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# Understanding Traditional and Modern Paints and Stains for Exterior Wood | 2014-01

Anthony & Associates, Inc. for Association for Preservation Technology International

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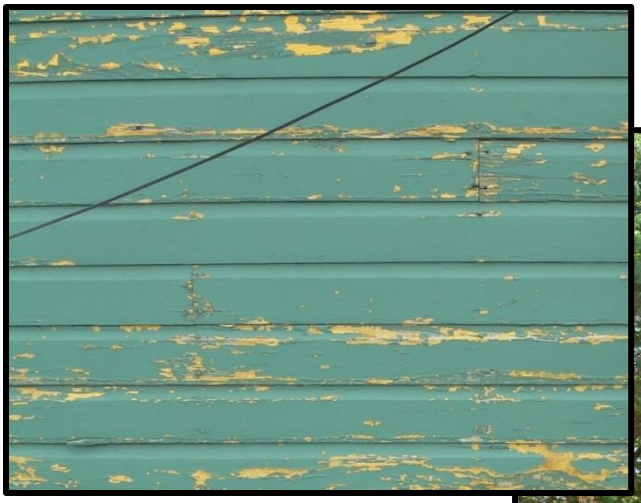

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# Executive Summary

Building stewards and project managers are often in a quandary when it comes to the application of a coating on historic exterior woodwork that has weathered or that has obvious coating performance issues. In 2011, the Association for Preservation Technology International received a grant from the National Center for Preservation Technology and Training to produce a manual for preservationists to facilitate the decision-making process of applying modern or traditional coatings to historic exterior woodwork. This document is intended to provide a foundation for understanding coatings and how they interact with the wood substrate and offer realistic preservation options for building stewards who must make decisions regarding exterior coatings for wood.

This manual provides information on the common components of exterior paints and stains, the historical development of those products, common types of wood substrates, mechanisms of deterioration for woodwork and coatings, and methods of identifying deterioration. This document also includes recommendations on repair options and specifications for replacement material, as well as application procedures and tools for coatings on new and weathered wood.

Chapter 1 introduces the topics discussed in the manual, identifies the intended audience, and includes a brief summary of the Secretary of the Interior's Standards for the Treatment of Historic Properties as they relate to exterior wood coatings. Chapters 2 and 3 provide an overview of common historic pigments, solvents, and binders and their physical properties and the history and development of exterior coatings for wood in the United States. Chapter 4 identifies the methods to determine the type of coating(s) and wood substrate present on historic structures. Coating and wood deterioration identification are also included in this chapter. Chapter 5 serves as a how-to guide for the application of coatings on new and historic wood substrates, including heavily weathered wood. A more extensive summary of the Secretary of the Interior's Standards for the Treatment of Historic Properties and decision guidelines are provided in the Appendix to facilitate the decision-making process.

# Chapter 1. Introduction: Understanding Traditional and Modern Paints and Stains for Exterior Wood

**Why this Manual?**

There is a vast array of products available for coating exterior wood products. Such a diverse selection of coating types can be overwhelming when one is faced with the need to find a product that will perform well on a historic wood substrate. For those decision-makers who are not trained in the technical aspects of historic preservation, determining the appropriate level of intervention and an appropriate coating product for historic structures can be a challenging endeavor. Factors to consider include the suitability, sustainability and performance of the exterior paints and stains themselves (the coatings), as well as the type and condition of wood to which they are applied. Added to these considerations are the possible interactions between the coatings, the wood, and environmental factors. To facilitate the decision-making process, this manual was compiled to serve as a reference document that provides general information on the types of traditional and modern wood coatings used in exterior applications. It also offers basic guidelines for determining the appropriate level of intervention needed as well as selecting and applying a coating that is suitable for the wood substrate.

Historic wood structures often suffer from a lack of regular maintenance, and exterior coatings, meant to protect the wood substrate, often fail before additional coatings are applied. Failure to protect the wood on the exterior of a structure contributes to the lack of durability and premature failure of exterior wood elements. Effective maintenance relies on using best practices for selecting and applying coatings. In today's mass market economy, exterior wood coatings are marketed for the durability and performance of the coating itself rather than its ability to protect the wood it covers. This is a critical distinction between modern and traditional exterior wood coatings. Traditional exterior wood coatings typically served as a sacrificial layer that functioned to protect the wood and, as such, performed in a symbiotic manner with the physical properties of the wood substrate.

Other factors that significantly affect the serviceability of exterior wood coatings that are not typically taken into consideration include: 1) the type of wood (species), the cut of the wood (e.g. plain sawn vs. quarter sawn), and quality of the wood being coated, 2) the condition of the wood being coated (new or properly prepared wood substrates vs. weathered wood), 3) the design and use of the structure, 4) the composition and quality of the coating, 5) the method(s) in which the coating is applied and maintained, and 6) the climatic conditions of exposure. Without proper consideration of these factors, any protective coating, whether traditional or modern, will generally not perform as intended or desired.

Current regulations encourage the use of products with lower environmental impacts and reduced volatile organic compounds (VOCs), particularly in surface coatings; thus, there is some impetus in the construction industry to turn to traditional wood coating formulations that contain few, if any, toxic components. However, the durability of these types of coatings is frequently in question due to limited data to assess long-term durability, and their use in historic preservation projects has not been fully embraced by the historic preservation community for a variety of reasons.

This manual seeks to address some of those concerns by examining the differences between modern coatings and traditional coatings and identifying the benefits and drawbacks of applying various types of coatings on different wood substrates, given individual project conditions and needs. It is intended to address the needs of building stewards or project managers without preservation backgrounds who oversee historic wood structures and who are seeking to maintain exterior wood surfaces in a manner that preserves historic fabric and authenticity without sacrificing durability of the wood substrate. Commonly, there are questions regarding the suitability and durability of coatings, both traditional and modern products, on historic wood substrates. While considerable testing of coatings has generally been conducted on new (fresh) substrates, less is widely known about the durability of coating products on old or highly weathered wood substrates.

The current best practice for exterior coatings applied to wood substrates is to either replace or sand all weathered wood surfaces to expose fresh wood prior to coating application. This approach, while appropriate for ensuring the longevity of the coating, fails to account for the visual impact that sanding and/or replacing weathered wood fabric will have on the appearance of a historic structure and does not reflect recommended guidelines as outlined in the *Secretary of the Interior's Standards for the Treatment of Historic Properties* (Weeks and Grimmer 1995). The need to sand exposed wood surfaces prior to reapplication of a coating can therefore be a complex issue to consider. This manual seeks to address this issue.

**Chapter Summaries**

This chapter conveys the rationale for producing this manual, identifies the intended audience, provides a summary of the other chapters' content, and provides an overview of the Secretary of the Interior's Standards for the Treatment of Historic Properties as they relate to exterior coatings.

Chapter 2 provides background information on the materials that compromise both traditional and modern coatings (including exterior paints and stains). Various types of traditional coatings are described, including lime washes, milk paints, and traditional linseed oil paints. Key ingredients used in coatings are also discussed, including various pigment types and paint binders, or vehicles, of both traditional and modern coating formulations. The types of wood, including the species, type of

cut, and quality of wood traditionally used for exterior cladding is described by general geographic area, and the material properties of the wood are included in the descriptions. These properties are contrasted with the properties of wood substrates that are commonly used today.

Chapter 3 summarizes the history of exterior wood coating use in the United States. The development of both exterior paints and stains is summarized, as well as the historical trends that shifted the culture away from traditional products and towards the resin and polymer coatings commonly used today.

Chapter 4 provides information on how to identify site-specific needs. This chapter is intended to outline the steps necessary for a building steward to determine the needs of an individual structure based on known properties and conditions. Paint analysis, wood species identification, and the basics of conducting a condition assessment of wood and coatings are addressed so that those without extensive historic preservation backgrounds can gain the foundational knowledge necessary to assist with determining the level of intervention needed and the appropriate materials for repair or replacement.

Chapter 5 is designed to aid building stewards in the selection of a suitable coating for the exterior wood of a historic structure. This chapter summarizes the application procedures that are currently recommended by the U.S. Forest Products Laboratory for coatings performance. These guidelines are recommended for all wood substrates, regardless of age; however, the special needs of historic structures are addressed through a discussion of common characteristics of historic exterior wood elements and the limitations that those involved with historic preservation often face –a desire to retain as much historic fabric as possible, a desire to preserve the historic authenticity of aged and/or weathered wood surfaces and a lack of sufficient funding to properly remove old coatings and refinish old exposed wood surfaces. These concerns often conflict with the proscribed methods of coatings application and this chapter attempts to bridge the gap between recommended best practices for modern coating performance and the need to preserve the authenticity of a historic material such as weathered clapboard siding, while still protecting the wood and the building from deterioration.

The final chapter summarizes the discussion of traditional and modern paints and stains on exterior wood. The chapter describes key factors to consider in historic preservation projects in order to determine the suitability and appropriateness of a potential coating.

An extreme exposure field test was conducted as part of this project using modern and traditional coatings on various wood substrate samples. The test procedures and results can be found in the accompanying document, *Understanding Traditional and*

*Modern Paints and Stains: A Limited Test Study*, which was conducted in an effort to provide additional information regarding the performance of traditional coatings in comparison to modern coatings on both weathered wood surfaces and freshly sanded wood surfaces.

**The Secretary of the Interior's Standards for the Treatment of Historic Properties**
Prior to conducting any preservation work, the historic status of a structure should be identified. While not every structure will have a recognized historic status, efforts can, and, in the opinion of the authors, should be made to adhere to the Secretary of the Interior's Standards for the Treatment of Historic Properties, when possible. The voluntary standards require that the historic character of a property be retained and preserved and recommend against the replacement of intact or repairable historic materials that constitute character-defining features of a property. Character-defining features may include the architectural woodwork and trim, exterior wood siding, as well as the paints, finishes, and colors. The Standards recommend repairing deteriorated areas of wood features rather than replacement. Similarly, the Standards recommend against the removal of paint unless there is paint-surface deterioration and the removal is part of a maintenance program to maintain protective coatings on wood surfaces. Additionally, the Standards list identifying, evaluating, and treating the causes of wood deterioration as key steps toward the primary goal of preservation and do not advocate sanding weathered wood surfaces to bare wood. Therefore, a survey of existing paint and substrate conditions is recommended to accurately determine the level of intervention necessary.

All work, including protective coatings, preservative treatments, and repairs should, therefore, be compatible both physically and visually with the wood elements and the structure as a whole, as well as documented and identifiable (upon close inspection) for future research and preservation efforts. Distinctive materials, features, finishes, and construction techniques or craftsmanship of the exterior wood should also be preserved. If chemical or physical treatments are necessary, such as the application of chemical preservatives or paint removal, those treatments should be applied or conducted using the most gentle methods possible. If areas of deterioration severe enough to require repair or limited replacement of an element exist, the deteriorated material should be repaired or replaced with the same species and match the original material in composition, design, color, and texture. Preservation Brief 10, *Exterior Paint Problems on Historic* Woodwork, and Preservation Brief 47, *Maintaining the Exterior of Small and Medium Size Historic Buildings* are of particular relevance for repairing, repainting, and maintaining exterior woodwork. Additional information on the preservation briefs and on the Secretary of the Interior's Standards for the Treatment of Historic Properties can be found online on the National Park Service website at http://www.nps.gov.

## Chapter 2. Exterior Paint and Stain Composition and Wood Substrates

There are, of course, a number of different coatings beyond paints and stains. Lacquers, varnishes, shellacs, epoxies, polyester resins, water repellent preservatives, and fire retardants are just some of the coatings commonly applied to wood substrates. A detailed analysis of the vast array of wood coatings is beyond the scope of this manual; however, it is important to note that paints and stains can contain components of other coating types. For the purposes of this manual, however, the focus will be on a limited number of "traditional" coatings and "modern" oil-based and water-based latex acrylic exterior paints.

**"Traditional" vs. "Modern" Coatings**

Because of the long history of custom mixing paint on an individual project-basis by artisan craftspeople, there are no definitive rules regarding the delineation between "traditional" and "modern" coatings. However, some general principles apply. For most traditional coatings, there is a lower percentage of solvent and a higher percentage of pigment than modern coatings. In some cases, there are no solvents at all in traditional paint recipes; this means that there is no release of volatile organic compounds (VOCs) into the atmosphere as the paint dries and/or cures. This can make some traditional coatings quite appealing, as more emphasis is placed on sustainable and environmentally sound building and maintenance practices.

For the purposes of this manual, traditional coatings are defined as those using no modern polymers, binders, or pigments (modern ingredients are considered to be those developed after 1930) and with minimal or no use of solvents. These types of traditional coatings include milk and other animal protein based paints, pure linseed oil paints, rye flour paints, lime washes, and distempers. There are also a number of traditional coatings that use other binders such as fish oil, pine tar, or other plant-derived oils. Modern coatings are perhaps more difficult to define, as new constituents are continually being developed and evolving to allow for increasingly complex products with a variety of chemical components and characteristics. Within this manual, acrylic latex coatings and alkyd oil coatings (both exterior paints and stains) will be the primary focus when discussing modern coatings. Additional information on the differences between traditional and modern coatings can be found in the following sections of this chapter.

**Defining Paints and Stains**

Exterior paints typically are comprised of three components: pigment(s), binder, and solvent(s). Exterior stains generally have the same three components, although the amount of pigment(s) can vary significantly depending on the opacity of the stain. Fillers and additives are also commonly added to modern coating formulations, but

in essence, all coatings have these three basic ingredients. One look at a modern coatings material safety data sheet, however, will indicate that far more than three ingredients go into a modern paint or stain product. These additional ingredients include emulsifiers, additional solvents, driers, and a multitude of other chemical additives that are intended to improve the coating's leveling ability and workability, limit sagging and runs, improve ultraviolet light resistance, and speed up or slow down dry times, as well as additives intended to inhibit mold and mildew growth.

Pigments serve to provide color and protect the wood substrate by blocking ultraviolet (UV) light and providing a physical barrier to abrasion from wind-blown debris. Pigments can also add texture and increase the durability of the coating. Binders hold the pigment(s) together and adhere the molecules to the substrate. Binders also form a film or protective coating that can inhibit moisture infiltration into the substrate. Solvents thin the mixture and allow the pigment and binder to be applied to the substrate with a somewhat uniform layer of coating. Solvents are volatile and evaporate, and thus are not a constituent of the final coating. Exterior stain formulations are similar to exterior paints but generally have lower percentages of pigments and binder and greater percentages of solvents; based on this similarity, exterior stains and paints have been grouped together for the purposes of this discussion of the components of coatings.

**Pigments**

Pigments are either natural or synthetic, and are either organic (carbon-containing) or inorganic. Most traditional coatings use natural pigments. Natural pigments include solids derived from calcium carbonate, mica, silicas, talcs, minerals, and clays. These are typically white, red, yellow, or brown in color, and are generally iron-oxide based. These pigments generally exhibit good light-fastness; that is, they do not tend to fade significantly over time. Natural pigments with colors outside the earth-tone spectrum such as blues and greens (derived from copper or other metallic oxides) tend to have less resistance to breakdown from ultraviolet rays and can fade significantly. Synthetic pigments are engineered molecules and can be found in a variety of colors.

While natural pigments are more limited in terms of color selection than synthetic pigments, there are inherent differences in the way natural pigments absorb and reflect light, when compared to synthetic pigments. The visual appearance of a pigment is dependent upon its particle size and shape and the absorption characteristics of its chemical constituents. The size of a pigment particle can vary significantly. In general, synthetic pigments tend to be smaller, purer in composition, and more consistently sized than natural pigments, which may contain multiple other pigments and/or have particles of varying sizes.

Light passing through layers of paint is reflected and refracted by particles of pigment and paint binder. The amount of refraction depends upon the crystal structure and translucency of the pigment particles, as well as by the chemical composition of the paint binder surrounding the particles of pigment. The larger and more irregular the pigment particles, the more light can both pass through the binder and be reflected from the refractive surfaces of the pigment. Synthetic pigments are much more uniform in size and shape than natural pigments and, thus, provide for more predictable and reproducible hues.

When natural pigments are prepared (generally by crushing and grinding), the particles vary in size, shape, and chemical composition, as the pigments are very rarely found in an entirely pure form. Other minerals are often present in small amounts (termed inclusions), and as a result, natural pigments will tend to reflect and transmit light in additional areas of the color spectrum than just the primary hue. Compared to synthetic pigments, which attain a level of purity rarely found in nature, natural pigments generally appear more chromatically intense because they reflect a wider part of the light spectrum than their synthetic counterparts.

As chemically manufactured products, synthetic pigments are defined by the quantities in which they are produced and used in coatings. This is an advantage to the modern coatings industry, where pigments are formulated to improve color nuances, brightness, and stability. Modern pigments are generally homogeneous in size, shape, and composition in order to provide predictable performance of the end product. The covering power of a pigment is based on particle size and the amount of pigment present in the coating; in general, even if the same pigment is present in the same amount in two different products, the coating with pigment ground to a smaller particle size will have a greater covering power (meaning fewer coats or less of the product must be applied to achieve the desired appearance). Synthetic pigments, therefore, generally provide better coverage than natural pigments but can result in a coating that lacks the luminosity of natural pigments.

Luminosity refers to the visual appearance of richness or depth of color that creates a sense of glow. Paints with little or no luminosity contain pigments that scatter and diffuse light, while paints with high luminosity contain pigments that allow for some degree of light to enter the pigment particles, where some wavelengths are selectively absorbed and others are reflected. Because the reflected light from these pigments is not as scattered and diffuse, colors can appear deeper, more saturated, and richer in tone. Synthetic pigments also serve to improve the shelf-life of ready-mixed paints and stains, as pigment particles that are uniform in shape and size tend not to settle out and separate from their binder as quickly as irregularly shaped/sized pigment particles, once inside a container. This increases the marketability of the product, but reduces its effectiveness to replicate the general appearance of traditional coatings.

A complete review of the multitude of pigments used in the past and those that are available today is beyond the scope of this manual; however, some of the most common white pigments are reviewed, as white was a predominant exterior color for many historic structures. Similarly, the discussion of binders, solvents, and additives has been condensed to focus on only the most common materials used in exterior coating formulations. Additional information on coating ingredients can be found in numerous recent and historical sources, such as *The Chemistry and Technology of Mixed Paints* (Toch 1907), *Analysis of Mixed Paints, Color Pigments, and Varnishes* (Holley 1908), *Modern Pigments and Their Vehicles* (Maire 1908), *Coloring, Finishing, and Painting Wood* (Newell 1940), *White Paint and Painting Materials* (Scott 1910), *House Paints, 1900-1960: History and Use* (Standeven 2011), and *Wood Coatings: Theory and Practice* (Bulian and Greystone 2009).

