at negative 20° C with a 50 percent relative humidity. Soft polyurethane in ethylacetate may be used as a consolidant if necessary (Koefoed et al. 1993).

Compared to the more traditional method, the packing process can be done very quickly. The addition of the water into the rope package allows the rope to float freely, which helps it hold its rounded shape. The authors describe the resultant rope as both stable and flexible. The polyurethane consolidant may leave surface deposits, which can be reduced by applying the consolidant to the center of the rope with a hypodermic syringe and allowing it to wick to the surface. The authors describe the end result as light in color and weight, with a somewhat dry appearance (Koefoed et al. 1993). Both the authors and Smith (2003) agree that the polyurethane coating renders this method irreversible. Smith (2003) also points out that the friable condition of the rope after freeze-drying is a very difficult condition to re-treat, and should also be considered irreversible.

The second method developed by the laboratory is used for less degraded rope. For this method, the rope is cleaned and packed as before. Instead of placing the rope into a casing filled with water, the rope is impregnated with PEG 200 to 2000 or an aqueous solution of three to 10 percent glycerol. The impregnated rope is then placed in

a container with a non-polar organic petroleum solvent, such as kerosene, with a low freezing point. The entire package is cooled to negative 25° C. The non-polar solvent prevents the PEG or glycerol from diffusing out, while allowing the rope to float. Because it is floating while being frozen, the rope will not flatten or unravel, and will remain rounded and swollen. After being frozen, the rope is then freeze-dried at negative 20° C and 50 percent relative humidity (Koefoed et al. 1993).

This method allows more flexibility of choice when choosing a bulking agent, which in turn allows the conservator to choose the optimum treatment for maximum strength and flexibility. The non-polar solvent imparts a light color. This method is preferred by the laboratory because it is reversible, uses less toxic materials, and the non-polar solvent may be reused (Koefoed et al. 1993). The treatment is not without its drawbacks, as Smith (2003) points out that rope conserved in this fashion is extremely sensitive to environmental change and very fragile.

The Basque Whaling Ship, a PEG, Ethulose, Glycerol, and Freeze-drying Method

In 1565, just off the southern coast of Labrador, a whaling ship thought to be the San Juan sank under 10 m of cold water. In 1979, excavations began, and among the materials recovered were several hundred hemp rope artifacts of varying sizes. After excavation, the artifacts were packed for shipping. The smaller artifacts were shipped frozen. Upon arrival at the lab, the artifacts were recorded while being sprayed with 70 percent ethanol in water to prevent dehydration and to stop the mold, which had already

begun to appear. Once the artifacts were recorded, they were stored in a freezer until treatment could begin (Hawley 1989).

The rope was cleaned mechanically with small tools, a gentle water spray, and brushes. The ropes were jacketed with open-weave materials and then the chlorides were removed from the rope with baths of tap water and deionized water. Once cleaned, the ropes were stored. The small rope was placed back in the freezer and the larger rope in an aqueous ethanol solution in a cooler (Hawley 1989).

A sample of rope which was allowed to air dry fell apart, indicating the need for a consolidant. Experimentation was carried out to determine which consolidant would be most effective, given the condition of the artifacts. In all, twenty experiments were carried out using various concentrations of consolidants including PEG, ethulose, glycerol, PVA, and Paraloid B-72. Of these, it was determined that the best consolidant for this rope was a pre-treatment in an aqueous solution of one percent Ethulose 400, five percent PEG 400, and two percent glycerol, followed by freeze drying. Further experimentation with the top three consolidants from the experiment supported the initial conclusions that the Ethulose 400, PEG 400, and glycerol mixture consolidated the samples best. The other two consolidants, an aqueous solution of two percent ethulose 400, 10 percent PEG 400, and two percent glycerol and an aqueous emulsion of two percent PVA and 10 percent PEG 400, were also acceptable (Hawley 1989).

Hawley's report (1989) includes tables simplifying the results of her experiments. These indicate the overwhelming tendency of the consolidants to produce a dry, rigid, brittle, fragile, or unraveled piece of rope. Only the top three consolidants

were listed as having any good attributes. Shrinkage was not discussed; however, the images and discussion indicate good results. The rope appears stable and natural in color, texture, and size, if slightly desiccated. The yarns are clearly visible, but look as if they may begin to flake if handled. No mention is made of the flexibility of the method, although Hawley mentions that it is easier to arrange the rope prior to freeze-drying. This comment intimates that it may be possible to arrange the rope after treatment, indicating that not all of the flexibility is lost during freeze-drying (Hawley 1989). According to Peacock and Schofield (1996), Hawley's treatments have become standard practice in many conservation labs. The paper goes on to attribute poor results obtained with the cellulose ether treatment to the widely varied types, viscosities, and concentrations used by different laboratories (Peacock and Schofield 1996).

Solvent Dehydration

Based on a series of tests carried out by the Conservation Division of the Western Australia Museum, Donny Hamilton's book (1996) recommends the use of solvent drying for cordage. The replacement of the water with a less polar liquid speeds the evaporative process and lessens the risk of shrinkage and cracking that may take place as the cellular structure of the fibers collapses under the surface tension of the evaporating water (Tarleton and Ordonez 1995).

For this treatment, any encrustation is removed with a 10 percent solution of hydrochloric acid, and then rinsed in running water. Pitch and tar are removed by soaking the rope in acetone. A five percent solution of oxalic acid will remove iron

staining if present, as will a five percent solution of EDTA disodium. Soaking time may take anywhere from a few hours to several days, and both treatments may be necessary if the iron staining is particularly stubborn. Once a stain removal treatment is carried out, the rope should be rinsed in deionized or distilled water before being placed into acetone to dehydrate (Hamilton 1996). Other solvents have been used for the dehydration process, including ethanol, ethanol and xylene, and tertiary butylalcohol (Hawley 1989; Peacock and Schofield 1996). Once the water removal is complete, the rope should be allowed to air dry. A consolidant may then be used if necessary (Hamilton 1996). In many cases, the rope treated through solvent dehydration does not shrink but is very lightweight, friable, and desiccated in appearance (Peacock and Schofield 1996).

The Trondheim Experiments

In order to conserve a significant amount of rope recovered from excavations in Trondheim, Norway, a broad survey of conservation techniques was carried out. The results led to an experiment which tested variations of the most successful methods of the time. Hawley's (1989) methods were reevaluated using different types of cellulose ethers and different concentrations of PEG 400 and glycerol. Hawley's polymer treatments were also reevaluated. Drying methods were investigated; including air-drying, freeze-drying, and freeze-drying in a block of ice. Finally, variations of the PEG 400 and PEG 4000 methods already applied to some of the Trondheim rope were tested, using various concentrations and combinations of both molecular weights, and testing the addition of glycerol to the solution (Peacock and Schofield 1996).

Before experimenting on the 57 available samples of highly degraded rope, the rope was cleaned and encased in polyolefin film. The samples were treated, and then evaluated for color, cohesion, texture, flexibility and overall acceptability by the conservators. The best color was produced when using PEG 400 or glycerol, alone or in combination. Good color was also obtained from the freeze-drying, and freeze-drying from a block of ice and the samples treated with PVA. The darkest color was obtained from the samples treated with PEG 4000. The best cohesion was obtained from the samples which included a cellulose ether, high concentration of glycerol, or freeze-dried. The worst cohesion was found in those samples treated with only PEG 400 and glycerol, air-dried, and freeze-dried from a block of ice. The best texture was obtained from the samples treated with cellulose ether, high percentages of glycerol, and freeze-dried. PEG 4000 and freeze-drying from a block of ice produced sticky results, while samples treated with a polymer other than PVA were considered dry and powdery. Many of the treatments displayed acceptable flexibility, the worst were those treated in PEG 4000, PVA, air-dried, or with no pretreatment. The samples judged most acceptable were those treated with cellulose ethers, PEG 400, and glycerol followed by freeze-drying. Those treated with high concentrations of PEG 4000 and those which had no bulking agent were considered least acceptable. The results of the Trondheim experiment were similar to that of Hawley's, ranking several of the treatments which included combinations of cellulose ether, PEG 400 and glycerol as the top choices (Peacock and Schofield 1996).

