DETERIORATION IN HISTORIC AND ARCHAEOLOGICAL WOODS FROM TERRESTRIAL SITES

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ABSTRACT

Wood buried in terrestrial sites or exposed to the environment is rapidly degraded by microorganisms. In addition to decay by fungi and bacteria, nonbiological processes also deteriorate wood. Archaeological wood that survives for long periods is found in environments that protect it from decomposition. Although decay processes are restricted, these woods are rarely free from attack. This paper reviews the types of deterioration associated with historic and archaeological woods from a number of terrestrial sites including Anasazi great houses approximately 1000 years old in New Mexico, USA; ancient Egyptian tombs; an 8th century, B.C., tomb found in Tumulus MM (Midas Mound), at Gordion, Turkey; and historic wood from huts built on Ross Island, Antarctica, and Ellesmere Island in the Canadian High Arctic between 1881 to 1911 by the early explorers of the North and South Polar regions. Soft-rot fungi were the major cause of wood decay in all of the woods examined. These fungi tolerated adverse environmental and substrate conditions and were able to cause extensive decay in many of the woods examined. Decay by brown-rot fungi was also found and was often associated with termite or other insect damage. In addition to microbial decay, a chemical defibration of wood was found associated with high salt concentrations. This type of attack occurred in woods from the Antarctic, Anasazi

great houses, and ancient Egyptian tombs, and is more prevalent and damaging than was previously realized.

INTRODUCTION

Wood and other organic matter will deteriorate over time from microbial decay and nonbiological degradation processes when exposed to the environment. In most temperate and tropical areas, wood decomposes rapidly, leaving little to no evidence of the original substrate. In some environments, however, wood is protected from biological and chemical attack and may remain relatively unaltered. But even in the most extreme environments where microbial growth is restricted and nonbiological deterioration processes are limited, wood can deteriorate. Over long periods, microbes that are able to grow in adverse conditions degrade the wood, and various compounds, such as salts, cause a slow chemical deterioration. Most, if not all, historic and archaeological woods have been affected to some degree by degradation.

Archaeological woods that survive the many forms of biological and chemical deterioration are extremely valuable resources since they can provide important information about past cultures. These woods can also be used to obtain accurate dating of materials from a site by dendrochronology observations (Schweingruber, 1993), determine where objects have originated by tree species identification (Tennessen et al., 2002) and provide information on past environments by examining chemical and biological signatures that have been left in the wood (Blanchette, 2000; Blanchette et al., 1994; Filley et al., 2001).

Most archaeological woods are found buried in saturated soils or peat bogs in a waterlogged condition. The major factor responsible for protecting the wood from decay in these environments is reduced oxygen concentrations (Blanchette, 2000). Oxygen is needed for aerobic microbes to grow and limited oxygen concentrations impede microbial colonization and decay. It is very rare, however, for oxygen to be completely excluded in these environments and for wood to be completely free from attack. Many investigations have demonstrated that different types of degradation and varied microbial successions occur in wood when it is buried and waterlogged (Bjordal et al., 1999; Blanchette et al., 1990; Singh et al., 1990). Archaeological wood may also be found in other terrestrial environments that are not waterlogged. In these situations, extremely dry environments, cold temperatures, or other types of adverse conditions have limited the rate and extent of wood deterioration taking place. Currently there is little information available on the microorganisms or degradation processes occurring in these situations. This paper provides an assessment of the types of deterioration that have been found in historic and archaeological woods from several different terrestrial (nonwaterlogged) environments and gives insights to better understand the decay processes that affect these woods. Information on wood deterioration is important in helping to develop appropriate conservation methods so that these valuable cultural resources can be preserved. It is also becoming increasingly important for developing successful methods of in situ preservation when wooden objects are reburied or preserved at the excavation site.