*White Pigments*

White lead was long regarded as the best white pigment available for use with drying oils. White lead pigment traditionally was made by hanging sheets of lead over vinegar in covered containers. The vinegar fumes reacted with the lead to form lead carbonate, which was then removed and ground to a fine powder. Early paint formulations in the U.S. often contained in excess of 80 percent white lead, with the balance of the formulation consisting of linseed oil binder and turpentine solvent. The ratio of linseed oil to turpentine influenced the properties of the paint. More oil than turpentine created a well-bound (the pigment particles were well-encapsulated within the oil molecules), glossy paint that had good weather resistance and was suitable for either indoor or outdoor use; more turpentine than oil resulted in a matte paint that was not weather resistant and was intended for indoor use only.

While white lead was the most commonly used pigment, other forms of white pigment were also used in conjunction with white lead to enhance or improve performance and covering ability. Some common white pigments of the 19$^{th}$ and early 20$^{th}$ centuries include lead sulphates and sulphides, sublimed white lead, zinc oxide, and lithipone, as well as inexpensive filler pigments such as calcium carbonate. Other colored pigments include lead oxides, ferric oxides, mercuric sulphides, and potassium bichromates. Most of these pigments are toxic metallic compounds that are legally banned today due to their potential health effects.

Zinc oxide was also commonly used in white exterior paints as a pigment. It was often combined with lead sulphate or produced as a co-fumed leaded zinc oxide pigment by direct burning of zinc sulphate and lead sulphate ores to form a pigment which was claimed by some paint manufacturers to give the best properties of both white lead and zinc oxide. The addition of zinc oxide was found to increase the hardness, durability and opacity of exterior paints, but it could not be used by itself on exterior surfaces, either in primers or paints, because it becomes brittle and causes delamination of the paint.

Titanium dioxide was discovered in 1821, but did not begin to be widely used as a pigment in paints until the 1920s. Today, titanium dioxide is the most widely used white pigment because of its high refractive index, opacity, and brightness. When used in a coating, it has a dry time that is slower than that of white lead but faster than zinc oxide. Titanium dioxide by itself dries to a spongy film that is not suitable for exterior coatings, so it is commonly used in conjunction with other pigments (typically zinc oxide) that provide a stiffer film on the substrate.

**Binders**

The binder in paints and stains serves as an adhesive to bind pigments together and has an impact on gloss, durability, and flexibility. Binders, like pigments, can be natural or synthetic. Most commonly, traditional coatings used linseed oil as a binder, but there are several other types of traditional binders, including animal proteins such as those found in blood, connective tissue, or animal hide (size), milk (casein), or egg whites (albumin). Vegetable-based proteins were also used, such as those found in wheat or rye flour (glutens). In some cases, such as pure lime wash, the pigment and the binder are the same agent. Typically, binders are either water-based or oil-based. Generally, binders that are water-based dry, while binders that are oil-based cure. In other words, drying binders evaporate, while curing binders polymerize. Depending on chemistry and composition, however, coatings can undergo either or both processes.

Linseed oil continues to be used as a component in many modern coatings. It is available in a number of different forms, and it is important to differentiate between them, as each form has different properties. Linseed oil and other naturally occurring oils used as binders are referred to as "drying" oils because the oils undergo oxidative polymerization; that is, upon exposure to oxygen, a chemical process takes place that changes the shape of the molecules resulting in crosslinking of the molecules. This crosslinking, or polymerization, results in the creation of a hard, durable, insoluble film. What are commonly referred to as "drying" oils are actually curing binders; non-drying oils never harden and leave surfaces oily or tacky to the touch, and are not suitable for use as the primary binder in paints or stains.

*Milk Paint and Other Animal Protein-Based Coatings*

Animal-protein based coatings can be divided into two groups - those that are considered glue paints, and those that are considered milk paints. Glue paints that use animal sizing or egg protein can, for the most part, only be used indoors because they dry to a very brittle film and are only slightly resistant to water. Milk paints and other animal protein paints are similarly delicate, but can be made more flexible and durable with the addition of linseed oil or another drying oil to the mix. Paints made from milk use the protein casein as a binder. Milk paints with added drying oils or hydrated lime were sometimes used in the U.S. for exterior applications, but were far more commonly used on interior surfaces. Ox blood or cow blood was also

sometimes used as a binder for exterior paints. Application of animal protein-based paints as an exterior coating was more common in northern Europe and Scandinavia in the 18th and 19th centuries than in the U.S.

*Vegetable Protein-Based Coatings*
Although more elastic than animal protein-based coatings, vegetable protein-based coatings are similar in that they lack the necessary durability for exterior applications, without the addition of a drying oil binder such as linseed oil. Although not commonly used in the U.S., paints based on wheat or rye proteins, with linseed oil, have been used successfully in Scandinavia for centuries as an exterior coating over wood substrates. The paint has a matte finish that chalks away gradually over time, and has been documented as lasting several decades without requiring repainting.

*Lime Washes*
Lime wash is a matte paint made from slaked lime and water, in its most basic formulation. The slaked lime provides both the pigment (calcite) and the binder (the chemical process of carbonation). Additional pigments and other ingredients are sometimes added. Lime washes were typically used over masonry, adobe, and concrete, but were also applied to wood substrates. The slaked lime undergoes a chemical reaction that hardens the coating as it dries. Glue, egg white, Portland cement, milk, flour, and linseed oil are sometimes added to lime washes to improve durability. Lime washes provide a breathable protective coating but are not impervious to water. While lime washes have been used historically in the U.S., particularly in farm building applications, they are rarely applied to wood substrates today.

*Linseed oil*
Linseed oil comes from the seed of the flax plant and has been used as a binder in coatings for centuries. As a drying oil, the molecular crosslinking creates an insoluble film, but the reaction does not stop when the coating is dry and will continue as time passes, eventually causing the coating to become brittle, resulting in coating failure. Linseed oil also yellows with age, particularly when exposed to UV light. Linseed oil can be used in a raw, refined, or boiled form. These various forms of the oil have different viscosities and drying times, and are often used in combination to improve a coating's leveling ability, workability, coverage, and/or drying time. Leveling refers to the ability of a coating to form a smooth film without leaving brush marks. Boiled linseed oil is the most common form used in exterior coatings. It is important to note that most products today that are labeled as "boiled linseed oil" are a combination of raw linseed oil, petroleum-based solvent(s), and metallic dryers and are not simply boiled, as the name implies. Historically, boiled linseed oil referred to oil that was heated without exposure to oxygen resulting in a thick, slow-drying oil; this type of linseed oil is commonly referred to as "stand oil"

today, and is generally not used in exterior coatings. Exterior paints that have linseed oil as a binder generally have good flexibility and durability but can be slow drying, have low gloss, and leave visible brushmarks. Linseed oil generally performs well as a binder in exterior stains but does have a tendency to facilitate the growth of mildew unless fungicides are added to the formulation.

*Tung Oil*

Tung oil began to be used as a binder in coatings on a broad basis as an inexpensive and more readily available alternative to linseed oil during the rationing that occurred during World War I (WW I). Historically it was less expensive than linseed oil. It also dries faster, has greater water resistance, and dries to a harder film than linseed oil. It is a common ingredient in other types of coatings such as interior varnishes and enamels. However, U.S. manufacturers were wary of it because the supply, which came from imported sources, was not dependable. In the 1920s, efforts were made to establish a tung crop in the U.S., however, demand far outstripped the supply, and alternative oils were developed to compensate.

*Less Common Oils and Binders*

Oiticica oil, Perilla oil, and fish oils were sometimes used as binders in exterior coatings in the 1930s. Oiticica oil was historically sourced from Brazil and has similar properties to tung oil. Perilla oil was also used as a binder, as it has similar properties to linseed oil, however, its use became scarce in the 1940s following the cessation of imports from the far east. Fish oils were also sometimes used, although their drying properties were not as good as plant-based oils. In general, fish oils were never popular in the U.S. and did not find their way into a broad market.

Various other plant resins and oils have been used as paint binders as well, although most are too reactive to UV light exposure to produce acceptable results. Pine tar was historically used in Scandinavia as a binding agent (combined with carbonized wood particles) for a protective exterior coating and to weatherproof wood used in boat construction, but was not commonly used historically in residential applications in the U.S.

*Alkyd Resins*

Alkyds are synthetic polyester resins that serve as the binder for most modern coating formulations. Alkyd oil coatings use a combination of natural oil and synthetic alkyd resins, and often also contain emulsified agents. Although discovered in the 1910s and developed in the 1920s and 1930s, coatings using alkyd technology were not widely manufactured until after World War II (WW II). Alkyd oil coatings have several characteristics that can result in a more durable coating; however, the use of synthetic alkyd resins necessitates an increase in the number of solvents, surfactants, and other additives that increase the VOC output of the coating. Alkyd oil coatings with alkyd resins contain emulsions of the resins in an organic

solvent such as turpentine or mineral spirits. Alkyd oil coatings do not dry, but cure through oxidative crosslinking, and polymerization occurs through exposure to oxygen in the presence of driers.

*Acrylic Resins*
Commonly referred to as acrylic latex, the inclusion of the word "latex" is something of a misnomer; modern paints do not contain natural latex, which is an extractive from the rubber plant. Latex refers to the emulsion of polymer microparticles (acrylic resins) in an aqueous medium. Acrylic latex coatings are water-based. Modern latex paints both dry and cure. The water evaporates and curing occurs as the acrylic resin binder particles polymerize.

**Solvents**
Solvents are typically added to exterior coatings to adjust the curing properties and viscosity of the product to make it easier to apply. Although solvents have been a component of paints and other coatings for centuries, some traditional coatings do not contain solvents. The solvent, if present, evaporates, and, thus, does not become part of the paint film. Solvents are generally produced from petroleum-based products and release VOCs as they evaporate. Water-borne paints and stains, such as modern latex and acrylic formulations, still typically have additional petroleum-based distillates, esters, and glycol ethers added to facilitate drying and/or curing. All petroleum-based solvents can have negative impacts on human health and are restricted in many applications.

*Turpentine*
Turpentine can be sourced from a number of tree species, but predominantly is produced from pine. The pitch of the tree is processed by distillation to create turpentine, which is used as a solvent in oil paints and varnishes. Turpentine has been in use in coatings for centuries, and, like linseed oil, is produced in various forms or grades. Turpentine produces VOCs as it evaporates and, while not a petroleum-based product, is a skin, eye, mucous membrane, and upper respiratory tract irritant in humans.

*Mineral Spirits*
Mineral spirits, also referred to as white spirit, mineral turpentine, or petroleum spirits, is derived from crude oil. It was developed in the 1920s initially as a solvent for dry cleaning, but became commonly used as a solvent in paints and stains as well. Mineral spirits remain a common coatings solvent today. As with linseed oil and turpentine, mineral spirits are available in multiple grades that are dependent on the quality of the crude oil used as the source and the type and method of distillation. Mineral spirits also contain VOCs that are released during the evaporation process but have a milder odor than turpentine.

**Additional Components**
Additional components of coatings, both modern and traditional, can include fillers and additives to bulk up the coating, increase gloss formation, speed or slow drying/curing time, increase crosslinking polymerization, facilitate application through the increase or decrease of viscosity, and any number of other properties. Additives and fillers typically make up only a small percentage of the coating formulation and will not be discussed in depth here, except to emphasize that "modern" coatings tend to have several additives and fillers designed to enhance various qualities of the coating. Since the additives are commodity products, paint formulations, even from the same manufacturer, may change over time, resulting in different performance of the coating than an earlier formulation.

**Wood Substrates**
*Wood Characteristics*
Because all wood comes from trees, a basic understanding of tree physiology is essential to understanding the properties of milled lumber and timber. Trees have a protective layer of bark, composed of dead wood cells, surrounding their trunks and branches. Just inside the bark is a very thin layer of cells called the cambium, which creates new wood cells. The new cells created on the inside of the cambium are a zone of living cells referred to as sapwood. Sapwood serves to store the nutrients of the tree and transfer sap up from the roots to the leaves. The size of the sapwood zone varies depending on tree species and the age and size of the tree. At the inner edge of the sapwood there is a transition into the heartwood. Heartwood is not "living" wood in that it is not involved in the transfer of nutrients throughout the tree, but it does contribute to its structural strength. Finally, at the very center of the trunk is the pith, a small core of weak cells generated from the first years of growth.

Under a hand lens or low-power light microscope, the cross section of wood somewhat resembles a bundle of straws packed tightly together. These "straws" are the tubular sapwood and heartwood cells whose long axes run parallel to the long axis of the tree trunk. The cells are made of cellulose and are bonded together by lignin, a cementing substance. The direction of these tubular cells is referred to as the grain of the wood; grain direction is very important to understanding how a piece of wood behaves when subjected to various environmental conditions because the properties of wood, such as shrinkage or swelling, with parallel grain differ significantly from wood with perpendicular grain. Most trees exhibit a pattern of concentric circles when viewed in cross section; these circles are bands of light and dark wood and represent the growth rings of the tree over the course of its life. The dark bands, called latewood, are denser and thinner than the light-colored bands, as they represent the growth of the tree in the fall and winter (Figure 2.1). The light-colored rings are generally much wider than the dark rings and represent the faster growth that occurs in spring and early summer. This earlywood is less dense and weaker in structure than latewood growth.

**Figure 2.1.** Cross section (end grain) of southern yellow pine, showing dark latewood bands.

Most of the exterior wood discussed in this manual will have come from milled wood (the exception may be log buildings). Trees can be milled a number of ways, and each piece of lumber will have different properties based on the orientation of the grain and how it was cut from the log. Varying grain orientation can cause pieces of lumber to behave differently as the wood dries (living trees contain significant amounts of water, and after a tree is cut, the water starts to evaporate). The differential behavior results in distortions or warp, including cupping, twisting, bowing, checking, and splitting. Exterior wood on historic structures may exhibit some or all of these characteristics, as a lack of maintenance can lead to excessive moisture uptake and the associated changes in dimension from shrinkage and swelling. Additionally, the manner in which a wooden element was milled will affect its durability when exposed to wood-deteriorating conditions such as ultraviolet light and cyclic moisture and/or freeze-thaw episodes. There are many sources for additional information on the nature of wood; an excellent reference that discusses the fundamentals of wood physiology is *Understanding Wood,* by R. Bruce Hoadley (2000).

Many historic structures are clad with wood or have exposed wood elements. Typically, wood used for exterior cladding came from local sources. In the southern regions of the U.S., southern pines and cypress were commonly used for cladding and exterior architectural elements, while in the north, eastern white pine, spruce, and firs were commonly used. As settlement progressed across the continent, the pattern of using locally available material continued; western states saw structures constructed and/or clad with Douglas-fir, western yellow pine, cedar, and redwood, to name a few. Older structures are more likely to have a variety of wood species used in their construction, as typically, timber and lumber was sourced on site in the early years of the country. As sawmills become more common-place and transportation passages developed, construction trends allowed for more uniform material, in terms of dimensions and wood species, to be ordered in bulk for framing

and cladding buildings. Thus, while numerous wood species may be used, only the most common are summarized here.

*Southern Yellow Pine*

Southern yellow pine (*Pinus* spp.) is not a single wood species, but rather a group of wood species that possess similar characteristics. Longleaf pine, loblolly pine, shortleaf pine, and slash pine are members of the southern yellow pine species group. Southern yellow pine was commonly used in structural and architectural applications, particularly in the southeastern U.S., and continues to be in use today. It is known for its density and strength, relative to other softwoods. Old-growth timber has a moderate degree of natural durability, that is, it resists some types of deterioration by insects and wood fungi to a moderate degree. The dense, dark bands of latewood that are characteristic of southern yellow pine often cause adherence problems for many types of coatings in exterior applications. Old growth pine used in historic structures tends to have a high extractive content (extractives are naturally occurring chemical compounds that can protect the tree from insect and wood decay fungi infestations) and slow growth rate, leading to wood with fewer grade-limiting characteristics (trees that grew slowly under the canopy of other trees had fewer branches which lead to knots in the wood) and a higher percentage of dense latewood to softer earlywood. Southern pines grown today are generally plantation grown and typically grow very quickly. Plantation-grown timber tends to have a lower overall density, lower concentrations of extractives, and wider growth rings with a higher percentage of earlywood to latewood, as well as more frequent knots and other grade-limiting characteristics.

*Eastern White Pine*

Eastern white pine (*Pinus strobus)* was a common wood used in construction in the northeast during the nascent years of the country's development. Eastern white pine is known for its low frequency of defects, straight grain, lightness, and workability. It tends to cut and tool easily, holds fasteners and glues well, and takes paints and stains well. Eastern white pine was used in both structural and architectural applications. Use of eastern white pine became less common after the turn of the 20$^{th}$ century due to the impact of the white pine blister rust fungus, introduced in the U.S. in 1898. Eastern white pine is still in use today, particularly for interior woodwork

*Spruce*

There are several spruce species (*Picea* spp.) that grow across the U.S. Although the trees display physical characteristics that make it possible to distinguish the separate species, it can be difficult to distinguish one species from another based on microscopic characteristics of the wood alone. They are often placed into either eastern spruce as a group or western spruce, which is primarily Engelmann spruce (*Picea engelmannii*). Spruce is a moderately lightweight softwood with good working characteristics. The wood was historically used for structural members and

architectural elements such as window trim, and sometimes for siding or cladding. Spruce continues to be in use today for window construction and interior woodwork.

*Cedar*

As with spruces, cedars (*Thuja* spp.) are geographically distinct; there is eastern red cedar, incense cedar, and western red cedar, to name a few. Atlantic white cedar, which is actually a cypress, is often included in this category as well. Cedars have not, historically or in modern use, typically been widely used in structural applications, except for niche applications, such as posts in ground contact, due to its natural durability. Cedar is known for its aromatic properties and its high extractive content, which makes it a more naturally durable wood than many others and makes it a more desirable wood for use in exterior architectural applications, where natural durability is of greater importance than applications where the members are protected from moisture and weathering processes. The extractives, however, can make coating the wood difficult, as the chemicals often bleed through paint and opaque stains, leaving yellowish stains on the coating surface. Special primers often need to be used with cedar prior to coating with an opaque finish.