These samples were reevaluated after two years of storage in a dark, climate-controlled environment. Of the initially favored treatments, only the sample treated with

one percent Ethulose 400, five percent PEG 400, and two percent glycerol (which had ranked as the seventh choice in the experiment) had retained any structure. The rest had deteriorated significantly. Some of those treatments which had not ranked at the top, including the air-dried sample and some of the PEG 4000 samples had also not broken down. Ironically, the shrinkage caused by air-drying held that particular sample together. The conclusion was that some post-treatment consolidation was needed prior to storage (Peacock and Schofield 1996).

A follow up experiment on better-preserved fibrous rope with an aqueous solution of one percent sodium carboxymethylcellulose, five percent PEG 400, and two percent glycerol followed by rinsing, freezing, and freeze-drying was more successful. Further successful treatment continued on untreated woody rope, in which it was impregnated in an aqueous 50 percent PEG 400 solution. The fibrous rope maintained a natural color and texture, flexibility, and cohesion. The woody rope was dark in color, maintained a good texture and cohesion, but was not strong (Peacock and Schofield 1996).

The Mary Rose, Slow Air Drying and Solvent Drying with Tetraethoxy silane (TEOS)

The carrack *Mary Rose* was the flagship of King Henry VIII's fleet that sank during a skirmish with the French in July of 1545, fully laden with men and arms. She lay buried off the coast of Hampshire until excavation began in 1982. During the excavation both rope and textile artifacts were recovered and conserved through the auspices of the *Mary Rose* Trust (Jones 2003:101-105).

The recovered cordage and textiles were first analyzed for fiber type, then carefully unfolded while submerged in a vat of water. This technique reduces stress on the artifact. The artifacts were then gently cleaned with deionized water, soft brushes, and sponges. A water cascade system was used to remove the soluble salts (Jones 2003).

Two different treatment methods were then applied to the cordage. The first was slow air drying. This procedure was carried out by placing the washed textile or cordage between dry paper towels and then weighting the whole down between glass plates. The slight weight of the plates does not cause the rope to flatten. Those artifacts that appeared brittle after treatment were consolidated by applying applications of a solution of equal parts bedacryl and xylene, or carboxymethyl cellulose (Jones 2003:101-105).

Some of the textiles and cordage from the *Mary Rose* were treated by dehydrating the artifact in acetone, then placing it into a solution of TEOS in acetone. Once the artifact was fully impregnated, it was removed from the solution and the acetone was allowed to evaporate. The evaporation of the acetone caused the TEOS to hydrolyze, leaving deposits of silicon dioxide. The cordage was then consolidated by applying a two percent solution of Bedacryl in toluene or a two percent solution of Bedacryl in xylene (Jones 2003:101-105).

The report states that no cellular collapse was evident when using the slow air-drying method. Peacock and Schofield's paper (2006:115) supports this statement, stating that the "air-dried, heavily tarred rope from the *Mary Rose* fared well." According to the same article; however, not all air-dried, archaeological rope fares as well (Peacock and Schofield 2006). No indication is given by the authors that weighting

the rope between the glass plates flattens the rope, although flattening could be a concern with rope in an advanced state of degradation. The rope artifacts from the *Mary Rose* remain stored in a low light, humidity controlled environment to prevent further decay. No other post-treatment results are noted, besides the concern that those artifacts consolidated with carboxymethyl cellulose may be prone to oxidation (Jones 2003:101-105). However, in her article, Hawley (1989) rejects TEOS as a treatment due to the lack of adhesion and the white residue formed by oxidizing of the TEOS. Peacock and Schofield (1996) also discuss some of the problems inherent with the application of TEOS; pointing out that most conservation laboratories now shy away from the use of TEOS due to its irreversibility, lack of adhesion, and the white powder (oxidation) which coats the surface of the artifact following treatment.

The Windover Textiles, Parylene Gas Phase Polymer Technology

The Windover bog excavation in Florida yielded 37 human burials from the mid-sixth century B.C. Among the human remains were pieces of textiles and cordage. The brackish peat bog provided an anaerobic environment and the artifacts were thoroughly incorporated with mineral salts and peat. The textiles and cordage were in an advanced state of decay. Initial attempts at consolidation with a PEG and ethulose solution followed by freeze-drying produced artifacts so friable that they could not be handled, examined, or transported. After months of testing, the PEG method was abandoned in favor of parylene gas phase polymer technology. Parylene gas has been used to conserve very ancient and very delicate artifacts (Humphrey, et al. 1991).

Prior to treatment the artifacts were stored in a controlled environment, maintaining the pre-excavation conditions as closely as possible. Periodic applications of isopropanol or ortho-phenylphenol were used to prevent mold growth. Soluble salts were removed through repeated rinsing with distilled water (Humphrey, et al. 1991).

Parylene is one of a group of polymers derived from xylene which are formed in a vacuum from a true gas phase. The polymer is sold in a dimeric form as a powder which is stable at room temperature and normal atmospheric pressure. The powder must be converted in a specialized vacuum. The vacuum system heats the powder to 120° C, causing the powder to sublime. The accompanying pressure forces the molecules into another heated chamber where they split into reactive monomer molecules. These then flow into the room temperature deposition chamber. The molecules, full of kinetic energy, bounce around the chamber, eventually losing enough energy to be absorbed and polymerize on the surfaces of the artifact. The monomers form long chains, which do not cross-link. The chains continue to grow until the supply of monomer is stopped or until the active ends of the chains are buried in a mass of polymer chains. The monomer chains form a film which grows as long as it is exposed to free monomers (Humphrey, et al. 1991).

Parylene gas was favored for the Windover bog textiles for a variety of reasons. The gas phase allows extremely delicate items, even spider webs, to be consolidated enough for careful handling. The film is transparent and conforms to the shape of the artifact, leaving no visible indication that the artifact has been treated. There is high penetration into porous substances, allowing the monomer to coat each fiber surface

evenly. Because deposition occurs as a gas phase, the film coating may be adjusted from 15 nm to any thickness. The process can be stopped, the artifact exposed to the air and examined. The deposition process can be reinitiated within an approximately 12 hour window without disrupting the continuous formation of the chains. Longer exposure to air will cause hydroxyl termination of the methylene groups rendering the ends of the chains inactive. A bonding agent is needed to attach the new film to the original film. When parylene gas is used to treat porous artifacts, there are no solvents, liquids, or plasticizers employed; thus only mechanical bonds are formed. These mechanical bonds are tight, making the removal of the film very difficult. Parylene gas phase polymer technology should not be considered reversible (Humphrey, et al. 1991).

According to the report, the conservators used a 10.6 microns thickness of the parylene coating. The durability of the artifacts increased such that they could be handled and all sides examined for the first time. Flexibility was increased to the point that the conservators were encouraged that they might be able to remove some of the peat coating from the artifacts (Humphrey, et al. 1991).

No images or further discussion of the results were included in the report beyond the conservators' satisfaction with the treatment as a success (Humphrey, et al. 1991). According to Barbara Purdy (1991), the Windover textiles should be placed into a restricted access, climate controlled environment. The artifacts may be handled with extreme care, but remain very delicate. The polymer treatment oxidizes rapidly when exposed to ultraviolet radiation. The oxidation causes undesirable, rapid yellowing and stiffening of the treated artifact (Tímár-Balázsy and Eastop 1998).

An Experiment in Supercritical Drying

Supercritical drying is a dehydration technique which uses carbon dioxide under pressure to prevent water from making the phase change from liquid to gas. Shrinkage and cellular collapse of weakened cell walls is avoided by eliminating the stress of surface tension changes associated with evaporation (Kaye et al. 2000).