*Douglas-fir*

Douglas-fir (*Psuedotsuga menziesii*) is a tree that grows in the western U.S.; as such, its use in early constructions was limited, and it is not typically found in pre-20$^{th}$ century historic structures in the eastern half of the country. Its use became more widespread following the development of the railroad. Douglas-fir is comparable to southern yellow pine in many respects, but was and is typically used for structural applications rather than architectural, although many architectural elements can be found in the western U.S. Douglas-fir has low to moderate natural durability, takes paints and stains easily and holds fasteners well.

*Redwood*

Redwood species (*Sequoioideae* spp.) include redwoods and giant sequoias. Their native range is limited to the coastal regions of the northwest. Both trees were logged on a massive scale in the late 19$^{th}$ and early 20$^{th}$ centuries. Old growth redwood is highly resistant to decay and insects. Giant sequoias are protected from logging today, and redwood logging activities are restricted, so modern applications are often limited to reuse of existing timbers and exterior woodwork. Redwood is particularly popular for decks today, but was often used for fencing, siding, and shingles. As with cedars, redwood has a high extractive content which can be problematic for opaque coatings unless the proper primer is used.

*Cypress*

Cypress *(Taxodium* spp.) trees include two U.S. species, bald cypress and pond cypress. Cypress are typically found growing in swampy, low-lying areas along the eastern coast. Cypress trees contain an extractive that protects the heartwood from

most types of decay fungi and insects. Old growth trees generally have much higher extractive concentrations than second growth trees, as it takes several decades to build up within the tree. Cypress trees were used historically in structural and architectural applications, but were most commonly used for exterior woodwork such as shingles and siding. Use of cypress is more limited today and generally restricted to exterior, non-structural applications.

**Wood Cut and Wood Quality**

In addition to the wood species having an impact on coating performance, the cut of the wood and the wood quality can also affect how well a coating performs. Wood is an anisotropic material; that is, it has different material properties and physical characteristics depending on the grain orientation. Therefore, the way in which the wood is cut from the log impacts how it behaves, both structurally and architecturally. It should be noted that terminology associated with the type of cut varies considerably, and can be quite confusing. The two primary cuts are flat grain (also called plain sawn and slash grain) and vertical grain (also called quarter sawn, edge grain, and occasionally rift sawn).

*Flat Grain*

Flat-grain lumber is wood that has been cut parallel to the tangential face of the log. This results in a pleasing characteristic "U" or "V" shaped grain pattern on the wide faces of boards and lumber (Figure 2.2). This cut is common because it maximizes the amount of useable material from the log. However, wood shrinks and swells the most in the tangential direction; therefore having large surface areas cut from the tangential faces of logs lead to boards and lumber that tends to cup, crown, bow, warp, and twist more than other cuts. This type of cut reduces the longevity of coatings due to greater shrinkage and swelling of the wood.

**Figure 2.2.** Flat-grained board with typical "U" shaped grain pattern.

*Vertical Grain*

Vertical grain lumber is cut to be as close as possible to the radial face of the log. This results in growth ring bands that are nearly perpendicular to the wide face of the wood and a minimization of tangential wood (Figures 2.3 and 2.4). Vertical grain wood exhibits the least movement in service, and, in some species with strong contrast between earlywood and latewood color, can have a strong, visually appealing striped effect caused by the alternating bands of earlywood and latewood on the wide face. Vertical grain lumber is the most expensive type of cut because it is the least efficient use of the log. Coatings can have difficulty adhering to the dense latewood when applied, particularly for woods such as southern yellow pine with a high ratio of latewood to earlywood. However, if properly maintained, the coating can have greater long-term stability because of the reduced shrinkage and swelling associated with this type of cut.

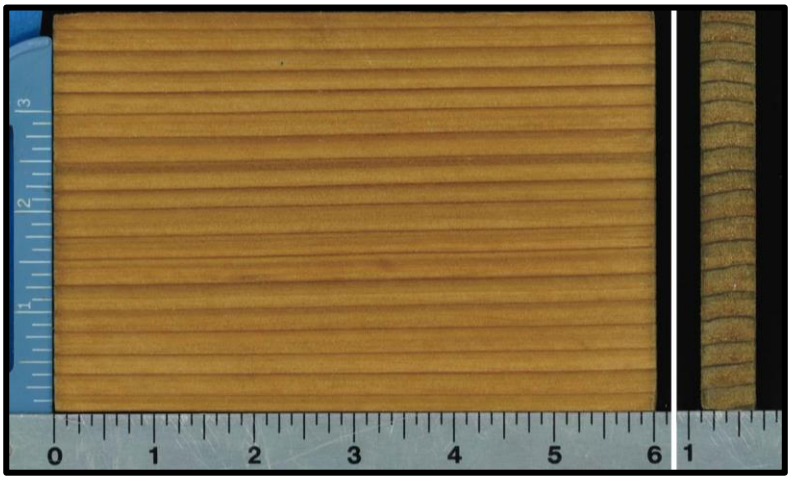


**Figure 2.3.** Vertical grain western red cedar showing the grain pattern on the wide (left) and narrow (right) faces.

**Figure 2.4.** Tight vertical-grained Alaska yellow cedar siding with the wood fibers oriented parallel to the long axis of the boards.

*Wood Quality*

In addition to the wood species and type of cut, wood quality can impact coating performance. In fact, the "nature of the wood [has] as much effect on the durability of the coating as the composition of the paint" (Browne 1954). Knots, bark inclusions, pitch pockets, slope of grain, surface and end checks, and end splits can all have an impact on how well a coating performs.

Knots, which are the remnants of branches, form areas of irregular grain and wood cellular structure that may not absorb a coating in the same manner as the surrounding wood (Figure 2.5a and 2.5b). Additionally, knotwood does not shrink or swell at the same rate as the surrounding wood fibers, thus leading to loose knots, knot holes, or cracks or splits in the surrounding wood fibers. Bark inclusions can behave in a similar manner, and also present rough patches that may be difficult to coat effectively (Figure 2.6). Pitch pockets, which are, as the name implies, pockets of tree sap or pitch that can seep out after coating, can lead to blisters or peeling (Figure 2.7).

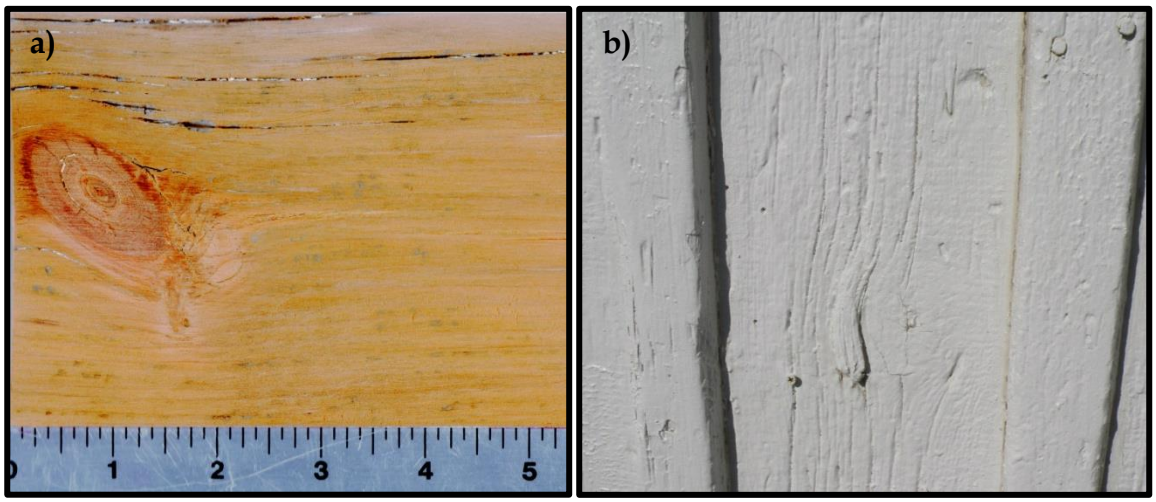


**Figure 2.5a.** An example of a knot on a sanded pine board.
**Figure 2.5b.** A knot that telegraphs through the paint on this board and batten siding.

**Figure 2.6.** Bark Inclusions occur when a bark-covered branch or a separate stem becomes incorporated into the main trunk.

**Figure 2.7.** Although there is no visible evidence of a pitch pocket on the surface of the wood, the sap indicates the presence of one beneath the surface.

Slope of grain is the angle of the wood fibers relative to the long axis of the piece; wood with a high slope of grain tends to exhibit more checks, splits, and movement in service than wood where the grain runs parallel to the length of the piece. Checks and splits, which generally follow the slope of grain, usually develop as wood dries. Checks and splits make it difficult to seal the wood with the coating (Figure 2.8). Wood with splits and checks can allow for moisture intrusion, which in turn will increase movement in service and facilitate the development of additional and deeper checks and splits.

**Figure 2.8.** Slope of grain visible through the painted surface of a beam.

**Plantation-Grown Lumber**

There has been much debate regarding the quality of plantation-grown lumber in comparison to old-growth or second-growth material. In general, plantation-grown lumber available today is grown quickly and the trees are harvested at a relatively young age. For softwoods, a rapid rate of growth results in a greater percentage of earlywood, which is less dense than latewood. This can result in a reduction in strength for structural elements. Additionally, unless pruned, the wide spacing of plantation trees allows for multiple branches to grow. Old-growth and second-growth stands of trees that compete for sunlight in a dense canopy tend to grow vertically with fewer branches. As mentioned above, knots affect the behavior of timber and lumber and can cause issues with coatings. In addition to these issues, the young harvesting age of plantation-grown lumber can impact natural durability, as harvesting the trees at a young age limits the amount of naturally occurring tannins and extractives that accumulate. As a result, plantation grown wood tends to have lower quantities of these naturally occurring extractives and are, therefore, less durable than old-growth wood.

Whether a wood substrate comes from plantation-grown or old-growth timber, proper coating application and maintenance will serve to protect the material and extend its service life. However, preserving existing historic wood substrates may provide additional benefit in that material from old-growth timber tends to have greater natural durability, fewer defects, and will likely perform better under a new coating than more recently harvested material.

# Chapter 3. Historical Background of Coatings for Exterior Wood in the United States

**Early History of Exterior Paints in the U.S.**

While evidence of paints can be found at least 40,000 years ago when people used pigments made from soot and earth with animal fat binders to adorn cave walls, the application of decorative coatings to surfaces may have an even longer history; yellow ochre pigments have been found with human remains that date to 100,000 years ago. And paints have been part of some of the oldest organized societies. Ancient Sumerian cultures produced finely painted pottery, and Egyptian society used paints with animal protein binders to decorate statues, walls, and papyrus texts. Despite the development of the use of pigments and coatings in early human history, however, they remained rare and expensive and were the purview of the upper classes for centuries. With the socio-economic and technological changes that began during the Industrial Revolution, the use of paints and coatings began to become more widespread. In northern Europe, the coating of exterior wood surfaces can be seen as early as 1200 C.E., with popular application of coatings arising in the 1700s for wealthier individuals. In the U.S., the coating of exterior wood surfaces did not become common practice until the 1800s (Moss 1994).

The application of exterior paints became much more common following the Civil War and the founding of Sherwin-Williams Company in 1866. Prior to the development of ready-mixed paints, paints were mixed by hand by craftspeople and were customized to individual structure conditions. Because of this, the quality and performance of the coatings varied greatly. Sherwin-Williams sold the first ready-mixed paint in 1880, but consumers continued to demand, and painters continued to make, customized, hand-mixed paints, until the middle of the 20$^{th}$ century, when the post-WW II industrialization boom and the development of new technologies and marketing strategies allowed for broader cultural acceptance of mass-produced, ready-mixed coatings.

**Traditional Paint Formulations**

During the early centuries of American colonization and in the country's nascent years, private residences and other structures were commonly unpainted on the exterior for decades or longer until expensive pigments, such as white lead, became affordable (Garvin 2001). Most historic white exterior paint formulations in use in the U.S. before the mid-20$^{th}$ century were composed of linseed oil and driers, white lead paste pigment, and were thinned with turpentine solvent. White lead was long regarded as the best white pigment available for use with drying oils. Solvents became more common as petroleum products were developed in the early 20$^{th}$ century and their properties were better understood. Milk paints and rye flour

paints often had linseed oil added to them to make them more durable, but were less commonly applied to building exteriors. The same is true for lime washes, which were used as exterior coatings through the late 19th century, although the popularity of lime washes continued for interior surfaces, particularly in farm buildings in the U.S. until the mid-20th century (Jackson 2011).

Regardless of the formulation, most traditional coatings were designed to be somewhat breathable or permeable. By allowing for moisture to move through the coating and the wood, the coating facilitated rapid drying of the wood substrate. This may seem counter-intuitive to modern thinking, but it was in recognition of the fact that water will, inevitably, penetrate any "impervious" barrier, over time. By maintaining a "breathable" coating, the wood substrate underneath may get wet but can also dry rapidly, without any long-term damage to the coating or substrate. Traditional coatings also were designed to wear away, from the exposed surface inward, over time, with exposure to wind, water, and ultraviolet light. This led to what is commonly referred to as "chalking," as the binder wears away, exposing pigment particles that can be physically wiped from the surface and resulting in a reduction of gloss. Linseed oil paints that chalk, however, could be "refreshed" with a new coat of linseed oil, which would serve to bind the exposed pigment particles to the paint layer as the fresh oil cured. This type of maintenance led to service lives of traditional coatings of 20 to 50 years on wood substrates, in many cases.

It should be noted that many of the traditional coatings discussed here are widely used in northern European and Scandinavian countries where exposure to ultraviolet light is limited. Ultraviolet light causes the breakdown of nearly all molecular substances, and causes embrittlement, yellowing, cracking, softening, and ultimately failure of painted surfaces, whether the coating contains synthetic or organic materials.

**Early History of Exterior Stains in the U.S.**

While the history and development of paints has been well documented, the history and development of exterior wood stains has not been the focus of historical research. One of the first preservative-based exterior wood stains was developed in 1877 by Samuel Cabot, the founder of Cabot stains. This creosote-based shingle stain spurred the development of a new coatings industry – one that sought to protect the exposed wood without hiding its natural characteristics. The use of exterior stains became more common in the 1920s and 1930s as synthetic binders and resins began to be developed, but true growth of the industry did not occur until the post-WW II era (Browne 1954). As more and more post-war era houses become eligible for historic designation, the need for understanding the history, development, and use of early exterior wood stains is becoming a more critical issue in historic preservation.

Because of the reliance on synthetic binders, based on the definitions used in this manual, although there may be historic stains, there are no truly "traditional" stain formulations. There are also the so-called "opaque stains," essentially paints that have rheological characteristics that allow the texture of the wood to show through the paint in a manner similar to the "transparent stains" described above, but have pigmentation that makes them opaque and more protective of the wood that they cover. They are especially popular on horizontal surfaces, such as decks and roofing. (See Cabot Paints literature for more details.)

**The Shift from Traditional to Modern Coatings**

Today, exterior wood coatings represent a huge segment of the home and building construction, maintenance, and home improvement industry. No longer seen as a product requiring special training to apply, exterior paints and stains are marketed as products that can easily and successfully be applied by anyone with minimal knowledge of painting and staining techniques. In today's mass market economy, exterior wood coatings are also marketed for the durability and performance of the coating itself rather than the ability of the coating to protect the wood it covers. This is a critical distinction; for, as discussed above, historic paints typically served as a sacrificial layer that functioned to protect the wood, and as such, performed in a symbiotic manner with the physical and chemical properties of the wood, rather than as a separate physical barrier.

So what caused the shift away from traditional coatings formulations? If they worked so well, why would there be a market for new products? The answer is multi-faceted but is due in large part to the adoption of a culture of consumerism that began with the rise of the Industrial Revolution in the U.S. and became fully entrenched for the majority of American households by the 1950s. Economically, the rapidly expanding industrialization of the country led to the wide availability of durable and consumable goods, while the increased mechanization of the manufacturing world led to the replacement of master craftsmen with semi-skilled or unskilled workers. One of the most obvious impacts of the shift from traditional consumption to consumerism is the appearance of vast quantities of "diverse products and packaging materials – such as paper goods, plastics, toxic chemicals, and synthetics," (Melosi 1981: 191) including those developed as paint and coatings binders, pigments, and solvents.

Although a long series of historical events spanning two centuries led up to the dramatic alteration of the consumption paradigm, the transition near the turn of the 20th century from a relatively closed system of reuse and recycling to an open, unidirectional industrial system where "materials and energy are extracted from the earth and converted by labor and capital into industrial products and byproducts which are sold, and [transformed] into waste" (Strasser 1999: 14) took only a few decades to complete (Strasser 1982). Multiple factors such as advertising, social

acceptance of new behaviors, access to and availability of new goods, and expanding populations encouraged an acceptance of modern consumption practices.

These modern consumption practices included the use of, indeed the demand for, new technologies in all aspects of building and construction. Created in part by shortages generated from the war efforts (both WW I and WW II), new technologies, materials, and products arose that were aggressively marketed as inherently "better" than their traditional counterparts.

The shift away from traditional coating products that were custom-created and applied by skilled tradespeople to mass-marketed, standardized products, was based in part on a shifting cultural ideology that standardized products were more modern, more technologically advanced, more reliable, more uniform or standardized, and therefore, more desirable, than custom-made items, products, or services.

Along with this ideological shift, the building trades became more fragmented and skilled craftspeople and tradespeople were replaced with less skilled workers, exacerbating the growing disconnect between an understanding of the wood substrate and the coating that was intended to protect it. The focus shifted away from preserving the far more costly wood siding to developing a more durable coating. However, this shift came at a cost, as the more durable (i.e., water-resistant) a coating became, the less it tended to work with the natural physiology of the wood substrate, which as a hygroscopic material, is constantly absorbing or releasing moisture to come into equilibrium with the environment.

**An Industry in Transition – Coatings in the 20th Century**

New products developed after the turn of the 20th century included asbestos, fiberglass, and other forms of synthetic insulation. Prior to the 1930s, the use of insulation was rare, and when used, it typically was made from organic materials such as cotton or hemp, which allowed moisture and air to move relatively freely through the wall cavity. Throughout the 1940s, an extensive marketing campaign was established to insulate homes with new synthetic materials which were designed to inhibit air flow. Synthetic insulation in the wall cavities and vapor barriers installed over framing that once was open often served to trap moisture and prevent its dissipation, leading to higher moisture contents of the exterior wood sheathing and subsequent coating failures. Perhaps not surprisingly, widespread reports of exterior paint and coatings failures began to become more prevalent in the 1930s and 1940s (Rose 2005). The poor performance of paint was blamed on poor quality paint and condensation within insulated wall cavities. Intense marketing campaigns that focused on preventing moisture intrusion into wall cavities helped to shift consumer opinion towards the use of pre-mixed paints with claims of higher quality controls, more consistent performance, and more durability than traditional coatings. This also

facilitated the development and use of additional new products such as vapor barriers.

By the 1950s, governmental and marketing campaigns designed to sell moisture control products were well underway, and moisture was campaigned against as an enemy to be defeated. In response to the coating failures of the 1930s and 1940s, manufacturers began seeking to develop coatings that were impervious to moisture penetration; new synthetic resins, binders, pigments, and solvents were also developed that were more water resistant in an effort to limit moisture penetration into the wood siding and the wall cavities. By and large the efforts of the coatings industry were successful, and durable coatings that inhibit moisture flow became the norm. Thus, the long tradition of applying a sacrificial coating to protect and preserve exterior wood surfaces was discarded. In its place came the widespread belief that the best coatings are those that last the longest, and that durability of the coating itself is equated to overall coating performance.

The impact of the Industrial Revolution on the development and application of exterior coatings on wood substrates cannot be overstated. The technological advances that allowed for the production of inexpensive pigments, solvents, and binders, as well as the mass production of these products and the growth of a middle class that could afford to buy such products was critical to the development of the industry. Additionally, the development of re-sealable cans (first patented by Henry Sherwin following his founding of the Sherwin Williams Company), and ready-mixed paints as well as marketing campaigns, encouraged the application of such products. The invention of the hand paint roller in the late 1930s also accelerated the Do-It-Yourself (DIY) trend in coatings use, making hand paint application faster and more uniform than in the past. But the exterior coatings industry also went through a second transition in the decades following the turn of the 20$^{th}$ century. The development of synthetic resins and binders led to the formation of new coatings and products. Further complexity was added to coating a wood substrate when a new industry was emerging that had great implications for the coatings industry - the insulation industry.

As an increasing percentage of the nation's built environment from the post-WW II period is approaching eligibility for local, state, and National Historic Registers, the lack of knowledge by preservationists and building stewards regarding the formulations and suitability of both traditional and modern exterior paints and stains is becoming a significant limitation to properly and economically extending the service life of exterior wood. This is primarily due to the transition away from traditional coatings made from organic materials to increased reliance on modern coatings with synthetic ingredients. While the coatings themselves became more durable, their ability to interact with the wood substrate in a manner that benefited

the wood diminished, and today, there is, generally, little understanding of what an appropriate coating is and how to maintain it.

A common concern for historic preservation practitioners is identifying a suitable exterior wood coating that will perform well over time with minimal maintenance. By considering coatings as a sacrificial layer meant to protect and preserve the wood substrate, the manner in which the chemistry of the coatings and of specific wood species interact has vastly more significance than the durability of the coating itself. Many traditional linseed oil and lead white paints used in exterior applications have demonstrated service lives of 20 years or more (Garvin 2002), while modern coatings typically require reapplication every 5 to 7 years, with the exception of some dark red (barn red) acrylic latex exterior paints, which can provide 15 years of reliable performance when applied to wood properly prepared prior to applying the coating. This is due in part to the UV resistance of the red pigments in the paint; however, it is important to note that some modern coatings can, in less harsh environments, perform nearly as well as lead-based linseed oil paints.

**Introduction of Modern Coatings**

The shift away from traditional coatings occurred for a number of reasons. As previously discussed, the introduction of modern synthetic pigments, binders, and solvents, in conjunction with the rise of the use of synthetic insulation products within wall cavities, changed the moisture relationship between coatings and the wood substrate. Additionally, increased moisture led to the rapid growth of mildew on the surface of traditional coatings. While historically designed to gradually chalk, allowing precipitation to wash some of the coating away and create a fresh, clean appearance, traditional coatings were susceptible to surface blackening of the surface. While this was often attributed to film failure or dirt, the likelihood is that mildew growth and, in some cases, a reaction to exposure of greater levels of air-borne pollution were the cause. This led to the development and addition of mildewcides and other chemicals that changed the coating formulations, as well as a search for synthetic ingredients that could not be used by mildew as a food source.

Simultaneously, as previously discussed, a culture of consumerism was actively being cultivated from the 1920s on – products that were new or used new technology were marketed as better, more advanced, and longer lasting. This culture is still in effect today, as a myriad of new coatings products continue to roll off the production lines and older products disappear. An associated shift in mentality occurred with the rise of a culture obsessed with "new" and "better" technology, one in which the consumer has expectations of product performance based on advertising claims rather than known or observed performance.

In addition to seeking to gain market share with new formulas and technologies, companies sought out a wider market by advertising their products as, "Do It

Yourself" paints claiming to out-perform more expensive traditional coatings applied by experienced craftspeople. If the coating failed prematurely, many consumers would simply buy and apply a new paint product. Subsequently, the knowledge regarding traditional paint durability, and the need for proper application and maintenance was lost as the employment of skilled paint craftsmen declined over time.

One of the mainstays of many traditional and modern exterior wood coatings was the use of white lead and other lead pigments. Lead pigments have been used for centuries and are known for their durability and flexibility over wood substrates. The use of lead pigments in coatings for interior use tapered off in the 1940s, but lead pigments were still used in the U.S. for exterior coatings through 1978. The shift away from lead-based paints impacted coating durability, as lead-white was a pigment exceptionally well-suited for exterior paint applications; thus, the durability of modern coating formulations and many traditional coatings were impacted as alternative pigments had to be found.

# Chapter 4. Identifying Materials and Project Challenges

A fundamental step when initiating a historic preservation project involving coatings is to identify the historic materials, such as the wood substrate and the type of coating on the structure today, as well as what may have been on the structure previously. Additionally, any conditions that need to be addressed prior to maintenance work, repairs, or new construction should be understood. Knowing the materials and conditions prior to undertaking maintenance or construction projects is not only imperative to mitigate the number of change orders, work delays, and ultimately, reduce overall costs, but also is critical to preserving as much historic fabric as possible and making only necessary repairs and/or replacements with in-kind or compatible materials, consistent with the Secretary of the Interior's Standards.

**Identifying the Coating**

Prior to any surface preparation, the existing type of coating, and previous coatings, should be identified. A paint analysis can identify the existing coating and any potential incompatibility issues, which can help to inform decisions on the selection of a new coating. Additionally, identifying the existing coating(s) can identify potential health threats such as lead paint and inform safe handling decisions. Paint analyses are typically used to identify the type(s) of coatings and their ingredients. Conducting a paint analysis therefore can also identify historic color schemes and can sometimes provide information on the construction sequence of additions or alterations, allowing for more informed decisions regarding color selection and historical interpretation.

As lead paint was widely used prior to 1978 when it was banned by the federal government from use in house paints, many historic structures will have lead paint on the exterior. There are a number of inexpensive test kits that can be used to determine the presence of lead in a coating. If lead is found and paint-surface disturbing activities such as sanding are necessary, 2010 federal regulations require that lead abatement must be conducted by an EPA-certified firm for any housing and child-occupied facility. Minor repair and maintenance activities may be exempt. Also in 2010, the EPA issued an advance notice of proposed rulemaking (ANPRM) concerning renovation, repair, and painting activities in public and commercial buildings. A public meeting was held on June 26, 2013 for interested stakeholders. Detailed information on the current regulations regarding lead paint abatement can be found on the EPA website, http://www2.epa.gov/lead.

Regardless of the presence of lead, a paint analysis should be conducted if there are questions regarding the building's historic paint scheme or if there is evidence of coating incompatibility. It is important to identify the objectives for a paint analysis prior to the work being done, so that the scope of work, number and location of samples, and types of analyses that meet project goals (and the project budget) can be determined.

There are numerous approaches to paint analysis, and there is no single methodology that suits every project. A thorough paint analysis may include historical research, in-situ investigation, and laboratory analysis of samples removed from the structure. While it is possible for a layperson to remove samples to be sent to a laboratory for analysis, the preferred approach is to have the samples removed by the professional conducting the analysis. Samples should be removed from areas that have been protected from weathering and possible previous stripping (such as vertical window trim under overhangs or eaves). It is best to remove samples from vertical elements rather than horizontal elements. Sampling techniques and sample sizes vary widely; however, a good approach is to remove a large enough sample (including some of the wood substrate) to allow for ease of handling, color matching, and any microscopic or instrumental analysis. Samples are typically removed with a curved metal blade such as a scalpel. The samples should be labeled during the collection process with typical information including the sample number, building name, building location, name of collector, date of collection, and specific data regarding the actual location of the sample.

The samples are then prepared in the laboratory and viewed under a microscope to identify the individual layers. Generally, each layer is also matched to a color on the Munsell Color System (The Munsell Color System is a scientifically defined range of reference colors based on hue, color saturation, and lightness/darkness). Based on the defined scope of work, a report is generally provided with information on each of the coating layers such as the type of coating, thickness, binders, and pigments, and the corresponding Munsell color, depending upon the identified scope of work. The Association for Preservation Technology International (APTI) has published *Practice Points 06: Architectural Finishes: Research and Analysis* (Krotzer 2008), available at http://www.apti.org/clientuploads/publications/PracticePoints/06-Krotzer.pdf, for more information on paint analysis techniques and determining the appropriate scope of work.

**Identifying the Wood Substrate**

Identification of the wood substrate is a key component in historic preservation projects that involve the reapplication of an existing coating or the application of a new coating. The type of wood, as well as the cut of the wood, can impact coating performance and may have implications for the type of coating selected and coating application procedures as well, as discussed in Chapter 2. Identifying the wood

substrate is also critical for identifying compatible materials for repairs. Material properties vary between wood species and wood will shrink and swell at different rates and to different dimensions with changes in moisture. Different woods also have varying degrees of natural durability (resistance to insects and wood-decay fungi). Although coatings tend to compensate for differences in natural durability, it may be important in situations where the wood is consistently at high moisture contents and where transparent or translucent stains are used. To identify the existing material, small samples need to be removed and should be sent to a wood laboratory for microscopic analysis. Samples can be sent to a number of private consultants for a fee or to a public or government institution such as universities with a forest products program. Typically, institutions that do not charge a fee for species identification may take longer to return results than a consultant or testing laboratory. This should be considered when budgeting and scheduling projects.

Wood samples should be taken from sound wood (without decay) and should measure a minimum of ¼-inch wide x ¼-inch deep x ½-inch long. Larger samples are acceptable and may be preferable in situations where the wood is difficult to identify based on microscopic characteristics alone. The soundness of the wood sample can be determined by rolling it between the fingers; if the wood breaks apart, it should not be submitted and a new sample will need to be taken. To extract a sample, use a sharp knife, craft saw blade, and/or a chisel to make two cuts across the grain of the element (Figure 4.1). These two cuts should be a minimum of ¼-inch deep and ½-inch apart. A specimen can be split out by prying up at one of the incised points with a knife, or if a chisel is used, the edge of the chisel can be placed in one of the cuts and then angled down the grain towards the other cut. A sharp tap with a small hammer should provide enough force to remove a good specimen from the host element. Samples should be taken from an inconspicuous area on sound elements or from pieces that will need to be repaired or replaced. Each sample should be recorded, labeled and bagged separately prior to shipment for analysis.

**Figure 4.1.** Example of a sample removed for species identification. Note that although the wood surface is weathered, the sample consists of sound wood.

**Identifying Project Challenges**
Just as it is important to identify the existing materials, it is equally important to determine the condition of those materials in order to define project goals and establish the appropriate level of intervention with minimal removal or alteration of historic fabric. Identifying the potential causes of the deterioration can help to mitigate future deterioration and is an important foundational aspect of any preservation project.

There are many causes of wood and coating degradation, and often multiple types of degradation can interact to affect the coating and the substrate. Appropriately selected and applied coatings can be effective in preventing or stopping some types of degradation, but only if the cause of the deterioration is identified and addressed. Accordingly, some understanding of the causes of wood and coating deterioration is necessary when considering the need for repair or replacement of wood substrate materials and/or reapplication of an exterior coating. These causes of deterioration are discussed only briefly in this chapter. There are excellent sources of information that can provide greater detail on wood deterioration listed in Additional References.

*Mechanisms of Deterioration - Moisture*
Excess moisture can lead to the failure of film-forming coatings. Moisture sources may stem from the external environment in the form of dew and precipitation. Moisture from exterior sources can lead to cracking, peeling, discoloration and premature paint failure (Cassens and Feist 1988). Water vapor that diffuses from humid interior spaces of a structure through the wall cavity can also cause peeling. Moisture blisters can occur when outside water penetrates wood joints or may result from plumbing leaks, improperly sealed walls, sink or tub overflows, or other interior conditions that allow excessive moisture to enter wall cavities.

While moisture is the most common cause of paint failure (Cassens and Feist 1988), it is not so much a mechanism of deterioration in wood substrates as it is the means for deterioration to develop and progress. A high level of moisture is a requirement for many forms of deterioration and is an integral component of weathering (including freeze-thaw action), decay, and insect attack. Moisture stains are not necessarily an indication of damage to the coating or the wood substrate but do indicate that the element has been exposed to water either repeatedly throughout its life or for an extended period of time.

Moisture can cause nails, screws, and other metal fasteners to rust, which can cause additional staining of the wood and coating (iron stains). Moisture aids in the weathering process by causing wood to swell and shrink, thus generating coating failures in the form of splits and cracks. Additionally, checks and splits in the wood substrate form as the wood fibers expand or contract. Wood substrates and associated coatings that are not exposed to environmental weathering or in contact

with a source of moisture or high levels of ultraviolet light can remain stable for decades or centuries. At moisture contents above 15 percent, the application of new coatings is generally not recommended due to adherence and penetration issues (there is sufficient moisture in the wood to prohibit proper binding and/or penetration of the coating). Existing coating failures in the form of blistering and peeling are likely to occur at moisture contents above 15 percent, and are extremely likely to occur at wood moisture contents above 20 percent. Wood substrates that reach moisture contents of 20 percent or more are at high risk from decay fungi and insect attack. Wood with a moisture content higher than 30 percent has a high probability of active wood decay and insect infestation; coating failure is inevitable if there is prolonged exposure to moisture contents above 30 percent. Note that most coating product manufacturers recommend a wood substrate moisture content no higher than 15 percent (it is recommended to follow the product manufacturer's application instructions) prior to the application of a new coating product.

*Mechanisms of Deterioration - Weathering*

Weathering of wood is the result of the action of cyclic wetting and drying, exposure to ultraviolet (UV) light and erosion of the wood through wind-blown debris (a process similar to sand blasting). Weathering is a long-term process and is a significant factor in the deterioration of wood siding and trim when maintenance has been allowed to lapse and protective coatings have failed or have begun to fail (Figure 4.2); however, weathering affects intact coatings as well. The weathering process can lead to soiling of intact coating surfaces and to erosion and chalking of the coating (Cassens and Feist 1988). Weathering gradually erodes exposed, uncoated wood fibers, but the process is slow enough that exterior woodwork can often survive several decades without a protective coating before beginning to lose serviceability.

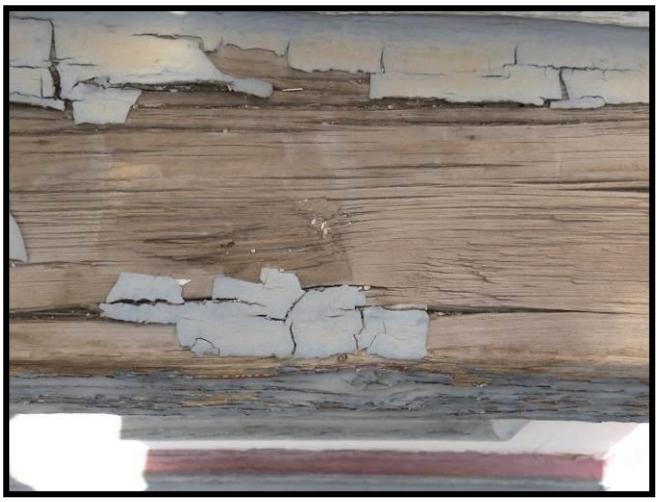

**Figure 4.2.** A window sill with failed paint and gray wood typical from UV exposure and weathering-caused cracks and checks that allow moisture penetration

Weathering is often the primary mode of initial deterioration of exterior wood and coatings in historic buildings, as siding, shingles, and external additions are typically exposed to precipitation and direct UV exposure. Weathering is readily apparent from the dull, chalky, and often cracked or peeling appearance of remaining coatings and the gray and brown surfaces of exposed wood and the small splits that develop during the weathering process.

As noted above, the weathering process consists of cyclic moisture exposure and associated shrinkage and swelling of the wood, coupled with exposure to high levels of ultraviolet light and erosion of the wood by wind-blown debris. Initially, the exposed wood in areas where the protective coating has failed grays or darkens and small seasoning checks and splits begin to develop on the wood surface that allow for moisture penetration. These develop into longer splits due to cyclic wetting and drying of the wood or freeze-thaw action. As moisture is absorbed into the wood, the wood expands, generating more splits and establishing a favorable environment for active wood decay.

In addition to the graying from UV exposure and swelling, shrinking, checking and splitting due to moisture intrusion, wind-blown debris erodes fibers on the exposed wood surface and collects in crevices, inhibiting drying and serving as a growth medium for wind-blown spores and seeds. For intact or partially intact coatings, UV exposure causes colors to fade and breaks down the surface layers of binder, leaving loose pigment particles on the surface, a condition known as chalking. As the weathering process continues, the coating erodes away. Areas of exposed wood experience differential weathering as the lighter-colored, less dense earlywood in the growth rings erodes faster than the darker, denser latewood bands, resulting in a rough surface texture (Figure 4.3).

**Figure 4.3.** Detail of an uncoated wood substrate with erosion of the earlywood due to weathering.

The exfoliation of wood fibers and small pieces of weathered wood exposes fresh wood surfaces to the on-going weathering process. This process is slow and varies by wood species and the amount of environmental exposure. In general, however, architectural wood elements such as low-density siding (such as cedars) can lose up to a quarter inch of thickness per century of exposure, depending on the wood species, if no protective coating remains. In addition to exposure, the weathering rate is greatly influenced by wood density, climate, exposure to the elements, and building elevation. Weathering of the wood over time may enable decay fungi to enter the wood through even minute checks and splits. Eventually, the decay process, which is much more rapid than weathering, will become the dominant means of deterioration.