Prior to treatment, a rope sample was wrapped in a linen bandage to prevent damage through handling. As water and carbon dioxide are not miscible, the rope was pre-treated in methanol, an organic solvent that is soluble in supercritical carbon dioxide. Pre-treatment prevents damage that could be caused by surface tension at the interaction between the carbon dioxide and the water. The methanol also acts as a topical biocide. The rope was sufficiently devoid of water after four changes of methanol. This determination was made by monitoring the density of the methanol until the water reached less than 1 percent of solution (Kaye et al. 2000).

The methanol is then replaced with supercritical carbon dioxide, a process carried out at 50° C. The artifact is placed into a sample chamber into which carbon dioxide is blown through pure methanol from the bottom of the chamber. This setup ensures that the artifacts will not lose methanol through evaporation and saturates the carbon dioxide with methanol as it enters the chamber, preventing a two-phase system from forming before sufficient pressure can be attained. The methanol must then be removed from the chamber, so that there is no separate liquid phase as the chamber is slowly decompressed. The authors used a low pressure methanol collector to separate the methanol from the carbon dioxide by keeping the chamber above 40° C, which

prevented the carbon dioxide from condensing. The methanol sank to the bottom of the chamber. Here it was removed through a valve, and the carbon dioxide flowed out, was heated, recompressed, and used again to dissolve more methanol. The closed system ensures a continuous process which is complete when methanol is no longer being collected (Kaye et al. 2000). After the methanol is removed, slow decompression can begin. Once ambient pressure is reached, the chamber is allowed to cool from 50° C to room temperature, after which treatment is complete (Kaye et al. 2000).

The specialized equipment needed for supercritical drying could be a drawback. However the chemicals involved, carbon dioxide and methanol, can both be recycled. The authors indicate that the technique can be scaled up to accommodate artifacts of any size (Kaye et al. 2000). However, with weakened cell walls and without the support of the water or consolidant filling the cells, a large artifact could collapse under its own weight. Collapse due to weight is generally not an argument against the use of supercritical drying for rope except in the case of very large diameter coils. The larger the chamber needed, the more expensive the process becomes.

The rope treated in the report maintained its shape and dimensions, but was very fragile. Because of the fragility, the rope was sealed in a polyethylene tube. The tube allows the rope to be examined while also providing protection. A post-treatment consolidant may improve the viability of this technique; as the dried rope was very fragile, had no cohesion, and crumbled easily (Kaye et al. 2000; Peacock and Schofield 1996). Appearance and condition were not judged, as no images of the treated rope were

included in the report. Color and flexibility are not discussed in the report, although we can assume that the rope exhibits little flexibility due to the fragility of the artifact.

Passivation Polymers Process (Silicone Oil Treatment)

Research in APRL at Texas A&M University by Dr. C. Wayne Smith, Dr. Donny L. Hamilton, and Dow Corning Corporation experimented with passivation polymers to conserve rope (Smith 1998b; Smith 2003). The method replaces the water within rope with a silicone oil and cross-linker solution, stabilizing the artifact and preventing structural collapse.

Silicone oil is not water soluble, thus the water trapped in an artifact is displaced with a series of baths in progressively more volatile organic solvents. These organic solvents are replaced with a solution of silicone oil and a cross-linker, methyltrimethoxysilane (MTMS). Rather than acting as a bulking agent, the silicone oil coats the interior of the cell wall and cross-links with the cellular structure through the MTMS to provide structural support. The availability of different centistokes of silicone oil allows the procedure to be adjusted for maximum penetration and desired flexibility. Excess oil is drained away, and the silicone oil is allowed to polymerize within the artifact. Polymerization is accelerated by the use of a tin based catalyst and renders the treatment irreversible (Smith 1998b; Smith 2003).

Passivation Polymers Process, as Applied to the Rope from La Belle

In the case of *La Belle*, a part of the ship sank slowly into the anaerobic silt on the bottom of Matagorda Bay. The exposed portions of the hull decomposed and disappeared through biological, physical, and chemical degradation processes. Within the silt, the ship and her contents continued the slow process of decay through continued exposure to water and salts, through anaerobic bacterial action, and through the interactions between the continued decomposition processes unique to various materials, such as the corrosion of the metals.

The recovery of *La Belle* was carried out as a land excavation. A coffer dam was built around the ship and the water drained from the site. This treatment of the site was both boon and bane. In the murky waters of the Gulf of Mexico, many of the smallest artifacts may have been missed during a conventional underwater excavation. The low visibility would have made recording the wreck difficult. Undoubtedly, much more information was recovered through the use of the coffer dam than may have been recovered otherwise. However, after three centuries underwater, the artifacts were in a precarious state of decomposition. Any exposure to the air, no matter how slight, had a detrimental effect on these artifacts, accelerating decomposition and exacerbating the damage already present. The site was kept wet by spraying water over the artifacts; however these artifacts were now no longer protected from an oxygenated environment. Thus, biological forces could again begin to act, including mold, bacterial, and insect attack. The buoyancy and support provided by submersion in water was absent, causing potential problems with weakened structures no longer being able to support their own

weight. The total saturation of cellular structures could no longer be ensured and the weakened cells began to collapse as evaporation caused the surface tension of the water to pull against the cell walls of delicate organic artifacts.

The amount of rope recovered from *La Belle* was considerable, given the location of the wreck in warm, shallow coastal waters and the salvage carried out prior to her total submersion. Fortunately, the anaerobic environment protected the store of rope in the hull from complete decay. The near pristine appearance of the rope is misleading, as microscopic evidence shows little cellular structure remaining within the individual fibers.

The success of the experiments carried out in the APRL led to the decision to use the passivation polymers process for *La Belle's* cordage (Helen Dewolf, personal communication 2007; Smith 1998b; Smith 2003). Other factors influencing the decision included the speed of the process, the ability of the treatment to withstand substantial fluctuations in humidity, and the ability to handle and manipulate the rope post-conservation (Helen Dewolf, personal communication 2007). The conservation of *La Belle's* rope was carried out at the CRL at Texas A&M University. Silicone oil was used for most of the rope artifacts, including a portion of the coils from the bow and all of the small diameter rope and coils.

The first step was ensuring the thorough removal of the soluble salts from the rope through immersion in fresh water baths. After the chlorides were removed, the rope began the organic solvent dehydration process through immersion in a 25 percent ethanol and 75 percent deionized water solution for six weeks. Each successive six week

period, the rope was moved to an incrementally higher concentration of ethanol until a 100 percent concentration was reached. The rope was soaked in two baths of 100 percent ethanol before being moved to a 25 percent solution of acetone in ethanol. Once again, at the end of each six week interval the rope was again moved into incrementally higher solutions of acetone until a 100 percent concentration was reached. After being soaked in two consecutive baths of 100 percent acetone, the rope was quickly immersed in a solution of a silicone oil (SFD-1 and SFD-5) and MTMS for the final six week period. The combination of two different weights of silicone oil imparts both flexibility from the longer molecular chains of the SFD-5 and the strength from the shorter molecular chains of the SFD-1. The concentration of MTMS varied between 18 and 25 percent (Helen Dewolf, personal communication 2004). No testing was carried out to determine if fewer organic solvent baths would sufficiently dehydrate the rope. However, the simple linear structure of the rope fiber cells allows rapid fluid exchange, and dehydration might well be accomplished with fewer organic solvent baths.

After the rope was removed from the silicone oil solution, it was allowed to drain; first on a rack to recover the majority of the excess oil, then on trays with newspapers to soak up the remaining excess. Once the rope drains, it is mechanically cleaned. Dental picks and brushes were used to gently clean away silt and debris manually. Brief submersion in MTMS or applications of MTMS with a brush helped to remove any remaining excess silicone oil and detritus. These applications of MTMS were carried out only until the rope was no longer sticky or oily. The application of too much MTMS can cause the rope to become desiccated. After the rope was cleaned

sufficiently of both debris and excess silicone, it was placed into a sealed container with a vapor catalyst, dibutyltin diacetate (DBTDA) to accelerate the polymerization process. This ability to mechanically clean an artifact after stabilization eliminated much of the stress that occurs when cleaning an untreated artifact.

Once treated with passivation polymers, the color of the rope usually ranges between medium to dark brown, although rope which was heavily tarred may appear almost black. These colors fall within an aesthetically acceptable range, and are probably very close to the original, or natural, color of the rope. The texture is very natural; not desiccated, glossy, sticky or waxy. While the rope does not retain a high tensile strength, nearly all of the rope exhibited enough strength and flexibility to be arranged and adjusted after conservation. Individual fibers are clearly visible with very little matting. Very short pieces of cordage did tend to unravel if not secured, but overall, unraveling was not a problem.

The passivation polymers process has benefits beyond the appearance and general stability of the artifact. Once polymerized, the procedure renders the artifact stable enough to be displayed without temperature or humidity controls. The stability of the treatment makes it an ideal treatment for use in areas where museums are not able to maintain a strictly controlled environment. The procedure is not reversible; however, artifacts conserved using silicone oil may be retreated if necessary (Smith 2003).

Mistakes in Passivation Polymers Experimentation

Missteps emphasize the need to continue experimentation and to understand the science behind a treatment before proceeding. The limits of the polymer treatment are continuously explored at APRL by the students and professors in the Nautical Archaeology Program at Texas A&M University. During *La Belle's* rope conservation, an experiment was undertaken with some success on a small rope sample. It was thus determined by the experimenter to be a fit procedure for conserving *La Belle's* rope without further testing and without consultation.

In this treatment exercise, the procedure for the passivation polymers treatment was altered. After dehydration the rope was placed into pure silicone oil with no cross-linker. Once saturated, the rope was removed from the silicone oil, minimally allowed to drain, and placed into a solution of MTMS and catalyst. The MTMS quickly saturated the surface of the rope. The exposure to the MTMS drew some of the remaining excess, unlinked polymer to the surface of the rope where it was almost instantly polymerized. The interior matrix of the rope remained saturated with some excess oil, as the fluid oil could not flow past the polymerized layer. The result was a “rubber”-coated artifact, which gradually polymerized until the entire rope became stiff and shiny (Figures 22 and 23) (Helen Dewolf, personal communication 2004). Thus, this treatment is not a recommended procedure.

In an attempt to repair the damage, baths of MTMS were used to draw as much excess silicone to the surface as possible. Although completely polymerized, the MTMS caused some of the unbound excess silicone to soften and migrate to the surface of the

rope, where it was gently removed with picks and soft brushes. The rope remains stiff and the individual fibers are matted together, but the shape of the rope has been maintained. The removal of the outer layer of excess silicone eliminated the shiny appearance and brought the rope surface into view. Further experimentation with heated MTMS or hydrofluoric acid may produce a solution whereby this rope may be restored to a more aesthetically accurate and pleasing appearance.



Figure 22. One of the damaged rope artifacts from *La Belle*. Photo by J. McCaskill.



Figure 23. Close-up of a segment of the damaged rope. Photo by J. McCaskill.

CHAPTER V

EXPERIMENTS WITH PEG

Introduction

The sectioned coils of rope from the bow of *La Belle* presented a conservation challenge, both because of the large amount of rope recovered and because of the degraded condition of the fibers. The packages containing the sectioned rope were transferred from the site to the CRL at Texas A&M University where they were placed into large metal vats filled with fresh water.

The fresh water served to remove the soluble salts from the rope and to protect what remained of the cell walls from collapse. During the three centuries the rope spent underwater, much of the cellular structure of the hemp fibers deteriorated. It was vital that the waterlogged cordage be kept wet until treated to prevent any further stress on the weakened cell structure. Before any conservation treatment could begin, water from the storage vats was tested to ensure that the chloride level was sufficiently low to proceed. Soluble salts, such as sodium chloride, must be removed prior to treatment, as they will crystallize within a cell and could cause the cell to burst. At the time of experimentation, chloride levels in the rope had dropped below 15 parts per million (ppm).

Treatment using silicone oil was chosen as the primary conservation treatment for most of the rope artifacts from *La Belle*. Given the enormous amount of cordage represented by the bow cable, the quantity of organic solvent required for dehydration would have been both costly and dangerous. Research into other treatments, discussed

above, revealed that over time many of the traditional treatments alter chemically and physically in an undesirable manner.

The most prevalent methods for conserving rope and textiles involve some combination of PEG and freeze-drying. PEG is a polymer which offers the advantages of being both water and alcohol soluble. It is relatively inexpensive and available in a range of molecular weights. These molecular weights may be combined, allowing the customization of the treatment. Unlike supercritical drying and parylene gas, PEG methods can be easily adjusted for large quantities of material. However, the results of PEG treatments are often less than satisfactory, particularly as the treatment ages. Depending on the molecular weight used in treatment, the rope is often desiccated or waxy, friable, inflexible, and matted after treatment. PEG acts as a humectant, attracting water vapor. PEG is also highly mobile in solution, and can migrate between cells. The combination of hygroscopicity, water miscibility and mobility may lead to a PEG treated artifact becoming unstable. The mobility of PEG can cause the artifact to sustain further damage as migrating PEG may cause distortion or move to the surface of the artifact leaving the cellular structure unprotected (Smith 1998a, 1998b, 1998c, 1998d, 2003). PEG must be kept in a climate and humidity controlled environment. Although, even under strictly controlled conditions, PEG still breaks down (Smith 1998a).

Several experiments, carried out under the direction of Dr. Smith in the APRL, examine methods for stabilizing PEG within an artifact through polymerization and catalyzation (Smith 1998c, 1998d, 1998e). The search for an alternative method with which to conserve the bow coils dovetailed with research being done in the APRL. The

desired result of a treatment is an artifact which maintains flexibility, has a natural appearance, and can be handled. The rope should not unravel, fall apart or appear desiccated or matted. Bulking the cells with PEG should provide structural stability. Catalyzing the PEG within the rope should stabilize the polymer. An aqueous PEG solution was used to impregnate the rope, thus MTMS could not be used as a cross-linker. MTMS forms a hard resin when combined with water (Wayne Smith, personal communication 2003). As an alternative, the water-soluble, polyoxyalkylene glycol, Jeffox W-L 440 Functional Fluid by Huntsman Performance Products (Jeffox), was tested by APRL as a potential additive for aqueous PEG (Wayne Smith, personal communication 2004). The experiments suggest that the addition of Jeffox to PEG 4000 prevents PEG from becoming hard at room temperature, but instead forms a softer malleable bulking agent. The addition of Jeffox causes the PEG 4000 to act as a better bulking agent, but it retains its melting point and appears to still be mobile with humidity, as it does not completely polymerize (C. Wayne Smith, personal communication 2009).

An experiment based on this research was developed at the suggestion of Dr Smith. The experiment was carried out on a portion of the bow cable, which was deemed in sufficient quantity that a section could be spared for experimental research.

The effectiveness of Jeffox as an additive for low molecular weight PEG was unknown. This experiment helped to determine its suitability for conserving cordage fibers. A two-bath method, starting with a bath of 10 percent Jeffox and followed by a

bath of 30 percent PEG was used. The two bath method was chosen with the idea that any excess Jeffox would be displaced by the PEG in the second bath.

The proposed experiment was used to determine which of three molecular weights of PEG (400, 600, or 1450) was the best choice for the conservation of *La Belle's* cordage. PEG 200 was not tested, as it was assumed that the molecular weight was too low to lend enough structural support. PEG 3350 was not tested, as the high molecular weight would cause the rope to become too stiff. A 30 percent aqueous solution of each of the molecular weights of PEG was tested. This concentration is higher than the five percent to 20 percent solutions used as a pre-treatment for freeze-drying in the treatments summarized in chapter four. With one exception, this concentration is also the highest concentration of PEG used in the Trondheim rope experiments (Peacock and Schofield 1997). The concentration of PEG is high, and caused some initial inflexibility problems. However, the excess PEG was removed from the rope through mechanical cleaning. An aqueous solution was chosen over an ethanol solution because of the ready availability of water, and because of the danger and expense of having a large quantity of a flammable organic solvent in an unsealed vat.