For many historic structures, the exterior wood elements will have experienced some degree of weathering due to a lack of maintenance of the protective coating (paint or stain). While wood that has decay due to fungus or insects will likely need to be repaired or replaced, weathered wood can remain in service if it meets aesthetic and serviceability requirements and proper surface preparation steps are followed. However, in some cases, weathered exterior fabric will need repair and/or replacement because it cannot meet long-term performance requirements.

*Mechanisms of Deterioration - Mold, Mildew, Lichens, and Moss*

Molds and mildew are types of fungi that do not deteriorate wood substrates or coatings but can cause discoloration of the coating surface and exposed wood surfaces (Figure 4.4). Most molds are green, orange, or black and mildews are typically black; both are powdery in appearance (Levy 1979). Spores can grow very quickly on moist surfaces or on exterior surfaces in very humid conditions. Since the conditions that are favorable for growth of molds and mildews are the same as for more destructive wood-decay fungi, mold and mildew should be considered as warning signs of potential problems but do not necessarily indicate that deterioration of the coating or the wood substrate has occurred. The source of the moisture should be identified and corrected, when possible (such as leaks and moisture intrusion).

Lichens and mosses are two distinctly different types of organisms that are often grouped together when discussing their relationship to exterior wood elements. Lichens are unique organisms that can grow on wood but typically do not harm the wood fibers. Lichens are typically only found on exterior wood elements where the protective coating has failed or no coating was applied (Figure 4.5). Lichens grow from spores and tend to grow very slowly. The fungal components of the lichen do not parasitize living plant cells, degrade wood cells or provide gateways for other pathogens to enter wood fibers (Goerig and Chatfield 2004). Because most lichens are firmly embedded in the substrates, improper forcible removal of lichens can cause significant surface damage to historic wood materials.

**Figure 4.4.** Yellow and white mold growth on an uncoated wood surface.

**Figure 4.5**. Lichens on the surface of a log structure.

Mosses are non-vascular plants that can thrive on a variety of porous, moisture retentive surfaces (Figure 4.6). Mosses grow from spores and require near-constant high levels of moisture to survive. The presence of moss is an indication of a continuous high moisture environment, and the sponge-like composition of the moss traps moisture at the wood surface. If mosses are present on wood elements of a historic building, moisture levels are likely to be very high and decay fungi are probable. Moss can be easily removed with careful cleaning (Figure 4.7), but unless the favorable underlying conditions are altered, the moss will return. Mosses can be controlled by reducing the amount of available moisture and trimming trees and vegetation to increase sunlight exposure to enhance drying.

**Figure 4.6.** Moss growth on a wood substrate.

**Figure 4.7.** Biological growth and weathered patina, both of which can be removed through cleaning, as shown here.

*Methods of Deterioration - Decay Fungi*

All wood is subject to a variety of deterioration mechanisms, the most damaging throughout the U.S. of which is wood-decay fungi. Wood-decay fungi excrete enzymes that break down wood fibers, which can ultimately lead to a loss of integrity and the inability of the wood to perform its intended function. Most wood-decay fungi are only able to grow on wood with a moisture content greater than 20 percent (but require high moisture contents to initiate) and are unable to damage adjacent dry wood (Levy 1979). Evidence of typical decay of wood products can be identified by the dry, cubicle cracking that occurs in the wood substrate and/or by fungal fruiting bodies visible on the wood surface, although other patterns of deterioration can occur (Figures 4.8 and 4.9).

**Figure 4.8.** Deterioration of wood caused by wood-decay fungi.

**Figure 4.9.** Fungal fruiting bodies growing out of a wood substrate.

*Methods of Deterioration - Insects*

Insect attack is generally a minor contributing factor to the deterioration of exterior wood elements throughout the U.S., as most insects seek out wood that has already been compromised by high moisture content levels and wood-decay fungi. However, there are a number of wood-boring insect species that can cause significant damage to historic structure exteriors. In the southeastern U.S. and other humid coastal regions, and some local areas, in particular, insects are more likely to be an issue than in most of the U.S. The diversity of insect species that can damage wood is quite broad. There are four primary wood-boring insect groups: termites, carpenter ants, carpenter bees, and wood-boring beetles. With all of these insect groups, damage from infestations can be identified through a thorough visual inspection that involves close examination of wood elements for bore holes, frass (wood substance removed by the boring action of the insect), mud tubes, and/or live insects or other evidence of wood-boring activity (Figure 4.10). Any suspected infestation should be

handled by a professional exterminator, preferably one with experience in historic preservation.

**Figure 4.10.** Bore holes in a stained column (also with deterioration by wood-decay fungi).

**Identifying the Coating Conditions**

Determining the existing condition of the exterior wood coating and the wood substrate are the first steps in assessing recoating, repair, and replacement needs. A condition assessment starts with a visual survey. Ideally, there is a single condition assessment that includes a simultaneous examination of the coating condition and the wood substrate condition. For explanatory purposes, however, the condition survey processes for the coating and for the wood substrate are addressed separately in this manual.

In general, a visual survey can provide enough information to determine if the coating on the exterior wood elements of a historic structure or building will need to be reapplied, as evidenced by peeling, cracking, or chalking paint, or in the case of penetrating stains, visibly gray wood that lacks stain pigmentation. However, a more detailed inspection of the coating conditions and a paint analysis can provide information on the possible causes of failure (such as moisture intrusion, lack of maintenance, or incompatibility of coatings) as well as reveal the original or historic color schemes.

*Moisture Intrusion Problems*

Cracking, peeling, blistering, staining, mold/mildew growth, and paint failure are all associated with moisture intrusion. Many of these problems are likely to occur at the ends and edges of siding and trim, where the wood end grain can easily absorb moisture (Figure 4.11). A visual inspection should include detailed observations of the siding and trim at the edges of boards, as well as below roof valleys, at structure corners, around window and door ledges, below any upper level projections, along

gutters and downspouts, and any place where rain runoff may make contact with coated wood surfaces (Figure 4.12).

**Figure 4.11.** Coating failure near the end grain in an area where water flowed down the face of the exterior cladding, as evidenced by the moisture stains on the exposed wood.

**Figure 4.12.** Fascia and soffit with failing paint due to moisture absorption.

If areas of blistering and peeling paint are identified in localized areas and an exterior source of moisture cannot be identified, determine if the location is near a kitchen, bathroom, or plumbing line that may be leaking water from the interior of the building (Figure 4.13). Peeling and blistering can occur due to water vapor moving through the walls from the interior, particularly if there is no vapor retarder in place; condensation from inadequately vented attics may also lead to peeling paint up near the top of gable walls (Cassens and Feist 1988) as well.

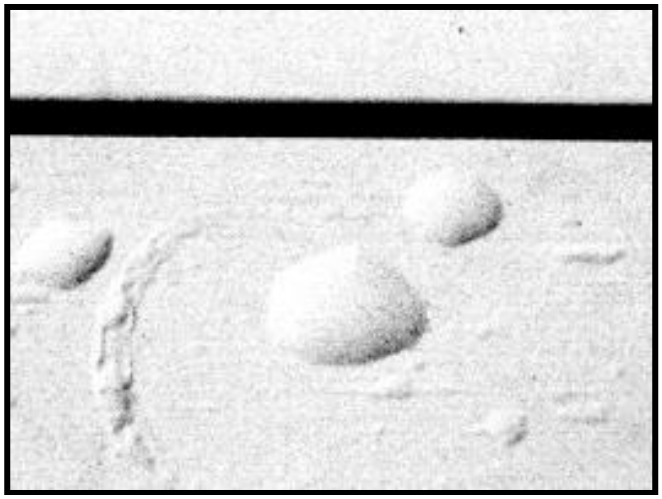

**Figure 4.13.** Moisture blisters in paint. Image from Cassens and Feist 1988.

*Peeling and Cracking*

Peeling from excessive moisture generally includes all layers of paint on a wood substrate, as shown in Figures 4.12 and 4.13 above. Intercoat peeling, where one layer of paint separates from the layer or layers below, is not generally the result of moisture but of a weak bond between coatings (Figure 4.14). This type of peeling can be caused if paint has been applied over heavily soiled or chalky paint without proper cleaning or surface preparation, and may be common on historic structures that have had only sporadic exterior maintenance.

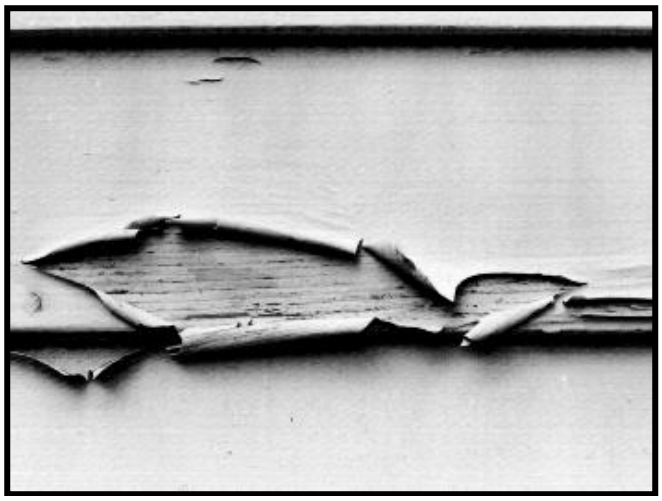

**Figure 4.14.** Intercoat peeling is indicated when older coatings remain adhered to the wood substrate. Image from Cassens and Feist 1988.

Cracking can occur for a number of reasons. Generally, cross-grain cracking, or alligatoring, occurs on historic structures because the paint layers become too thick and brittle and can't expand and contract with the movement of the wood substrate (Figure 4.15). Alligatoring can also occur if paint is applied too thickly in a single

coat, or if a second coat is applied before the first coat has thoroughly dried. Alligatoring is indicative of a failed bond between the wood substrate and the coating(s) and paint that exhibits this type of cracking must be entirely removed and a new coating applied.

**Figure 4.15.** Cracking and cross-grain cracking (alligatoring) of the paint.

*Chalking*

Chalking, as previously described, is the result of the weathering processes of UV exposure and erosion from wind-blown debris. Ultraviolet rays penetrate and break down the binder's cellular bonds and the loose material is either washed or blown away, leaving pigment particles exposed on the surface. The result is a coated surface that is faded and looks and feels chalky (Figure 4.16). This condition can be identified by wiping an area with a cloth or gloved hand; if a dusty, paint-colored residue can be removed, chalking has occurred. Although the wood substrate underneath is still protected from UV exposure, if the coating has begun to chalk its ability to resist moisture has been compromised and recoating the structure is necessary. Proper surface preparation procedures, which will be discussed in the following chapter, must be followed in order to prevent intercoat peeling of the new coating.

A visual survey of the coated surfaces should be conducted to identify areas with peeling, blistering, cracking, and/or chalking. For non-film-forming coatings such as penetrating stains, the primary mechanism of coating failure is weathering, so areas of gray or discolored wood should be identified. Where possible, the causes of the coating failure should also be identified to facilitate decisions regarding repair and replacement. The survey should identify areas in need of complete paint removal and recoating, areas that need only to be cleaned and recoated, areas in need of substrate refinishing and areas in need of substrate repair and/or replacement. Marking these areas on elevation drawings can make project estimates for replacement materials easier and more accurately calculated. Additional information

on visual surveys and paint conditions can be found in numerous online publications such as *Preservation Brief 10* and on the NPS park service website listed in Chapter 1.

**Figure 4.16.** Wood siding and trim with areas of chalking. The splits in the wood are due to overdriven fasteners, not the performance of the coating.

**Identifying Wood Substrate Conditions**

There are a number of resources that identify the procedures and steps for a thorough wood inspection. Included in the Cited References is "Practice Points 03: Basics of Wood Inspection: Considerations for Historic Preservation" (Anthony 2007). Although the article addresses the assessment of structural members, the basic principles of assessment remain the same whether they are for architectural or structural wood elements. The basic steps of a wood condition assessment for architectural wood have been summarized below.

To identify potential problems with the wood substrate prior to repair and the application of coatings, exterior wood elements should undergo a condition assessment survey. A simple, but thorough, condition assessment should include a visual inspection, probing in likely problem areas, and taking moisture content measurements. In general, this work can be done by laypeople; material experts may be called following visual inspections that determine there are problems that will impact the long-term serviceability of the wood with no easily identifiable cause or solution.

Visual inspection, probing, and moisture content readings are sufficient for a preliminary condition assessment of the wood substrate. The tools necessary for a condition assessment survey, other than visual acuity and tactile senses, include a blunt awl and a moisture meter. Awls and moisture meters are relatively inexpensive, easy to use, and exceptionally useful for identifying potential problems. Assessment findings should be recorded in the event that long-term monitoring

efforts may be needed. Elevation drawings are useful for recording assessment findings and for quick-referencing the problem areas.

*Visual Inspection and Probing*

Visual inspection provides a rapid means of identifying areas that may need further investigation and should be the first step in assessing wood conditions. Visual examination allows for identifying components that are missing, broken, under insect attack, or in an advanced state of deterioration due to weathering and/or wood-decay fungi (Figure 4.17). The repair or replacement of missing or severely damaged components that were intended to prevent moisture intrusion into the building envelope may be essential to prevent long-term damage to the structure.

**Figure 4.17.** Missing window sill.

Visual inspection also allows for the detection of current moisture problems as evidenced by the presence of decay fruiting bodies such as mushrooms or white, cottony fungal bodies. The presence of mold, mildew, and/or moss should also be noted, as growth of these organisms is an indication of high moisture content at the wood surface and of environmental conditions that are suitable for wood-decay fungi. Insect activity can also be identified through a visual inspection by identifying the presence of insects, insect bore holes, or wood substance (frass) removed by wood-destroying insects.

Probing the wood with a blunt awl (Figure 4.18) enables rapid detection of voids just below the surface in wood that may not be detectable by a visual inspection alone. A sharp object, such as an ice pick, may easily penetrate even completely sound wood, so it is important to ensure the tip of the probing instrument is rounded and blunt. For architectural woodwork, thicker architectural elements, such as porch or deck columns, wood pilasters, or handrail posts, should be the focus of probing efforts. For thin architectural elements such as siding, probing may not be necessary, and

may damage the surface of the wood, so use of a probe should be judicious, especially in highly visible areas.

**Figure 4.18.** Probing at the base of a porch column with an awl reveals some deterioration.

Internal decay or insect damage in larger wood elements is often hidden by sound-looking wood on the surface but it can be detected when an awl is able to pierce what visually appears to be sound wood. Probing can allow detection of advanced decay, especially in cases where internal voids are present near the surface, and early-stage or incipient decay. Wood without decay has much more resistance to probing due to the higher density and intact internal wood structure of sound wood. Unsound wood or wood with internal voids may sound hollow or dull when tapped on with the awl handle, and wood with significant insect damage or decay below the surface will be easily penetrated.

*Moisture Detection*

Prolonged exposure to moisture can produce undesirable conditions and long-term maintenance issues for wood siding and trim. Excessive shrinkage or swelling, checking, loose fasteners and connections, and decay are typical problems. Moisture content measurements can be taken using a pinless moisture meter at locations where moisture content levels may be elevated, such as near ground level, downspouts, and water spigots (Figure 4.19).

Moisture meters that do not have pins are useful for thin wood elements such as siding and trim. These types of meters, called capacitance meters, provide an average moisture content of the zone penetrated by the electric field generated by the meter. The effective depth of the measuring field ranges from ½ inch to 1 inch, depending on the make and model of the meter. Pinless meters are not as well suited for use on larger structural elements as the electric field cannot penetrate deeply

enough to provide meaningful moisture content measurements for elements greater than two inches in thickness.

**Figure 4.19.** Use of a pinless (capacitance) moisture meter to determine the moisture content of siding.

When taking moisture content readings, the user should be aware of recent precipitation or watering that may affect the reading on damp wood surfaces. Since the internal moisture content is of interest for determining whether conditions are favorable for decay, artificially high moisture content readings due to liquid water on the wood surface can prevent determining the true internal moisture content. If high moisture contents are found, the source and/or cause of the increased moisture should be identified and mitigated prior to any repair work to prevent continued or additional deterioration of the replacement or repaired material.

Once a visual survey of the coating conditions and the wood substrate conditions have been completed, elevation drawings marked with the areas of deterioration can be reviewed by the project team in order to make decisions regarding recoating, repair, and replacement. Material quantities (for coatings or replacement material) as well as labor costs can be estimated with relative accuracy using footage calculations determined from the drawings. Completing a visual survey and documenting conditions are therefore key steps for budgeting as well as for preserving as much historic fabric as possible. These steps are part of the Conditions and Repair Guidelines presented in the Appendix.

# Chapter 5. Developing a Coating and Repair or Replacement Strategy

**Historical Context**
Prior to selecting a coating, it is important to have identified the type(s) and color(s) of coatings used in the past. New coatings and the requisite surface modification necessary for the application of new coatings can significantly impact the appearance of a historic structure and can alter the visual relationship of the structure to the surrounding landscape (Figure 5.1). Therefore, decisions about reapplication of coatings and the repair or replacement of weathered exterior wood must include consideration of the impact such changes may have in terms of historical authenticity and how visitors, tourists, and the community experience the structure.

Additionally, on some historic structures, no coating may ever have been applied, and the application of a coating in such cases should only be considered if loss of the structure will result. In most cases, adherence to the Secretary of the Interior's Standards for the Treatment of Historic Properties is the best practice for preserving historic fabric, context, and historical authenticity.

**Figure 5.1** Weathered cladding from a naturally durable wood species that results in an appearance quite different than if it was painted.

**Understanding the Maintenance Needs for Coatings and Wood Substrates**
It is important to note that there will be costs associated with wood coatings beyond the initial product purchase and application. Painting or staining historic fabric and replacement materials is only one step in extending the service life of the exterior wood and the structure. Coatings and exterior wood elements require regular inspection and maintenance to ensure that moisture issues have been addressed, deterioration is not occurring, and that coatings are performing as expected. When

undertaking a reapplication of a coating or when deciding to repair or replace deteriorated wood material, it is important to budget for long-term maintenance costs as well. This can include supplies for future coatings and disposal costs associated with lead-contaminated material. In today's market, new products are continually under development and production while older products with known performance track records are often discontinued. Be aware of the potential for product discontinuity and ensure the compatibility of any new coating with previously applied ones if they are no longer available. Additionally, some exterior paints and many exterior stains contain toxic chemicals that are under environmental regulations in local jurisdictions. As the U.S. moves towards a greener product marketplace, many of the products currently available may be restricted or banned from use. Project managers and building stewards should be alert for changes in environmental laws that may impact the decision to apply a particular coating to exterior wood.