Post-treatment submersion helps to remove excess silicone oil and debris from rope conserved using silicone oil, thus it was used for some of the samples in these experiments. Once cleaned of excess PEG and any remaining dirt which had worked its way to the surface from within the matrix of the rope, the artifacts were exposed to the catalyst DBTDA, in an attempt to polymerize the PEG within the rope structure; stabilizing it, and preventing the leeching of mobile PEG out of the rope.

Initial Experiment

An initial experiment to determine the effectiveness of a modified PEG treatment was undertaken. However, measurements were not obtained prior to the experiment because of an oversight; thus the observations of the results were based on appearance, texture, and flexibility. This oversight was later corrected in a second experiment.

In the initial experiment, a short section of the nine-strand bow cable was divided into six short samples of three-strand cordage (artifact 4909). The samples were cleaned by gentle rinsing in deionized water, and the ends of each sample were wrapped and tied with cotton string to prevent unraveling during treatment.

Table 1. List of the treatments applied in the first experiment.

Sample	Aqueous 10% Jeffox solution	Aqueous 30% PEG solution	Post-impregnation treatment	Catalyst
Sample 1	no	PEG 400	None	DBTDA
Sample 2	no	PEG 600	None	DBTDA
Sample 3	no	PEG 1450	None	DBTDA
Sample 4	yes	PEG 400	None	DBTDA
Sample 5	yes	PEG 600	None	DBTDA
Sample 6	yes	PEG 1450	Cleaned with MTMS	DBTDA

Each of the six samples was treated with a different chemical combination (Table 1). After immersion in a bath of either Jeffox or PEG, all six samples were placed under

a low vacuum for 24 hours. After the initial bath, those samples impregnated with PEG were removed from solution and allowed to dry slowly between layers of paper toweling. The samples in the Jeffox were removed from solution and placed one each into an aqueous solution of PEG (Table 1). These samples were again placed under a low vacuum for 24 hours. Once impregnated with PEG, the samples were removed from solution and allowed to dry slowly between layers of paper toweling.

To determine the efficacy of using MTMS to remove excess PEG, sample 5 was immersed in MTMS for 10 minutes, drained, and allowed to air dry. After all treatments were complete, the samples were exposed to DBTDA for one week. The catalyst was changed daily. The samples were then evaluated for appearance and flexibility.

Second Experiment

For the second experiment, twelve samples were chosen; two for each treatment. These samples were selected for apparent quality of preservation. In their report, Godfrey and Smith (1990) discuss the varying results obtained when treating artifacts that have different levels of degradation. In the initial experiment discussed above, this factor may have affected the results somewhat. Three of the samples displayed less structural integrity at the beginning of the experiment, and these same three samples showed less cohesion and are less flexible than was expected at the end of the experiment. Thus six samples were taken from a section of cable which appeared relatively well-preserved, and six were taken from a section of cable which appeared

heavily degraded. These samples were paired, one stronger sample and one degraded sample, each pair to undergo one of six treatments (Table 2).

Table 2. List of the treatments applied in the second experiment.

Sample	Aqueous 10% Jeffox solution	Aqueous 30% PEG solution	Post-impregnation treatment	Catalyst
1	Yes	PEG 400	Cleaned with MTMS	DBTDA
2	Yes	PEG 600	Cleaned with MTMS	DBTDA
3	Yes	PEG 1450	Cleaned with MTMS	DBTDA
4	No	PEG 400	Cleaned with MTMS	DBTDA
5	No	PEG 600	Cleaned with MTMS	DBTDA
6	No	PEG 1450	Cleaned with MTMS	DBTDA
A	Yes	PEG 400	Cleaned with MTMS	DBTDA
B	Yes	PEG 600	Cleaned with MTMS	DBTDA
C	Yes	PEG 1450	Cleaned with MTMS	DBTDA
D	No	PEG 400	Cleaned with MTMS	DBTDA
E	No	PEG 600	Cleaned with MTMS	DBTDA
F	No	PEG 1450	Cleaned with MTMS	DBTDA

Prior to impregnation, the samples of rope were carefully rinsed in deionized water. Each sample was weighed, measured, and photographed. As in the initial experiment, each end of the samples was secured with cotton string to prevent unraveling. The better preserved samples were labeled A, B, C, D, E, and F, the degraded samples were labeled 1, 2, 3, 4, 5, and 6 (Figures 24 through 29).



Figure 24. Sample 1 (top) and sample A (bottom), prior to treatment in an aqueous solution of 10 percent Jeffox followed by an aqueous solution of 30 percent PEG 400. Photo by R. Sasaki.



Figure 25. Sample 2 (top) and sample B (bottom), prior to treatment in an aqueous solution of 10 percent Jeffox followed by an aqueous solution of 30 percent PEG 600. Photo by R. Sasaki.



Figure 26. Sample 3 (top) and sample C (bottom), prior to treatment in an aqueous solution of 10 percent Jeffox followed by an aqueous solution of 30 percent PEG 1400. Photo by R. Sasaki.



Figure 27. Sample 4 (top) and sample D (bottom), prior to treatment in an aqueous solution of 30 percent PEG 400. Photo by R. Sasaki.



Figure 28. Sample 5 (top) and sample E (bottom), prior to treatment in an aqueous solution of 30 percent PEG 600. Photo by R. Sasaki.



Figure 29. Sample 6 (top) and sample F (bottom), prior to treatment in an aqueous solution of 30 percent PEG 1400. Photo by R. Sasaki.

The procedure for the second experiment was similar to that carried out in the first experiment (Table 2). Samples A, B, C, 1, 2, and 3 were placed into an aqueous solution of 10 percent Jeffox and placed under a low vacuum for 24 hours. The samples were then removed from the Jeffox solution and placed into an aqueous PEG solution (Table 2). These samples were again placed under a low vacuum for 24 hours before being removed from solution and allowed to dry slowly between layers of paper toweling and newspapers. The remaining six samples were placed directly into an aqueous PEG solution (Table 2). The samples were placed under a low vacuum for 24 hours before being removed from the solution and allowed to dry slowly between layers of paper toweling and newspapers.

After the samples were dry, each was weighed and measured, then immersed in MTMS for 10 minutes. The samples were allowed to dry in order to evaluate the appearance and effect of the MTMS on the samples. The samples were then mechanically cleaned of any adhering debris and exposed to DBTDA for two weeks. After treatment was complete, the samples were weighed, measured, and photographed before being evaluated.

CHAPTER VI

RESULTS

After the samples were treated, each was evaluated for appearance, flexibility, texture, and shrinkage. The ideal treatment produces rope which is flexible, has good cohesion, and does not shrink. The rope should have a natural appearance and texture. Treated rope should not be greasy, waxy, sticky, or desiccated nor should the rope have surface deposits of chemical. The treatment should not cause the rope fibers to darken or bleach in color, but should retain a natural color.

The initial experiment, while not quantitatively measured, was evaluated for appearance, flexibility, and texture. The results are summarized in the Table 3. Samples treated with PEG 400 maintained acceptable flexibility, with sample 4, which was treated with 10 percent Jeffox and 30 percent PEG 400, maintaining the best flexibility. The other samples were noticeably stiffer, and those treated with PEG 1450 felt almost like wood. All the samples maintained an almost black color except sample 5, which was treated with 10 percent Jeffox and 30 percent PEG 600, which was rinsed in MTMS. This sample lightened in color to a medium-dark brown. Every sample except sample 5 had a greasy or waxy texture, several displaying a slight stickiness. Sample 5, having been cleaned with MTMS, was not tacky or waxy, and exhibited minimal greasiness. The two samples treated with PEG 400 were next best, with only a slight tackiness on sample 4, which was treated with 10 percent Jeffox and 30 percent PEG 400, and a slight greasiness and stickiness on sample 1, which was treated with 30 percent PEG 400.

None of the samples unraveled, and all showed some matting. Matting was slightly less evident on those samples treated with lower molecular weight PEG and those treated with Jeffox. Most of the samples shed some fibers, except for those reinforced with PEG 1450, which made the sample too stiff to bend, breaking fibers.

The results of the initial experiment indicate that the use of Jeffox may reduce matting, and encourage flexibility. The results show that PEG 1450 is not suitable for rope by itself, the high molecular weight produces a texture more appropriate for wood than rope. Both PEG 400 and PEG 600 appear to be appropriate choices for rope, with PEG 400 having the edge as it produces a more flexible end result. The use of MTMS lightens the dark color which is typical of PEG treated artifacts and draws dirt to the surface of the artifact where it can be manually cleaned. The less greasy, waxy texture of the MTMS treated artifact indicates success in the removal of excess PEG, at least from the fiber surface. None of the rope appears shrunken or desiccated, although all of the samples except those treated with PEG 1450 maintain a delicate, fragile feel. Although the samples can be handled, they do shed, indicating that post-treatment handling and manipulation should be kept to a minimum. Several of the samples, notably samples 1, 2, and 5 appear to be from more degraded rope than samples 3, 4, and 6. This experiment indicated that the amended PEG method was a potentially viable treatment. However, further experimentation was needed to test the amount of shrinkage which occurs during these treatments, the effect of MTMS on other molecular weights of PEG, and the effect of treatment on rope that has experienced different levels of degradation.

Table 3. Results from the first experiment.

Sample	Treatment	Flexibility	Color	Texture	
1	PEG 400	Slightly flexible. Bends but returns to original shape when released.	Very dark brown	Slightly greasy and tacky	Fragile, with shedding. Did not unravel, but did break. Slightly matted.
2	PEG 600	Stiff, although it will bend slightly.	Very dark brown	Slightly greasy and tacky.	Fragile, with shedding. Did not unravel, but did break. Matted on the bottom and the ends.
3	PEG 1450	Very stiff, does not bend at all	Very dark brown	Waxy, minimal tackiness	Minimal shedding. Did not unravel, although one strand is broken through. Matted on bottom and ends.
4	Jeffox with PEG 400	Very flexible, almost soft. Holds the angle to which is bent.	Very dark brown	Minimally tacky	Fragile, with some shedding. Did not unravel. Slightly matted.
5	Jeffox with PEG 600 Cleaned with MTMS	Slightly flexible. Will bend, but goes back to original shape when released.	Medium dark brown	Not tacky or waxy; almost natural feel with slight greasiness	Fragile, with some shedding. Did not unravel. Slightly matted at the ends and on the bottom.
6	Jeffox with PEG 1450	Very stiff, does not bend at all.	Very dark brown	Waxy, no tackiness	No shedding, matted on bottom and ends. Slightly shiny.



Figure 30. Treated rope samples from the second experiment. Photo by R. Sasaki.

Table 4. Quantitative results for the degraded rope from the second experiment.

Sample	1	2	3	4	5	6
Wet Mass	72.92 g	63.50 g	56.05 g	70.93 g	99.52 g	65.55 g
Wet Length	26.75 cm	17.50 cm	19.75 cm	19.00 cm	22.75 cm	21.00 cm
Wet Diameter	3.70 cm	3.30 cm	3.80 cm	3.35 cm	3.60 cm	3.00 cm
Post-Jeffox Mass	73.10 g	60.58 g	61.47 g	x	x	x
Post-PEG Mass	76.52 g	66.20 g	67.70 g	74.1 g	99.67 g	63.65 g
Dry Mass (no MTMS)	23.13 g	21.87 g	23.92 g	32.62 g	28.33 g	28.18 g
Final Mass	17.29 g	15.55 g	16.00 g	24.24 g	20.55 g	19.32 g
Final Length	16.80 cm	14.90 cm	17.50 cm	18.5 cm	22.40 cm	16.6 cm
Final Diameter	3.40 cm	3.00 cm	3.20 cm	3.60 cm	3.40 cm	3.00 cm
	unraveled	flattened	unraveled	flattened	flattened	flattened
Mass Variance	-55.63 g	-47.95 g	-40.05 g	-46.69 g	-78.97 g	-46.23 g
Length Variance	-9.95 cm	-2.60 cm	-2.25 cm	-0.50 cm	-0.35 cm	-4.50 cm
Diameter Variance	-0.30 cm	-0.30 cm	-0.60 cm	0.25 cm	-0.20 cm	0 cm
% Mass Variance	-76.29%	-75.51%	-71.44%	-65.83%	-79.35%	-70.53%
% Length Variance	-37.20%	-14.86%	-11.39%	-2.63%	-1.54%	-20.95%
% Diameter Variance	-8.11%	-9.09%	-15.79%	7.46%	-5.56%	0%

The variances in Table 4 indicate that the heavily degraded samples experienced shrinkage, evident both in the appearance and in the variance between the initial and the final diameter. Final measurements for length and diameter were difficult to obtain, as many of the samples experienced material loss or breakage during treatment. The final diameters are deceptive. These samples flattened considerably during treatment, and are no longer rounded in cross-section. As the samples were not weighted, the flattening

might be attributed to cellular collapse under the weight of the water and artifact. These samples are very light weight and fragile. All of the samples except sample 2, treated with 10 percent aqueous Jeffox and 30 percent aqueous PEG 600, and sample 3, treated with 10 percent aqueous Jeffox and 30 percent aqueous PEG 1400, remain slightly flexible. Samples 2 and 3 are brittle and stiff. Although the quantitative evidence suggests that the rope experienced longitudinal shrinkage, the change in length can be attributed primarily to loss of material and the separation of broken yarns from the whole. Some of this breakage occurred during treatment, although much occurred prior to treatment during the natural degradation process and recovery of the artifacts. Until the treated rope was allowed to air dry, the tension provided by the liquid-swollen fibers prevented these broken pieces from separating from the whole. Although these samples were all heavily degraded at the outset, some were more so than others. The degradation is evident in comparisons between Figures 24 through 29 and Figure 30, and in the variances recorded in Table 4. Because of the lack of cohesion and the state of these samples after treatment, the quantitative results do not provide conclusive evidence regarding which of these treatments was most successful. The results however, do indicate that the amended PEG method is not the ideal treatment for rope in an advanced state of degradation.

The quantitative results for the better preserved samples (Table 5) show little variance in the lengths of the samples. These differences may be attributed primarily to a loss in material, the loss of a single protruding yarn would affect the length (Figures 24 through 30). Likewise, those examples which appear to be longer than previously

measured could be attributed to mistakes in measuring or to the loosening of a fiber so that it protrudes from the main body of the rope sample. The variances in diameter were unexpected, as with two exceptions (samples B and F) the diameter is actually slightly larger post-treatment. The source of the size difference is undetermined, although it may be due to fibers and yarns no longer being pressed and weighted together by the impregnating liquids. Although every effort was taken to measure the rope at the widest point, the slight variations in diameter might also be attributed to the rope being measured in a slightly different spot. *La Belle's* rope was created by hand rather than by machine and there are variations in fiber, yarn, and strand thicknesses. The most telling quantitative information comes from the changes in mass through the experiment. There is significant variance between the initial mass and the final mass. Much of the difference can be attributed to the removal of water from the artifact. However, the changes that occur during treatment indicate that weight is added when the rope is placed into Jeffox and then again when it is placed into PEG. These higher masses indicate that the materials are being absorbed into the rope during treatment. The difference between the dry mass measures and the final mass measures can be attributed to the removal of the excess PEG from the artifact. The samples treated with Jeffox show a higher variance between the initial mass and final mass than those not treated with Jeffox. Further study at the cellular level may better determine the reason this variance is occurring. The variances between the different molecular weights of PEG were unexpected, as it was supposed that the higher molecular weight PEG would show less variance in the final outcome. The slight variance between the molecular weights

may be attributed to the greater penetration of the lower molecular weight PEG into the cellular structure. The quantitative differences are very slight across the board, and no definitive selection could be made based purely on quantitative results. However, the PEG 400 only treatment exhibited the least loss in mass, the PEG 600 with Jeffox treatment demonstrates the least change in diameter, and the PEG 400 with Jeffox and PEG 1450 only had the lowest variances in length.