**Repair and Replacement Options**

There are many reasons for seeking to repair or replace exterior wood elements. Architectural wood elements play an important role in mitigating moisture intrusion into the building envelope and are necessary for preserving the long-term service life of structural wood members, so repairing or replacing elements that no longer perform as necessary can be critical to prevent structural damage. In addition to the protection of structural elements, architectural wood elements are typically a part of the historic fabric and contribute to the historical significance of a structure; repairing as much of the existing fabric as possible may be preferred over replacing material. Following the idea of embodied energy, maximizing preservation of the wood fabric is consistent with the philosophy of a green rehabilitation or restoration project.

*Determining the Need for Repairs or Replacement*

With many historic structures, a lack of maintenance has led to deterioration of the coatings and exterior wood elements. While the reapplication of a paint or stain may seem like a simple issue at first glance, the condition of the wood substrate plays a critical role in the performance and durability of the coating. Therefore, the wood substrate should be assessed for condition (as discussed in the previous chapter) and then a determination of its suitability for continued service must be made (Figure 5.2). In general, weathered wood siding and trim that does not have deterioration, severe surface checks, or splits, can remain in service and can be recoated with paint or a stain with proper surface preparation. However, surface preparation of weathered wood surfaces includes a number of processes that alter the look of the wood, and ultimately, the entire structure, sometimes significantly. Historic preservation goals and objectives relating to the historic visual relationship that the structure has in the landscape and with adjacent structures should be well-defined prior to conducting repairs and reapplication of a coating. Once an acceptable aesthetic and a minimum of performance-related requirements have been identified,

determining the need for repair or replacement can be based on the established criteria.

**Figure 5.2**. Deterioration of the staves of this water tank has resulted in friable wood surfaces that are delaminating. Given the fragile surface condition of many of the staves, repainting is not advised due to the potential damage that could result from removing the existing paint and properly preparing the surface for repainting; instead, replacement material can be painted to match the existing color, and the existing paint allowed to continue weathering.

In structures with little or no insulation, the conditions are generally such that any moisture that gets through the building envelope can dissipate and little, if any, moisture gets trapped in wall cavities. In these situations, weathered siding or siding that has cupped, crowned, or has end splits or through-checks may be left in place, depending on preservation goals for the aesthetics of the structure (Figure 5.3). From a performance perspective, warped siding will allow for more water and/or air intrusion into the building envelope than new siding; however, the open construction in most historic structures and the ability of the water to dissipate may preclude the need for extensive replacement of historic fabric. In cases of adaptive reuse where insulation and vapor barriers are to be added to increase energy efficiency, however, cupped or split siding that allows for moisture intrusion into the building envelope can cause deterioration of the architectural elements and/or structural components and should therefore be replaced rather than repaired or left in-situ. While caulking around new or unweathered wood elements can be beneficial in some instances, caulking weathered or split material is only a stop-gap measure that may serve to trap moisture in the wall cavity rather than prevent it from penetrating into the cavity, necessitating an intensive maintenance program. In most cases, gaps due to wood movement (shrinkage and swelling with changes in relative humidity or moisture absorption), limited deterioration, or splits should not be caulked to avoid additional deterioration of the wood substrate and to avoid potentially more serious long-term damage to underlying structural elements. Similarly, wax-based water

sealers generally should not be applied to historic wood surfaces because the wax interferes with coating penetration and adhesion, and the sealers typically require significant maintenance to provide for continuous protection against moisture intrusion.

**Figure 5.3.** Cupping and splitting of boards on a historic theater building.

*Repairs*

Repairs may vary depending on the type of element and the condition of the element, as well as the functional and aesthetic goals of the project. In some cases, as those discussed above, where the building envelope is not undergoing extensive alterations for improved energy efficiency, it may be acceptable to leave cupped or crowning wood siding in service, provided that the potential air and/or moisture intrusion and maintenance issues are thoroughly understood and are acceptable to the project team, building stewards, and building maintenance staff. In other cases, aesthetic and/or performance concerns may dictate the repair or replacement of historic material.

Typically scarf-joint or other types of wood joint repairs are preferable to butt-joints for both horizontal and vertical elements to increase the gluing surface area and holding power of the repair. Butt joints have square-cut end grain of two pieces of wood that are joined or "butted" up against one another (Figure 5.4). Scarf joints, in their most basic form, involve miter cuts across the end grain so that the two pieces of wood overlap, allowing for a greater cross section of wood to be used as the gluing surface and thus tending to form stronger joints than butt joints (Figure 5.5). However, scarf joints that are not tight will have more end grain exposed to potentially absorb moisture. Attention to the repair details is critical to prevent future problems associated with the repairs. Scarf joints on vertical elements should be angled up and towards the interior of the structure so that water will not be readily absorbed into the joint.

**Figure 5.4.** Horizontal siding with a butt joint. Note the siding has also been face-nailed in an attempt to prevent or minimize cupping. Face nailing tends to lead to board failure, as the wood is forced to move differentially, leading to splits, as shown here.

**Figure 5.5.** Example of a keyed scarf joint in an historic structural timber. Simple scarf joints can be used for architectural elements (courtesy of Douglas Porter, Conservation Associates).

For thicker or larger wood elements, repairs with in-kind replacement (new or reclaimed) material can be spliced to remaining sound wood using a variety of wood joints or a "Dutchman" repair. A Dutchman repair involves removing the deteriorated wood and using wood of the same species, cut, and moisture content to fill in the cut area (Figure 5.6). An epoxy resin or waterproof exterior glue can be used to ensure adhesion between the pieces; however, epoxies tend to inhibit moisture flow through the member and may cause the repair to fail at a much faster rate than if no adhesive is applied if a protective coating is not maintained. Therefore, if moisture issues are not addressed prior to repairs being implemented,

or maintenance is not done after the repairs are made, the likelihood of deterioration occurring and additional repair being necessary are increased.

**Figure 5.6.** A Dutchman repair on an exterior column that had deteriorated in ground contact (courtesy of Douglas Porter, Conservation Associates).

Caulking around window and door openings and repair materials, if necessary, should be completed following the application of a paint primer but prior to coating application to ensure a good adhesion surface. In general, caulk can be applied to new materials and works best filling vertical gaps and horizontal gaps that are protected by an overhang (such as the bottom faces of horizontal siding). **Caulk should not be used to fill weathering checks or splits**, or on exposed horizontal surfaces (such as window sills) as it will fail relatively quickly with UV and/or moisture exposure. Caulk should not be relied upon for waterproofing, as wood movement will invariably cause the bond between the caulk and the wood to fail and can lead to the moisture problems previously discussed. Decisions regarding the use of caulk should be based on the wall cavity construction and the air exchange of the building; a rehabilitation project installing vapor barriers and seeking a low rate of natural air exchange would require a moisture-tight exterior envelope, whereas excessive caulking of exterior clapboards on a preservation project to preserve a seasonally used, un-insulated building may do more harm than good. For additional information on understanding moisture movement, vapor barriers, and air exchanges, see NPS Preservation Brief 39, *Holding the Line: Controlling Unwanted Moisture in Historic Buildings* (Park 1996) available at the NPS website, http://www.nps.gov.

*Epoxy Repairs for Weathered Surfaces*
For heavily weathered window sills or horizontal siding with deep fissures that allow moisture intrusion and debris build-up, an alternative approach to replacement of historic material is to consider an epoxy consolidant and epoxy filler repair. These types of repairs are not reversible and may not adhere to the Secretary of the Interior's Standards for Preservation. However, it may be preferable to replacement in situations where budget limitations prohibit extensive replacement of material or in other cases where it is undesirable to replace the historic material. Epoxy consolidants and fillers can encapsulate old paint, including lead paint, and consolidate weathered or deteriorated wood surfaces to some degree, providing for a more stable surface for the application of new coatings than the weathered or deteriorated wood alone. For heavily weathered surfaces, liquid epoxy consolidants bind the exfoliating wood fibers on the surface together while a thicker epoxy paste is used to fill fissures, cracks, and checks. Once the epoxy cures, it can be sanded or tooled to match any existing profiles. These types of repairs have their drawbacks; epoxy resins are much more impervious to moisture than the untreated wood surrounding them, therefore accelerated deterioration can occur near the repairs as the epoxy acts as a barrier that prevents moisture movement through the wood. Regular inspection and maintenance of the repaired wood is required to prevent additional deterioration due to trapped moisture or a failed coating.

*Linseed Oil Consolidation*
A limited number of long-term studies on the performance of coatings applied to heavily weathered wood surfaces have been completed (Williams et al. 1999; Williams and Knaebe 2000); these studies indicate that oil-modified latex-base coatings containing a low percentage of solids, a low latex/acrylic resin content, and a minimum of 10 percent raw linseed oil can provide exceptional service on weathered wood surfaces (Williams et al. 1999). While the scope of these tests were limited as far as products tested and wood species used as a substrate, some coatings were shown to last 11 years and longer when applied to weathered (but not decayed) redwood or western red cedar surfaces.

Linseed oil molecules are very small, which allow for the oil to penetrate deeply into wood cells, penetrating the cell lumen and even the cell wall. Once absorbed into the wood, cellular structure of the linseed oil fatty acids bonds to the hydrogen bonding sites within the wood cells and displaces water molecules; the curing process of the oil (through cross-linking polymerization) then not only consolidates friable wood cells but also makes the those cells less hygroscopic (Schneider 1980a; Schneider 1980b; Schneider and Sharp 1982). Since the primary failure mechanism of coatings on heavily weathered wood surfaces is adhesion failure between the coating and the wood due to degraded wood cells on the substrate surface, consolidation of the cells and adequate bonding between the coating and the wood can greatly improve coating performance.

Based on research conducted by Williams et al. (1999), coatings being applied to weathered wood should contain no more than 40 percent total solids, no more than 11 percent latex/acrylic resin content, and have a minimum of 10 percent raw linseed oil. Low solid-content allows the coating to act more as a penetrating stain rather than a film-forming finish, which will aid in wood surface consolidation and overall coating performance. Application of raw linseed oil to cleaned weathered surfaces prior to the application of a coating may also be beneficial in consolidating the wood surface, but may contribute to mildew growth (Williams and Knaebe 2000).

**Specifying Repair and Replacement Material**

Repairs and replacements should be made in kind, that is, with wood that is not only the same species but also the same cut and that exhibits similar physical characteristics such as the size and number of knots, grain orientation, and the number of growth rings per inch. Because of the natural variability of wood, repairing and replacing wood with material that matches the species, cut, and physical characteristics serves to limit potential problems with incompatible materials. The moisture content of the repair/replacement material also needs to be similar, as wood will change dimensions until it reaches the equilibrium moisture content (EMC) of its environment. The EMC is the point at which the wood is no longer gaining or losing moisture; in exterior applications, the EMC of the wood is constantly fluctuating based on weather and exposure conditions, but tends to stay in certain ranges based on geographical location. For additional information on the EMC in a specific geographic location, see the document, *Equilibrium Moisture Content of Wood in Outdoor Locations of the United States and Worldwide* (Simpson 1998). **Matching the wood moisture content of replacement material with existing material will prevent excessive differential movement in service and, therefore, improve coating performance.** Replacement wood with high moisture content that is painted or stained before reaching the EMC of the surrounding wood may have paint performance issues, such as peeling or blistering, as water movement (drying) inside the replacement wood is inhibited by coatings. Durability, aesthetics, and movement in service can also vary greatly by wood species; by ensuring that the repair or replacement material is of the same species and that it closely matches the existing material, performance issues tied to dissimilar material properties can be minimized.

Therefore, as mentioned above, proper specification of replacement material should include wood species, type of cut, and limitations on slope of grain (grain angle), growth ring density, moisture content, and knot size ( number of knots). It may be important to consider surface texture; if matching weathered wood, smooth replacement material may be too visually divergent from the existing material to satisfy aesthetic objectives. Replacement wood can be distressed to achieve a similar textural appearance. Similarly for existing material that was rough-sawn or has a

distinct surface texture, replacement material should be specified with a surface texture that is visually compatible.

For wood with a smooth surface, mill glaze on new material can be a problem in relationship to the application of paints and stains. Mill glaze refers to a layer of burnished wood on the surface, caused by the milling process. Wood with mill glaze takes paints and stains differentially and can prevent good coating adhesion. Prior to coating replacement material, the faces of the wood should be lightly sanded to remove mill glaze. Additional information on surface preparation for replacement and historic material can be found in the following sections. Also, please see the Appendix for the Conditions and Repair Guidelines.

**Selecting a Coating**

An appropriate coating should be identified based on the results of the coating and historical analyses, the condition survey, pre-determined project and maintenance requirements, and the preservation goals for the structure. Acceptable color(s), sheen or finish, surface texture, weathering and or aging aesthetics, and maintenance needs are issues to consider prior to making a decision. For opaque, film-forming coatings such as paints, application procedures should also be addressed in order to ensure the tactile and visual impact of the new coatings meet agreed upon standards. Material and application costs, as well as future product availability and reapplication requirements (such as surface sanding or complete removal of the previous coating) should also be considered. Although there is no single strategy for all historic structures, careful consideration of the information provided by historical research, laboratory analyses, and physical investigation, as well as consideration of the project budget, future maintenance requirements, and environmental concerns will allow for solid decision-making regarding product selection. See the Appendix for the Coatings Decision Guideline regarding product selection.

**Application Procedures**

While it is beyond the scope of this manual to document the extensive history of coatings application and testing procedures conducted by private and government agencies, a brief review of proper application procedures is warranted, as marketing claims regarding the performance, durability, and ease of application of new coatings and wood products are continually evolving, and it is easy to be overwhelmed by the sheer volume of information. Virtually regardless of the type of coating selected, certain procedures for surface preparation can ensure a longer service life for the coating and the wood substrate. Federal publications such as those by Cassens and Feist (1988) and Williams and Feist (1999), detail the steps to take to maximize the service life of new coatings on new and existing exterior wood, and it is not the intent of this document to recount or reexamine the myriad of publications on this topic, but rather to summarize the best practices for application procedures from a historic preservation perspective, acknowledging that there may be restraints on a historic

preservation project, such as preserving the weathered texture of exterior cladding, that prevent the full implementation of accepted application procedures.

*Surface Preparation*

As previously discussed, the surface of exterior wood elements is generally weathered from exposure to UV, precipitation, and wind-blown debris and has its own unique texture and patina. If the determination has been made to reapply a coating that has partially or significantly failed, it is imperative to identify preservation goals and, specifically, aesthetic concerns prior to reapplication of the coating. Those goals and concerns should include issues such as planned changes to insulation and/or the addition of vapor barriers, acceptable levels of air or moisture intrusion into the building envelope if historic materials are to remain in place, acceptable surface texture and appearance of new and historic material, and an acceptable planned maintenance schedule. All of these issues can impact the degree and extent of surface preparation and should be carefully considered.

*Paint Removal*

Coatings should be applied to sound wood that is free of dirt, flaking paint, and loose wood fibers. Once a determination of the lead content of any existing paint has been made, appropriate paint removal efforts can be undertaken, if necessary. These steps may include hand-scraping areas of peeling paint, low-grit media blasting of the old surfaces, or the use of infrared heating devices that allow for the softened paint to be scraped from the wood surface. Hand scraping can be completed with a paint scraper available at most paint and home improvement stores. Media blasting should be conducted by a qualified media-blasting contractor with significant experience with historic wood surfaces. Hand-scraping and media blasting should be used judiciously, as existing historic material is likely to be fragile and easily damaged. Media blasting should be limited to sodium bicarbonate, corncob fragments, walnut shell fragments, synthetic sponge material, or similar materials, if suitable. Sand-blasting and pressure washing should never be used on historic wood materials due to the excessive abrasive nature of the process and damage that results to the wood surface. Infrared heating of the painted surfaces is a labor-intensive process that requires technical expertise but is the most sound from a historic preservation and environmental perspective. The primary risk of using infrared heating is burning or scorching the historic wood substrate. In cases where multiple layers of paint have obscured character-defining details of the exterior wood, infrared heating and removal of the paint layers can allow for historic profiles and details to be made visible.

For historic structures with coatings that are generally in good condition and are going to remain on the wood substrate, following the removal of loose and peeling paint (and regardless of the type of paint removal method used), the wood should be sanded with 120-150 grit sandpaper. Bare wood should be sanded until new-looking,

straw-colored wood appears and the gray weathered patina has been removed. On heavily weathered surfaces, removal of the gray wood may not be possible, and extensive sanding may remove a desired "weathered" texture. Intact existing coating areas should be sanded as well, provided that no lead is present in the coating or proper lead mitigation techniques are followed. Sanding bare wood allows for an open grain that facilitates adhesion and penetration of the coating. On wood surfaces with paint remaining, sanding reduces the thickness of the coating in areas where there is a transition to bare wood, which can improve the visual look of the final finish. Typically, this sanding is light enough to be done by hand, as palm sanders can be aggressive and remove too much material, but on flat surfaces, powered sanding may be acceptable. In many cases, to preserve the profiles of siding and trim, sanding by hand is necessary to avoid removing the character-defining appearance of the wood.

In situations where it has been determined to apply a coating to wood that is heavily weathered, sanding, epoxy consolidants and fillers, and/or the repair or replacement of heavily weathered wood may be considered; however, the durability of epoxy repairs in exterior applications has not been documented. If there are budget limitations or if the intent is to recoat the wood but let the weathered texture show through and sanding or repair of the weathered surfaces is not an option, coatings can be applied to the weathered wood substrate provided that the expected decrease in the service life of the coating and the additional maintenance needs are acceptable to the project manager and building stewards. Application of a low-solids oil-modified latex coating containing raw linseed oil or the application of raw linseed oil to cleaned weathered surfaces prior to coating application may help to extend the life of the coating.

To apply a coating to a weathered wood surface, first brush the surface with a stiff natural bristle brush to remove loose wood fibers and debris. Brush across the grain to prevent excessive removal of the less dense earlywood. The surface may be rinsed with water before and after brushing (use low pressure garden hoses only). Do not use a metal bristle brush, as it can gouge soft surfaces and leave metal filings that can negatively interact with water-based coatings. Remove as much of the loose gray wood fibers as possible and ensure the wood is dry before the application of a primer or a stain. Because of the cellular structure breakdown of the wood in the outer few cells, the wood will be extremely porous and absorb more of the primer or stain than new wood; two or more coats may be required. A low-solids coating with raw linseed oil will penetrate the wood surface better than thick, film-forming coatings and provide some consolidation of the wood fibers. When using a pure linseed oil-based paint on weathered wood, it may be beneficial to have one or two coats of linseed oil brushed into the grain prior to paint application.

An accelerated maintenance schedule should be adopted when recoating heavily weathered wood that has not been sanded. Coatings expected to last 5 to 7 years on new wood should be inspected annually for failures following application on weathered wood. Since paints are film-forming finishes, any cracks that develop in the paint surface are an indication that maintenance is required. Moisture content measurements should also be taken on an annual basis to determine if moisture is being trapped within the wood, even if the coating does not show signs of failure. Debris should be cleaned out from checks and splits in the wood. Organic debris holds water against the wood or coating surface and inhibits drying, allowing for a greater opportunity for moisture penetration through the coating. Its removal can play a significant role in extending the service life of a newly applied coating. Reapplication of coatings should be based on an annual assessment of the condition and performance of the coating.

*Priming and Undercoats*

Once the sanding has been completed, it is important to verify that any moisture issues have been mitigated. Recheck the existing wood with a moisture meter to ensure that the sanded wood is dry enough to be coated. Most manufacturers have recommendations on an acceptable moisture content level; generally, it is 15 percent or less. Once any repairs have been made and the surfaces have been sanded, a primer coat should be applied if the repaired area is to be painted. Most stains do not require primer coats. Primers are not compatible with all paints, even from the same manufacturer, so care must be taken to ensure their compatibility. Further, some coating manufacturers claim that their paint can be used without priming (one-coat systems). Despite these claims, however, most research indicates that by priming all the wood faces (including the back face and end grain) of siding, the coating performs better. It is recommended to seal all sides of replacement material (including the back and the end grain) prior to installation. For existing material, prime any bare wood. Epoxy and Dutchman repairs should be completed before priming. Verify that glues have fully dried and any epoxy resins have cured prior to applying a coating. Some epoxy products produce a chemical haze on the surface while curing that will cause coating failure; the epoxy surfaces should be sanded to remove any haze prior to priming. Apply the primer according to manufacturers' directions and ensure that the primer is compatible with the finish coat.

*Brushes and Other Tools for Application*

Depending on the type of coating, the application tools will vary. A close inspection of the existing coating, if it is in good condition, will indicate if it was applied by brush, roller, or sprayed. This can be determined by the pattern or texture of application marks (or lack of application marks, in the case of spray applications). There are natural and synthetic bristle brushes designed for acrylic and oil paints and stains; brush size, bristle length, and stiffness impact the final appearance of the coating, so it is important to use brushes designed for the coating being applied,

including the primer coat, as it provides the foundation for the top coat. Paints for new construction are typically sprayed on; this is not recommended for historic structures as the coatings were originally applied by hand. Paint that is sprayed has a smooth, plastic-like appearance and lacks brush marks, which, while suitable for new construction, generally is not appropriate for historic structures. Additionally, sprayed coatings tend to be thinner than hand-applied coats because of the liquid agents added to the coating mix to prevent the sprayer from clogging. It may be acceptable to spray the primer coat and use a brush to apply top coats, or to spray all coats by using back-brushing or back-rolling. Back-brushing is done to work the paint into crevices and gaps that it does not reach when sprayed. Brush strokes should follow the grain of the wood. For roller applications, select a roller with the appropriate nap based on the surface texture and follow manufacturers' direction for application procedures. See the reference section for additional information on application tools and procedures.

**Weather and Other Conditions**

Because it is not possible to control exterior conditions, when possible, materials should be removed and recoated in an environmentally controlled building or workshop to ensure that the wood is dry prior to application, is fully coated on all sides during application, and allowed to fully dry prior to reinstallation on the structure without the risk of temperature fluctuation, precipitation, or winds that can blow contaminants into the drying coating film. This will ensure optimal paint or stain application. Few historic preservation projects have budgets or timelines that can accommodate such an approach, however. If possible, coating exterior wood should occur on an overcast day with low humidity and little chance of precipitation for a minimum of 72 hours. Avoid temperature extremes and applying coatings in direct sunlight. For more information on weather requirements for application, refer to manufacturer application recommendations and to the reference section of this report.

Coatings applied to horizontal surfaces or to wood elements in ground contact will not perform as well and will fail at an accelerated rate when compared to coatings applied to vertical surfaces or to wood that cannot absorb moisture from the ground. Similarly, coatings on western and southern elevations tend to exhibit more fading, chalking, and weathering due to the higher exposure to UV rays. Coatings in moist climates will exhibit greater tendencies for mildew growth on northern and eastern elevations than those same coatings used in an arid climate.

**Drying/Curing Times**

The time it takes for a product to dry or cure depends on its formulation, the porosity of the wood substrate to which it is being applied, the thickness and number of coatings, and weather conditions. Many acrylic and alkyd-oil coatings are dry to the touch within one hour. Traditional linseed oil paints, however, can take several days

to weeks to fully dry, depending upon conditions. Therefore, if a pure linseed oil paint is to be applied, plan accordingly for the necessary dry times between coats. Applying a second coat before the initial coat has had time to dry can lead to sagging, flashing, and even cracking of the paint. Sagging is evidenced by a coating that has sloughed off the substrate, pulled by the weight of a second coat, because the first coat did not have time to adhere properly. Flashing can result when areas of heavy coating deposition result in inadequate penetration into the wood substrate, leaving shiny, tacky spots on the coating surface. To reduce the occurrence of curing problems, follow the manufacturers' application recommendations.

# Chapter 6. Summary

Historic structures may require unique considerations for the reapplication of paints or stains to exterior woodwork, particularly in cases where the wood has weathered or deteriorated. The Secretary of the Interior's Standards for the Treatment of Historic Properties place emphasis on retaining the historic character of a structure, including distinctive materials, features, colors, and finishes. Accordingly, a careful evaluation of existing conditions should be conducted to determine the appropriate level of intervention (see the Conditions and Repair Guidelines in the Appendix). A paint analysis and species identification of the wood substrate can identify previous color schemes, paint formulations, and the type of wood used for the exterior architectural wood (see the Coatings Decision Guideline in the Appendix). This information can help in historical interpretation, coating product selection, and wood substrate replacement material selection.

For distinctive exterior wood features with severe deterioration, repair or limited replacement is preferred over full replacement. For coatings that remain intact in some areas, limited sanding and recoating is preferred. With all treatment options, new material and coatings should match the old in composition, color, and texture as much as possible, but compatible substitute materials, particularly for coatings, may be acceptable. Using aggressive methods such as mechanical sanding or sandblasting to remove weathered wood or strip painted wood surfaces may remove character-defining features or visually significant weathering characteristics that change the historic visual relationship of the structure with its surrounding environment in a negative way, and should be avoided. Overall, the preservation approach should use the gentlest means possible.

It is also important to note that the Secretary of the Interior's Guidelines are intended to provide general parameters of acceptable and unacceptable work techniques and treatments. Each historic structure is unique and decisions concerning the reapplication of coatings, the type of coating, surface preparation, and the level of intervention (such as repairs to weathered wood surfaces) must be reached by considering the historical significance of the material to be coated, repaired, or replaced, the project goals, the performance and maintenance requirements, as well as the parameters outlined by the Standards and Guidelines. In some structures the Standards and Guidelines must be balanced against the need for energy efficiency, minimizing future maintenance costs, and/or functionality.

Wood coatings are generally grouped into two categories. Opaque, film-forming coatings such as paint provide the most protection to the wood substrate. Translucent, penetrating coatings such as stains that allow the texture and grain of

the wood substrate to show through offer less protection from weathering than opaque finishes. Historically, the use of exterior stains did not become prevalent until the post-WW II era, and the preservation of these finishes has not become a focus of historic preservation work. In contrast, considerable research has been conducted on paint analyses and preservation. The historical performance of exterior stains has not been as widely researched and selecting a compatible, well-performing stain product can be a challenging prospect.

It is important to have some understanding of the causes of coating failure and wood deterioration. Some forms of biological growth, such as mold, may cause no significant damage to coatings or their underlying wood substrates, while decay fungi can cause severe deterioration to the underlying wood. Most wood coatings do not provide protection against decay fungi and wood-boring insects; translucent stains provide minimal protection against weathering from UV exposure, while opaque, film-forming coatings such as paint provide greater protection. Both types of coatings provide a limited degree of protection against moisture absorption.

The potential benefits and drawbacks of coating application or reapplication must also be considered for each project. The potential lead hazard should be addressed when considering old coating removal from exterior surfaces. Additionally, maintenance requirements of coatings, frequency of reapplications, and future product availability can impact decisions on surface preparation and coating application. Coatings applied to horizontal surfaces or to wood elements in ground contact will not perform as well and will fail at an accelerated rate when compared to coatings applied to vertical surfaces or to wood that cannot wick moisture from the ground. Similarly, coatings on western and southern elevations tend to exhibit more fading, chalking, and weathering due to the higher exposure to UV rays. Coatings in moist climates will exhibit greater tendencies for mildew growth on northern and eastern elevations than those same coatings used in an arid climate. In general, coatings should be applied to wood that is dry and does not have visible evidence of surface weathering in order to ensure coating durability.

If extensive weathering has occurred, or if the wood is continually wet due to environmental conditions that have not been addressed, new coatings will not adhere well to the wood substrate. If coatings are to be applied to weathered surfaces, an acceptable compromise between surface preparation and preservation of the historic, weathered wood substrate, and coating performance and durability must be achieved. In the same manner, decisions regarding the repair or replacement of weathered wood surfaces should strike a balance between preserving the visual appearance of historic authenticity while insuring the capacity of the building envelope to protect the structural integrity of the building, at a bare minimum, in addition to meeting energy efficiency and human occupancy comfort needs as well, if relevant.

For most historic structures, the reapplication of a coating to exposed wood surfaces is a consideration when deterioration in the form of peeling paint, weathered wood substrates, or even failures of the building envelope have begun to appear and there are concerns about the long-term serviceability of the wooden elements. If moisture problems and subsequent deterioration were caused by a lack of maintenance, there is generally no need to extensively replace weathered exterior wood elements, unless the maintenance issues cannot be addressed or the project is to be mothballed for a significant period of time. If the structure has drainage conditions that cannot be mitigated, or if there are construction or design flaws that have led to deterioration, the replacement of weathered wood cladding meant to prevent moisture intrusion into the building envelope may be warranted.

Application procedures for paints and stains are critical. Care must be taken to properly prepare the surface of the wood substrate prior to coating application. Surface preparation procedures must consider the potential loss of texture or other historically significant features and should reflect the overall project goals. When specifying materials and products for repairs, it can be beneficial to request samples so that the end product can be compared to the existing finishes and textures. If the project has sustainability or reduced environmental impact goals, the coating should be assessed for sustainability, toxicity, and VOC content, in addition to performance and maintenance. Likewise, the surface preparation and application methods should meet environmental quality standards.

There is considerable technical literature available regarding coatings and coating applications on wood substrates. Some of these resources have been listed in the reference section of this report. Because technologies are always evolving, it may be difficult to find information on new products, however, the preponderance of research conducted over the past 80 years indicates that it is not necessarily the nature of the product but the thoroughness of the surface preparation, sound application procedures, and routine maintenance that allows for a long-lasting protective coating. Therefore, decisions regarding the specific coating formulation are less significant than those regarding the surface preparation, application, and establishing a regular maintenance program.

## Cited References


Anthony, Ronald W. (2007). "Basics of Wood Inspection," Practice Points 03, Association for Preservation Technology International. Available as an electronic document, http://www.apti.org/clientuploads/publications/PracticePoints/03-Anthony.pdf.

Browne, F. L. (1954). "Natural Wood Finishes for Exteriors of Houses." No. R1908. United States Department of Agriculture Forest Service, Forest Products Laboratory, in cooperation with the University of Wisconsin, Madison, Wisconsin.

Bulian, Franco, and Jon A. Graystone (2009). *Wood Coatings: Theory and Practice*. Elsevier Press, Amsterdam, The Netherlands.

Cabot (2013). Electronic document, http://www.cabotstain.com/woodcarecouncil/index.html, accessed September, 2013.

Cassens, Daniel L. and William C. Feist (1988). "Paint Failure Problems and Their Cure," NCR-133, Wood Finishing, Purdue University Cooperative Extension Service, West Lafayette, Indiana. Available as an electronic document, http://www.extension.purdue.edu/extmedia/ncr/NCR-133.html.

E.P.A. (2013). "Lead," electronic document, http://www2.epa.gov/lead, accessed September 2013.

Garvin, James L. (2002). *A Building History of Northern New England*. University Press of New England, Lebanon, New Hampshire.

Goerig, David J., and James A. Chatfield (2004). 10 Things You Should Know about Lichens. *Ornamental Plants Annual Reports and Research Reviews 2004.* Special Circular 195, The Ohio State University Bulletin, Extension Research. Electronic document, http://ohioline.osu.edu/sc195/029.html, accessed June 12, 2008.

Gross, Christie (2013). *Historical Siding Types*. eHow Home, electronic document, http://www.ehow.com/list_6879854_historical-siding-types.html, accessed September 2013.

Hoadley, R. B. (2000). *Understanding Wood: A Craftsman's Guide to Wood Technology*. Newtown, CT: The Taunton Press.

Holley, Clifford D., and E.F. Ladd. (1908). Analysis *of Mixed Paints, Color Pigments, and Varnishes*. John Wiley & Sons, New York.

Jackson, Sarah (2011). *Study on the Durability of Traditional and Modified Limewash.* National Center for Preservation Technology and Training, U.S. Department of the Interior, National Park Service. Electronic document, http://ncptt.nps.gov/blog/study-on-the-durability-of-traditional-and-modified-limewash/.

Krotzer, Dorothy S. (2008). "Architectural Finishes: Research and Analysis," Practice Points 06, Association for Preservation Technology International, available as an electronic document, http://www.apti.org/clientuploads/publications/PracticePoints/06-Krotzer.pdf.

Levy, Michael P. (1979). *A Guide to the Inspection of Existing Homes for Wood-Inhabiting Fungi and Insects*. Department of Housing and Urban Development, Office of Policy Development and Research. Washington D.C.

Maire, Frederick (1908). *Modern Pigments and Ther Vehicles: Their Properties and Uses Considered Mainly from the Practical Side and How to Make Tints from Them*. John Wiley & Sons, New York.

Melosi, Martin (1981). *Garbage in the Cities: Refuse, Reform, and the Environment, 1880-1980*. College Station: Texas A&M University Press.

Moss, Roger W. (1994). *Paint in America: The Colors of Historic Buildings*. John Wiley & Sons, Inc. New York.

Newell, Adnah C. (1940). *Coloring, Finishing and Painting Wood*. The Manual Arts Press, Peoria Illinois.

Park, Sharon C. (1996). "Holding the Line: Controlling Unwanted Moisture in Historic Buildings," *Preservation Briefs 39*, U.S. Department of the Interior, National Park Service, Cultural Resources Heritage Preservation Services.

Park, Sharon C. (2007). "Maintaining the Exterior of Small and Medium Size Historic Buildings," *Preservation Briefs 47*, U.S. Department of the Interior, National Park Service, Cultural Resources Heritage Preservation Services.

Rose, William Browning (2005). *Water in Buildings: An Architect's Guide to Moisture and Mold*. John Wiley & Sons, New York, New York.

Schneider, M.H. (1980a). "Microscopic Distribution of Linseed Oil after Application to Wood Surface," *Journal of Coatings Technology;* 52: 665: p. 64.

Schneider, M.H. (1980b). "Model for Moisture Diffusion through Wood Containing Linseed Oil," *Wood Science;* 12: 4: pp. 207-213.

Schneider, M.H. and A.R. Sharp (1982). "A Model for the Uptake of Linseed Oil by Wood," *Journal of Coatings Technology;* 54: 693: p. 91.

Scott, Winfield G. (1910). *White Paint and Painting Materials: Source and Manufacture; Composition and Properties; Uses and Formulas; Physical Tests and Chemical Analysis*. Chicago; Modern Painter.

Simpson, William T. (1998). *Equilibrium Moisture Content of Wood in Outdoor Locations in the United States and Worldwide*. United States Department of Agriculture, Forest Service, Forest Products Laboratory, Research Note FPL-RN-0268. Available as an electronic document, http://www.fpl.fs.fed.us/documnts/fplrn/fplrn268.pdf

Standeven, Harriet A. L. (2011). *House Paints, 1900-1960: History and Use*. Getty Conservation Institute, Los Angeles, California.

Strasser, Susan (1999). *Waste and Want: A Social History of Trash*. Henry Holt and Company, LLC, New York, New York.

Toch, Maxmillian (1907). *The Chemistry and Technology of Mixed Paints*. D. Van Nostrand Company, New York.

Weeks, Kay D., and David W. Look (1982). "Exterior Paint Problems on Historic Woodwork," *Preservation Briefs 10*, U.S. Departement of the Interior, National Park Service, Cultural Resources Heritage Preservation Services.

Williams, R.S. and Mark Knaebe (2000). "Restoration of Severely Weathered Wood," *Journal of Coatings Technology* 72: 902: pp. 43-51.

Williams, R.S. and William C. Feist (1999). *Selection and Application of Exterior Stains for Wood.* Madison, Wisconsin: U. S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Williams, R.S., P. Sotos, and W.C. Feist (1999). "Evaluation of Several Paint Systems on Severely Weathered Wood," *Journal of Coatings Technology* 71: 895: pp. 97-102.
Weeks, Kay D., and Anne E. Grimmer (1995). *The Secretary of the Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring, and Reconstructing Historic Buildings.* U.S. Department of the Interior,

National Park Service, Cultural Resource Stewardship and Partnerships, Heritage Preservation Services, Washington, D.C. Electronic document available, http://www.nps.gov/history/hps/tps/standguide/index.htm.

## Additional References

American Society of Civil Engineers (1982). *Evaluation, Maintenance and Upgrading of Wood Structures: A Guide and Commentary*. New York: American Society of Civil Engineers.

Avarami, E. C. (1993). *Preserving Wood Features In Historic Buildings, An Annotated Bibliography,* U. S. Dept. of the Interior, National Park Service, Washington D. C.