Table 5. Quantitative results for the well-preserved rope from the second experiment.

Sample	A	B	C	D	E	F
Wet Mass	188.90 g	158.50 g	145.47 g	131.20 g	125.42 g	119.60 g
Wet Length	26.50 cm	23.25 cm	24.00 cm	24.50 cm	24.00 cm	18.75 cm
Wet Diameter	4.20 cm	3.80 cm	4.10 cm	4.40 cm	4.10 cm	3.90 cm
Post-Jeffox Mass	196.7 g	165.21 g	154 g	x	x	x
Post-PEG Mass	202.70 g	183.89 g	155.54 g	165.98 g	141.08 g	125.20 g
Dry Mass (no MTMS)	62.69 g	50.88 g	39.00 g	63.76 g	49.45 g	43.78 g
Final Mass	55.05 g	44.40 g	37.65 g	54.84 g	43.77 g	38.17 g
Final Length	26.60 cm	24.10 cm	22.50 cm	25.20 cm	23.20 cm	18.70 cm
Final Diameter	4.40 cm	3.80 cm	4.40 cm	4.50 cm	4.30 cm	3.80 cm
Mass Variance	-133.85 g	-114.10 g	-107.82 g	-76.36 g	-81.65 g	-81.43 g
Length Variance	0.10 cm	0.85 cm	-1.50 cm	0.7 cm	-0.8 cm	-0.05 cm
Diameter Variance	0.20 cm	0 cm	0.30 cm	0.10 cm	0.20 cm	-0.10 cm
% Mass Variance	-70.86%	-71.99%	-74.11%	-58.20%	-65.10%	-68.09%
% Length Variance	0.38%	3.66%	-6.25%	2.86%	-3.33%	-0.27%
% Diameter Variance	4.76%	0%	7.31%	2.27%	4.88%	-2.56%

Table 6. Qualitative results for the degraded rope from the second experiment.

Sample	Treatment	Flexibility	Color	Texture	General Condition
1	Jeffox and PEG 400 MTMS	Slightly stiff, but yarns flex easily.	Dark brown	Slightly hard, not tacky, waxy, or greasy	Poor, little fiber shedding, but unraveled. Little shrinkage, Fibers somewhat matted together but visible on sample ends.
2	Jeffox and PEG 600 MTMS	Very stiff and brittle, individual fibers also stiff	Nearly black	Not greasy, waxy, or tacky, hard	Poor, fiber shedding, slight shrinkage. Cohesion due to stiffness, matted at sample ends, but can see individual fibers.
3	Jeffox and PEG 1450 MTMS	Stiff, almost brittle, some flexibility in the individual fibers	Nearly black	Slightly dry	Very poor, no cohesion between elements,. Overall shrinkage caused unraveling. Matted, although individual fibers can be seen.
4	PEG 400 MTMS	Some flex, but brittle	Very dark brown	Slight greasiness, hard	Cohesion is acceptable given condition, some shedding, slight shrinkage apparent, matted.
5	PEG 600 MTMS	Stiff, very slight capability to flex. Individual fibers flexible.	Dark brown to nearly black	Not waxy, Natural feel. Very slight greasy or tacky feel.	Poor, lack of cohesion between elements and shedding,. Overall shrinkage apparent, but not excessive. Individual fiber separation, but tangled. appearance
6	PEG 1450 MTMS	Stiff and somewhat brittle, little capability to flex.	Medium brown to nearly black with some light fibers	Hard, not waxy or greasy, very slight tackiness	Some fiber shedding, acceptable cohesion, shrinkage apparent. Individual fibers are difficult to distinguish except on ends.

Table 7. Qualitative results for the well-preserved rope from the second experiment.

Sample	Treatment	Flexibility	Color	Texture	General Condition
A	Jeffox and PEG 400 MTMS	Flexible, but does not hold bend well. Slight stiffness after MTMS exposure.	Dark brown	Slight hardness after MTMS exposure	Good cohesion, little or no visible shrinkage, Matting only evident on “bottom”, some shedding.
B	Jeffox and PEG 600 MTMS	Stiff, but will flex slightly and return to original shape.	Medium to dark brown	Natural feel, slightly dry	Good cohesion, slight shedding, individual fibers visible, slight matting on ends. Little or no apparent shrinkage.
C	Jeffox and PEG 1450 MTMS	Stiff, with a slightly brittle feel. Little flex capability.	Dark brown with some light fibers	Slightly dry.	Satisfactory cohesion given condition. Some shedding,, slight matting, and little or no apparent shrinkage.
D	PEG 400 MTMS	Flexible, although short sample does not hold shape. Individual fibers flexible.	Medium to dark brown	Not waxy , slight tacky or greasy feel.	Good cohesion, shedding, little or no apparent shrinkage. Individual fibers not all visible except on ends, some matting.
E	PEG 600 MTMS	Stiff, with a slight capability to flex. Individual fibers flexible	Dark brown with some light fibers	Not tacky or waxy, negligible greasiness.	Good cohesion, some shedding individual fibers visible, slight matting at fiber ends. Little to no apparent shrinkage.
F	PEG 1450 MTMS	Very stiff but not brittle, very little capability to flex.	dark brown with light fibers	Hard, not waxy or greasy, very slight tackiness	Good cohesion, little shedding, little or no apparent shrinkage, visible but acceptable matting, some gloss

The qualitative results decisively indicate that although both the amended PEG treatment and PEG alone may be used to stabilize rope fibers, the treatments are not successful in preventing the loss of cohesion or shrinkage when applied to heavily degraded rope (Figure 30 and Table 6). Although good results were achieved regarding flexibility in the yarns for sample 1 (10 percent aqueous Jeffox and 30 percent aqueous PEG 400) and 4 (30 percent aqueous PEG 400), most of the samples were stiff and friable. Any cohesion in these samples is either due to cellular collapse and shrinkage holding the elements together or a high molecular weight PEG lending strength and stiffness. Much of the material exhibits matting, if not on the rope or strand level, at the yarn level where the fibers are difficult to distinguish individually or are tangled together. While rope at the high level of degradation exhibited by examples 1 through 6 may not respond well to any treatment, it is a level of degradation that conservators must be prepared to deal with. In this instance, silicone oil may be the best treatment to prevent the total loss of the artifact. While other treatments do stabilize the material, they may not successfully preserve the artifact, as the rope may lose cohesion or bulk.

The results of the treatments regarding the preservation of heavily degraded rope are both decisive and undesirable. The conclusion here is that none of these treatments is suitable for heavily degraded rope, with the possible exception of PEG 1450 to prevent material loss. Therefore, the remainder of the results section with regard to the second experiment will compare the treatments used on the better preserved rope (Table 7) to each other and to the initial experiment (Table 3).

The qualitative results of the second experiment support the initial results that Jeffox may reduce matting in better preserved material (Table 7). When compared to the initial results (Table 3), it is evident that the use of MTMS post-treatment also helps to reduce matting by removing the PEG on the surface of the rope. The samples all maintained good cohesion; although, those treated with higher molecular weight PEG retained the best cohesion with the least amount of fiber shedding. None of the samples (A through F) exhibited any noticeable degree of shrinkage, which contributes to the good cohesion found throughout the samples.

The rope treated with lower molecular weight PEG or PEG with Jeffox exhibits the best flexibility, particularly in combination. Until sample A, treated with 10 percent aqueous Jeffox and 30 percent aqueous PEG 400, was cleaned with MTMS, it held a slight curve when bent. Unfortunately, the slight hardness or dryness exhibited by samples A, B, and C (all treated with 10 percent aqueous Jeffox) indicate that the 10 minutes of immersion in MTMS may have been excessive for these samples. In addition, the same qualities of the lower molecular weight PEG that impart flexibility also increase fiber shedding. The stiffness and cohesion provided by the higher molecular weight PEG helps to reduce the amount of material shed from the rope samples.

The best color was exhibited by Samples A, B, and D (10 percent aqueous Jeffox with 30 percent aqueous PEG 400, 10 percent aqueous Jeffox with 30 percent aqueous PEG 600, and 30 percent aqueous PEG 400 respectively). These results indicate that the lower molecular weight PEG is less likely to darken the rope excessively. The results also indicate that the addition of MTMS and Jeffox to the treatment helps to reduce the

dark appearance often associated with PEG impregnation. In addition, while all of the samples lightened with the application of MTMS, those samples treated first with Jeffox maintained a more even color. Those not treated first with Jeffox became lighter on one side. This color variance may indicate that the addition of Jeffox to the solution helps to maintain a more even distribution of PEG through the artifact.

The texture of Samples A through F was good. None were overly greasy, waxy, or tacky. The slight dryness or hardness in Samples A, B, and C (all treated with Jeffox) can likely be attributed to overexposure to MTMS. This effect has been noted when the polymer passivation treatment using silicone oils is applied to rope. Sample D, treated with 30 percent aqueous PEG 400, was the only sample to exhibit more than a trace of greasiness, and it was so slight as to be considered acceptable. There is a slight gloss on the surface of Sample F, treated with 30 percent aqueous PEG 1400, which may be attributed to the higher molecular weight PEG, or it may be that 10 minutes was not enough exposure to remove the excess PEG. The slightly greasy texture of Sample D, treated with aqueous PEG 400, may also indicate that the rope treated with PEG only may need slightly more exposure to MTMS than rope treated with both Jeffox and PEG.

Overall, the results indicate that while all of the treatments produce acceptable results, PEG 400 with Jeffox, PEG 600 with Jeffox, and PEG 400 alone produced the better results. Time trials may support the use of a higher molecular weight PEG, such as PEG 1450; however, the initial result is stiff and “unropelike.” PEG 400 both with and without Jeffox has a slight edge over PEG 600 with Jeffox for flexibility, although PEG 600 with Jeffox demonstrates less fiber shedding. All of the samples in this second

experiment have a delicate fragile feel, and should likely be handled as little as possible. Those exhibiting more fiber shedding may need to be treated with a post-treatment consolidant.

CHAPTER VII

CONCLUSIONS

The selection of a conservation method for any artifact should take into account the composition and chemistry of the artifact. The best treatment produces a stable artifact which is natural in appearance and texture, but one that will also stand the test of time. The treatments should vary based on the particular challenges posed by each artifact; no one treatment has been successful for treating every artifact. The experiments illustrated above represent only one approach to the conservation of rope, the literature review presents a few more. Constant reevaluation of methods is a must, as many apparently successful methods alter greatly over time. Before the application of any method, the conservator should have some idea of the aging process of the method, as even conservation treatments do not last forever. As a treatment ages, the artifact should be harmed as little as possible and the conservation treatment should remain stable. A stable treatment permits the re-treatment of an artifact as necessary. With rope, stability is vital, for once the cellular structure has collapsed, the rope has become desiccated, or lost its structural integrity; it is nearly impossible to reverse. With the traditionally used PEG methods, the life expectancy is measured in decades rather than centuries. A close eye should be kept on artifacts treated with this polymer. Close observation will ensure that retreatment or stabilization of the PEG within an artifact can be carried out before the artifact is compromised. The potential polymerization of PEG within an artifact

should help prevent some of the inherent problems that occur over time when using PEG.

It is important that experimental results can be duplicated. The initial PEG experiment discussed in this report was repeated successfully and produced similar results. However, experiments applied to real life situations do not always live up to expectations. The method chosen to conserve the remainder of *La Belle's* bow cable is one of these (Figure 31). Although moderate success has been obtained, much of the rope was more degraded than the initial appearance indicated. The rope structure had been compromised and shrinking and stiffening occurred during treatment as the cells collapsed. Unfortunately, Jeffox and PEG 400 did not provide enough structural support. Not all of the rope was thus affected, and much is still flexible. The rope may in future need a post-treatment consolidant, as the condition of this rope is still very fragile.

To ensure the best conservation treatment for any artifact, careful records regarding the treatment and storage of the artifact during and after excavation should be provided to the conservator. The smallest detail may alter how an artifact is treated. In the case of *La Belle's* cables, the excavation of the ship as a land site meant exposure to air and the renewal of aerobic degradation. The dramatic discovery of the skeletal remains sprawled across the cable provided a public focal point for the excavation, but also resulted in a longer period of exposure for the rope. In addition, the majority of the anchor cable did not begin conservation until eight years after the excavation was complete. Although the rope was immersed in freshwater throughout this period, it was no longer protected in an anaerobic environment. Thus, the forces of decay continued to

act upon it, furthering the degradation process. Much of the anchor cable, while appearing relatively strong, had little cellular structure left. The application of the amended PEG method to the anchor cable had varying results. Sections of cable which had appeared in excellent condition prior to treatment became desiccated and stiff, while other sections, treated at the same time, remain flexible. Those sections which appear in better condition may have been those more deeply buried in sediment. Those that have stiffened and shrunk are probably those lengths that were recovered from the top of the coils. The complications described above stress the importance of providing documentation to the conservator and for carrying out conservation as quickly as possible.



Figure 31. Placing the anchor cable into treatment. Photo by J. Swanson.

Mistakes were made as the amended PEG method was carried out. The vat in which the rope was conserved was a partially sealed outdoor vat. After being treated, the packages of rope lay draining in the vat. I neglected to leave the drain valve open on the bottom of the vat, and a rainstorm deposited two inches of water in the low end of the vat, soaking three packages of rope over a weekend. The rope in these packages lost much of the PEG to diffusion, and became some of the worst preserved sections of the bow cable.

Further experimentation might include molecular weights of PEG not tested, such as PEG 3350 and PEG 200, different percentages of PEG within solution, or the addition of glycerine to the PEG solution. Other post-treatment cleaning methods should be tested. MTMS is effective for removing excess PEG; however, acetone, ethanol, or hot water might also work. Continued experimentation will ensure that this amended PEG method becomes a viable and valuable addition to the conservator's toolbox.

Overall, the method has been successful. The rope is stable, and for the most part, in good condition. The more degraded sections are stiff and friable, and a post-treatment consolidant should be considered to prevent fiber shedding. The amended PEG treatment does not reproduce the dramatic results that are seen with the passivation polymers process. Silicone oil remains the only treatment discussed in this paper that maintains the flexibility of rope, imparts strength, and maintains a natural fiber color and texture over a long period of time. While silicone oil may be the best currently available choice for treating waterlogged rope, the amended PEG method discussed in this paper does appear to be an acceptable choice for better-preserved waterlogged rope. Moreover,

it has been successfully demonstrated that MTMS can be used to remove excess PEG from rope. The use of MTMS may enable the retreatment of previously PEG treated rope. Jeffox is less well understood and more research should be carried out at the cellular and molecular levels. Of the myriad of treatments covered in this report, none is completely successful all of the time. The passivation polymers method exhibits the best potential for being a more adaptable and generic treatment. Even with passivation polymers there are drawbacks, particularly if the rope is very heavily degraded.

Time will provide more information on the success of this treatment. The samples from the initial experiment have had two years in which to age. No real change has been noted for any of them, other than some shedding of fibers, an increase in the tackiness of samples 1 and 2, and the deposition of white residue on samples 3 and 6 (Tables 1 and 3). If the ability to polymerize the PEG within an artifact proves successful, perhaps the inherent stability problems of PEG will be solved.

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