Center for Wood Anatomy Research, Forest Products Laboratory, USDA Forest Service (Date Unknown). *Wood Identification Procedures*. Madison, Wisconsin. Electronic document, http://www2.fpl.fs.fed.us/WoodID/idfact.html, accessed July 24, 2008.

Chicora Foundation, Inc. (2008). *Whitewash*. Electronic document, http://www.chicora.org/whitewash.pdf, accessed July 24, 2008.

Davison, A. D. and R. S. Byther (1999). Algae, Lichens and on Plants. Pacific Northwest Plant Disease Control Handbook. p. 39.

Desbenoit, Brett, Eric Galin and Samir Akkouche (2004). Simulating and Modeling Lichen Growth. *Eurographics* 23:3.

Feilden, B. M. (1994). *Conservation of Historic Buildings*. Oxford, Boston: Reed Educational and Professional Publishing Ltd.

Feist, William C. (1990). Outdoor Wood Weathering and Protection. In *Archaeological Wood: Properties, Chemistry, and Preservation*, edited by Roger M. Rowell and R. James Barbour. Advances in Chemistry Series 225, Symposium papers from the 196th National Meeting of the American Chemical Society, Los Angeles, California, September 25-30, 1988. American Chemical Society, Washington D.C. 1990, pages 263-300.

Forest Products Laboratory, Forest Service and U.S. Department of Agriculture (2000). *Wood Handbook: Wood as an Engineering Material*. Washington, D.C.: U.S. Government Printing Office.

Myers, John H., revised by Gary L. Hume (1979, revised 1984). Preservation Brief No. 8: *Aluminum and Vinyl Siding on Historic Buildings: The Appropriateness of Substitute Materials for Resurfacing Historic Wood Frame Buildings.* National Park Service, U.S. Department of the Interior.

Old House Web (2008). *Termites, Ants and Other Wood-Destroying Organisms*. Electronic document, http://www.oldhouseweb.com/stories/Detailed/10324.shtml, accessed August 9, 2008.

Ridout, B. (2000). *Timber Decay in Buildings: The Conservation Approach to Treatment*. London; New York: E & FN Spon.

Soller, Jon (2005). *Resolving Common Epoxy Issues & Problems*. Soller Composites. Electronic document, http://www.sollercomposites.com/images/Resolving%20Common%20Epoxy%20Issues.doc, accessed November 29, 2008.

Swearingen, John (2004). *Le Décor – St. Astier Lime Paints*. GreenHomeGuide. Electronic document, http://www.greenhomeguide.com/index.php/product_detail/422/C134, accessed July 6, 2008.

Watts, Anthony (2007). *Bad Paint Job = Rising Surface Temperatures Part 2: A Test of Wood Surface Temperatures Related to Paint*. Electronic document, http://www.norcalblogs.com/watts/2007/05/bad_paint_job_rising_surface_t.html, accessed May 23, 2008.

Weaver, M. E. and F. G. Matero (1997). *Conserving Buildings: Guide to Techniques and Materials*, *Revised Edition*. New York; Chichester; Weinheim; Brisbane; Singapore; Toronto: John Wiley & Sons, Inc.

Wikipedia (2008a). Linseed Oil. Electronic document, http://en.wikipedia.org/wiki/Linseed_oil, accessed November 28, 2008.

Wikipedia (2008b). Tung Oil. Electronic document, http://en.wikipedia.org/wiki/Tung_oil, accessed November 28, 2008.

Williams, R. S., M. T. Knaebe and W. C. Feist. (1996). *Finishes for Exterior Wood: A Comprehensive Guide to the Painting/Staining and Maintenance of Homes, Decks, Log Structures and More*. Madison, Wisconsin: U. S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Williams, R.S. and William C. Feist (1999). *Water Repellents and Water-Repellant Preservatives for Wood*. Madison, Wisconsin: U. S. Department of Agriculture, Forest Service, Forest Products Laboratory.

# APPENDIX

**Secretary of the Interior's Standards for the Treatment of Historic Properties**

**Condition and Repair Guidelines**

**Coatings Decision Guideline**

## Secretary of the Interior's Standards for the Treatment of Historic Properties

The Secretary of the Interior has published voluntary standards (the Standards) for the preservation, rehabilitation, restoration, and reconstruction of historic properties. The Standards provide a philosophical framework for responsible preservation practices for all historic resource types (Weeks and Grimmer 1995). The Secretary of the Interior's Guidelines for Preserving, Rehabilitating, Restoring, and Reconstructing Historic Buildings (the Guidelines) apply specifically to structural resources (buildings), and were developed to facilitate the application of the Standards. The Guidelines provide recommended work treatments and techniques that are consistent with the Standards. The Standards are based on four treatment options for historic buildings. The four treatment options are Preservation, Rehabilitation, Restoration, and Reconstruction. The Standards differ for each treatment option, and the subsequent Guidelines vary as well. Use of wood preservatives and/or pressure-treated wood as repair or replacement material may or may not be an acceptable work treatment depending upon the treatment option.

The Standards for each treatment option have been reprinted below. The Guidelines have been summarized to reflect the suitability of coating removal and/or reapplication, and wood substrate repair and/or replacement within each treatment option. Full Guidelines can be found on the National Park Service website (www.nps.gov/index.htm).

*Standards for Preservation*

- A property will be used as it was historically, or be given a new use that maximizes the retention of distinctive materials, features, spaces, and spatial relationships. Where a treatment and use have not been identified, a property will be protected and, if necessary, stabilized until additional work may be undertaken.
- The historic character of a property will be retained and preserved. The replacement of intact or repairable historic materials or alteration of features, spaces, and spatial relationships that characterize a property will be avoided.
- Each property will be recognized as a physical record of its time, place, and use. Work needed to stabilize, consolidate, and conserve existing historic materials and features will be physically and visually compatible, identifiable upon close inspection, and properly documented for future research.
- Changes to a property that have acquired historic significance in their own right will be retained and preserved.

- Distinctive materials, features, finishes, and construction techniques or examples of craftsmanship that characterize a property will be preserved.
- The existing condition of historic features will be evaluated to determine the appropriate level of intervention needed. Where the severity of deterioration requires repair or limited replacement of a distinctive feature, the new material will match the old in composition, design, color, and texture.
- Chemical or physical treatments, if appropriate, will be undertaken using the gentlest means possible. Treatments that cause damage to historic materials will not be used.
- Archeological resources will be protected and preserved in place. If such resources must be disturbed, mitigation measures will be undertaken.

The Preservation treatment option is based on an assumption that the historic features of a building remain essentially intact. The primary goal of the Preservation approach is to retain historic fabric through maintenance and repair work; replacement of historic fabric should be minimized.

*Standards for Rehabilitation*

- A property will be used as it was historically or be given a new use that requires minimal change to its distinctive materials, features, spaces, and spatial relationships.
- The historic character of a property will be retained and preserved. The removal of distinctive materials or alteration of features, spaces, and spatial relationships that characterize a property will be avoided.
- Each property will be recognized as a physical record of its time, place, and use. Changes that create a false sense of historical development, such as adding conjectural features or elements from other historic properties, will not be undertaken.
- Changes to a property that have acquired historic significance in their own right will be retained and preserved.
- Distinctive materials, features, finishes, and construction techniques or examples of craftsmanship that characterize a property will be preserved.
- Deteriorated historic features will be repaired rather than replaced. Where the severity of deterioration requires replacement of a distinctive feature, the new feature will match the old in design, color, texture, and, where possible, materials. Replacement of missing features will be substantiated by documentary and physical evidence.
- Chemical or physical treatments, if appropriate, will be undertaken using the gentlest means possible. Treatments that cause damage to historic materials will not be used.
- Archeological resources will be protected and preserved in place. If such resources must be disturbed, mitigation measures will be undertaken.

- New additions, exterior alterations, or related new construction will not destroy historic materials, features, and spatial relationships that characterize the property. The new work shall be differentiated from the old and will be compatible with the historic materials, features, size, scale and proportion, and massing to protect the integrity of the property and its environment.
- New additions and adjacent or related new construction will be undertaken in such a manner that, if removed in the future, the essential form and integrity of the historic property and its environment would be unimpaired.

The Rehabilitation treatment is similar in many respects to the Preservation treatment option, except that it is assumed that the historic fabric does not survive intact and that more repair and some replacement of material will be necessary. Rehabilitation also allows for alterations and additions for modernization and alternate uses.

*Standards for Restoration*

- A property will be used as it was historically or be given a new use which reflects the property's restoration period.
- Materials and features from the restoration period will be retained and preserved. The removal of materials or alteration of features, spaces, and spatial relationships that characterize the period will not be undertaken.
- Each property will be recognized as a physical record of its time, place, and use. Work needed to stabilize, consolidate and conserve materials and features from the restoration period will be physically and visually compatible, identifiable upon close inspection, and properly documented for future research.
- Materials, features, spaces, and finishes that characterize other historical periods will be documented prior to their alteration or removal.
- Distinctive materials, features, finishes, and construction techniques or examples of craftsmanship that characterize the restoration period will be preserved.
- Deteriorated features from the restoration period will be repaired rather than replaced. Where the severity of deterioration requires replacement of a distinctive feature, the new feature will match the old in design, color, texture, and, where possible, materials.
- Replacement of missing features from the restoration period will be substantiated by documentary and physical evidence. A false sense of history will not be created by adding conjectural features, features from other properties, or by combining features that never existed together historically.
- Chemical or physical treatments, if appropriate, will be undertaken using the gentlest means possible. Treatments that cause damage to historic materials will not be used.

- Archeological resources affected by a project will be protected and preserved in place. If such resources must be disturbed, mitigation measures will be undertaken.
- Designs that were never executed historically will not be constructed.

In contrast to the Preservation and Rehabilitation treatment options, the intent in Restoration is to return a building to its appearance at its most historically significant time period. Restoration allows for the removal of historic fabric that does not date to the period of significance and allows for the replacement of missing features from the restoration period.

*Standards for Reconstruction*

- Reconstruction will be used to depict vanished or non-surviving portions of a property when documentary and physical evidence is available to permit accurate reconstruction with minimal conjecture, and such reconstruction is essential to the public understanding of the property.
- Reconstruction of a landscape, building, structure, or object in its historic location will be preceded by a thorough archeological investigation to identify and evaluate those features and artifacts which are essential to an accurate reconstruction. If such resources must be disturbed, mitigation measures will be undertaken.
- Reconstruction will include measures to preserve any remaining historic materials, features, and spatial relationships.
- Reconstruction will be based on the accurate duplication of historic features and elements substantiated by documentary or physical evidence rather than on conjectural designs or the availability of different features from other historic properties. A reconstructed property will re-create the appearance of the non-surviving historic property in materials, design, color, and texture.
- A reconstruction will be clearly identified as a contemporary re-creation.
- Designs that were never executed historically will not be constructed.

The Reconstruction treatment option is applied when it is necessary to re-create a building that no longer exists. Similar to Restoration, the intent is to build a structure that accurately depicts the original building in its most historically significant time period. This treatment option is undertaken only rarely and has extensive documentation requirements.

The suitability of new coatings and the repair or replacement of architectural exterior wood is determined by the treatment philosophy being applied to a specific building and by the Guidelines. It is important to note that the Guidelines are intended to provide general parameters of acceptable and unacceptable work techniques and treatments. Each historic building is unique and decisions concerning coatings and the repair or replacement of exterior wood elements must be reached by considering the

historical significance of the material to be coated, repaired, or replaced, as well as the parameters outlined by the Standards and Guidelines.

**General Principles for all Treatment Options**

Although the four treatment options vary in intent and expressed goals, there are some basic tenets. Retaining the historic character and maximizing the retention of distinctive materials, features, spaces, and spatial relationships is integral to all of the treatment options. Another common theme is that the evaluation of existing conditions to determine the appropriate level of intervention is essential. For distinctive or character-defining features with severe deterioration, repair or limited replacement should be undertaken rather than full replacement (see Figure 5.2 as an example). For all treatment options, new material should match the old in design, composition, color, and texture as much as possible, but compatible substitute materials may be acceptable, particularly if the original coating is no longer permitted for public health reasons. No matter the treatment option being followed, chemical or physical treatments, if determined to be appropriate, must use the gentlest means possible. Additionally, for all treatment options, archaeological resources must be protected and preserved in place or, if they must be disturbed, appropriate mitigation measures must be followed.

**Rehabilitation-Specific Criteria**

The Rehabilitation treatment option is the most commonly applied and is the only approach that allows for alterations and additions to be made. Because of this, Rehabilitation has special criteria relating to additions and alterations. New additions, exterior alterations, or related new construction must not destroy historic materials, features, or spatial relationships that characterize the property, and new work must be distinguishable from the historic. Additionally, the results of new work must be compatible with the historic materials, features, size, scale and proportion, and massing to protect and retain the integrity of the property and the environment.

## Condition and Repair Guidelines

1. **Determine the historic status of the structure**. If it is eligible for listing on the National Register of Historic Places or other state or local registries, work with a state or local historic preservation officer to define the project goals and scope of work.

2. **Define project goals. Work with project team leaders to identify the goals of the project, the scope of work, budget, and project timeline(s).**
    a. Identify which Secretary of the Interior's Standards Treatments the project falls under (Preservation, Rehabilitation, Restoration, or Reconstruction).
    b. Identify if the existing coating, color, texture, and/or weathered appearance is considered a defining feature of the structure.

3. **Determine existing conditions.**
    a. Conduct a visual inspection of the existing coating and wood substrate.
    b. Take moisture content measurements in suspect locations and record results.
    c. Record locations of bare, weathered wood, areas of deterioration (including missing elements, elements with decay, elements with through-splits, deep checks, cupping, warping, or insect damage).
    d. Identify potential causes of deterioration (problems with gutters, downspouts, plumbing leaks, inadequate attic venting, improper flashing details, sprinklers that spray the structure, poor drainage conditions, etc.).

4. **Determine existing materials.**
    a. Conduct a lead test to determine the presence of lead in the existing coating.
    b. Remove samples from elements in need of possible repair or replacement for wood species identification.
    c. Conduct a paint analysis to determine existing and previous paint formulations, historic colors, and/or possible construction sequences.

5. **Conduct any mitigation work necessary to allow for recoating, repairs, and replacements to be completed, including repair of conditions leading to excessive moisture and insect mitigation, if necessary.**

6. **Identify if modifications are going to be made to the wall assembly, e.g., will a vapor retarder or insulation be added for improved energy efficiency?**
    a. Yes – vapor barriers and other changes to the wall assembly that substantially decrease the air exchange rate of the building require

building envelopes that are as moisture tight as possible. All cladding or siding and trim with through-splits, holes through the element, or warping (cupping, twist, or crowning) that result in gaps greater than what can be effectively caulked should be replaced. Horizontal elements with deep surface checks should be replaced or repaired with epoxy consolidants and fillers. If the existing color, texture, and/or weathered appearance is considered a defining feature of the structure, additional analyses should be conducted to determine a suitable structural solution that allows the historic material to remain in place without compromising the integrity of the structural members or leading to accelerated deterioration of the exterior cladding and trim elements.

b. No – cladding and trim with through-splits and warp may remain in service if it meets aesthetic standards as determined by the project goals.

7. **Determine the appropriate level of intervention, guided by project goals.**
    a. If the desire is to maintain the texture of the weathered wood, even under a protective coating, replace only elements that can no longer perform as intended (e.g., elements that are missing, broken, or deteriorated due to wood decay fungi and/or insect activity). Choose partial replacement or repair over total replacement where possible. Clean wood surfaces thoroughly and remove loose wood fibers with a stiff, natural bristle brush. Remove all loose (peeling, cracked, chalking) coating material. Hand-sand surfaces without excessive removal of surface texture, where possible.
    b. If the desire is to reduce the maintenance needs and extend the maintenance cycle, remove all loose paint using appropriate methods, and sand all exposed, weathered wood surfaces to expose fresh wood (using care not to remove any character-defining profiles or details). Replace all weathered materials with deep surface checks, through-splits, or excessive movement, or knot holes, or repair using epoxy consolidant and filler.

8. **Repair and replace with in-kind material**. Specify the wood species, moisture content, cut, ring density, and desired surface texture for replacement material. Request samples of the material and verify with project team members that it meets quality and aesthetic standards before repairs are conducted.

9. **Identify weather conditions for the projected coating timeframe and insure that temperatures, relative humidity, and wood moisture content meet manufacturer's specifications.**

10. **Conduct recoating activities.**
    a. Prime bare wood surfaces following manufacturer's directions and recommendations using a primer compatible with the selected paint.

Prime all surfaces (front, back, end grain) where possible. Use application techniques suitable for the texture and final appearance as identified in Project Goals.

b. Apply a selected coating following manufacturer's directions, using application techniques suitable for the texture and final appearance as identified in Project Goals.
c. Ensure proper dry times are accounted for.

11. **Record products and materials used, application techniques and procedures, companies and/or individuals involved in the coating application process.** Label and store any unused coating products in sealed containers in a climate controlled environment.

12. **Conduct routine maintenance on an established schedule.** Include visual inspection of coating performance to identify and mitigate issues that may impinge on long term coating performance.

## Coatings Decision Guideline

**After identifying existing conditions, coatings, project goals, and conducting necessary repairs and replacements, it can often be overwhelming to identify a suitable coating product to apply. While the goal of this project is not to recommend one type of coating product over another, these guidelines have been provided to help direct the decision-making process.**

1. **Determine coating formulations compatible with the existing coating.** Use the coatings analyst, technical representatives with prospective coating companies, and other consultants, such as the project architect, to provide recommendations.

2. **Identify climatic conditions.**
    a. Structures in areas of high relative humidity or that are shaded with heavy surrounding vegetation growth will need to consider products with mildewcides in their formulations, or determine acceptable maintenance cycles to remove mildew build-up.
    b. Structures in areas with exposure to high levels of UV radiation will need to consider products with ingredients that provide protection from ultraviolet light degradation and that resist fading.

3. **Identify project goals.**
    a. Sustainability and a reduction of environmental impact? Look at green products and environmentally sustainable traditional paint formulations that meet the requirements identified in steps 1 and 2.
    b. Historical authenticity and color/luminosity/texture reproduction? Look at traditional paint formulations, if applicable, that meet the requirements of steps 1 and 2.
    c. Minimization of maintenance? Look at modern formulations that meet the requirements of steps 1 and 2.

4. **Identify a coatings craftsperson with expertise in the selected coating**

5. **Identify a project timeframe favorable for recommended application and dry times**