MICROBIAL WOOD DECOMPOSITION

Moisture is essential for microbial decay to take place, and there are few natural environments where there is no moisture. Even in buried tombs from arid regions some moisture is usually present, allowing selected microbes to grow and progressively degrade the wood. In addition to moisture, many other factors influence microorganism growth, such as temperature, pH, nitrogen, and other nutrients (Eriksson et al., 1990). Favorable conditions allow rapid colonization by fungi and fast decomposition, but unfavorable conditions usually cause other organisms that tolerate the extreme environmental conditions to dominate. The type of wood and presence of extractives within the wood cells also influences decay. Woods from cedar, juniper, cypress, redwood, and oak are more resistant to microbial decay than are pine, birch, beech, aspen, and other woods that have fewer extractives (Zabel and Morrell, 1992).

When microorganisms decay wood, they cause distinct morphological and chemical changes that are signatures of the causal organisms. Examination of the patterns of microbial attack can reveal what type of organism was responsible and provide a great deal of information on the current condition of the wood. Under aerobic conditions, fungi are the primary decomposers of wood. Fungi that cause wood decay have been classified into broad categories of white, brown, and soft rot based on the color and texture of the residual wood after decay (Blanchette, 1998; Eriksson et al., 1990). White-rot fungi are common wood degraders in forest ecosystems and have the capacity to produce extracellular enzymes that degrade all cell wall components. The type of enzymes produced and the sequence of their production govern the amount and extent of cellulose, lignin, and hemicellulose degradation from wood. Some species are very efficient degraders of cellulose while others degrade extensive amounts of lignin without significant cellulose degradation (Blanchette, 1991). Different forms of white rot result when cell wall components are degraded from the wood in varying amounts. Although white-rot fungi are some of the most prevalent wood-decaying organisms in nature, they are not commonly found attacking archaeological wood. Another group, brown-rot fungi, are common wood degraders in forest ecosystems and are frequently found attacking wood in service (Zabel and Morrell, 1992). These fungi preferentially degrade the polysaccharide components of wood and do not degrade appreciable amounts of lignin. During incipient stages of decay, extensive depolymerization of cellulose occurs, resulting in significant losses in wood strength properties. As decay progresses, cellulose and hemicellulose are removed, leaving a highly lignified and recalcitrant woody residue. Brown- and white-rot fungi are taxonomically placed in the Basidiomycota.

Soft-rot fungi are classified as Ascomycota and Deuteromycota and can be distinguished from other decay fungi by decay patterns they produce in wood (Blanchette, 1998; Nilsson et al., 1989). Typically, soft-rot fungi produce cavities that spiral within the secondary wall of wood cells following the microfibrillar orientation of cellulose (Type I attack) (Daniel and Nilsson, 1998). In transverse sections of wood, holes of varying sizes can be observed in the secondary walls, whereas in radial or tangential sections they are elongate cavities, often with pointed ends. In some woods, a different form of attack occurs (Type II attack) and the entire secondary wall is gradually eroded, leaving a relatively intact middle lamella. Soft-rot fungi are often associated with waterlogged woods, and the term soft-rot is used because the affected wood surface appears soft in wet environments. Soft rot can also occur in nonwaterlogged conditions and the advanced stages of decay appear brown and crumbly and may look similar to brown-rotted wood. Soft-rot fungi are often found in environments that are not conducive to the growth of brown- and white-rot fungi. Since soft-rot fungi can completely degrade the entire secondary cell wall, they have the capacity to degrade some lignin as cellulose and hemicellulose are metabolized. The highly lignified middle lamella, however, is not degraded and persists even in the most advanced stages of decay.

Bacteria are commonly found in wood and may be associated with decay fungi or act as scavengers to utilize previously decomposed substrates. They may also be primary degraders of wood in wet environments. Some bacteria are restricted in their capacity to degrade only the pit membranes of wood cells while other types can directly attack the cell wall. Three major groups of wood-destroying bacteria have been identified—erosion, tunneling, and cavitation bacteria. Since these types of bacterial degradation are most prevalent in waterlogged woods and have not been identified from relatively dry terrestrial sites, they will not be discussed in detail. For reviews on bacterial degradation of wood see Blanchette (2000), Blanchette et al. (1990), Daniel and Nilsson (1998), and Singh and Butcher (1991).

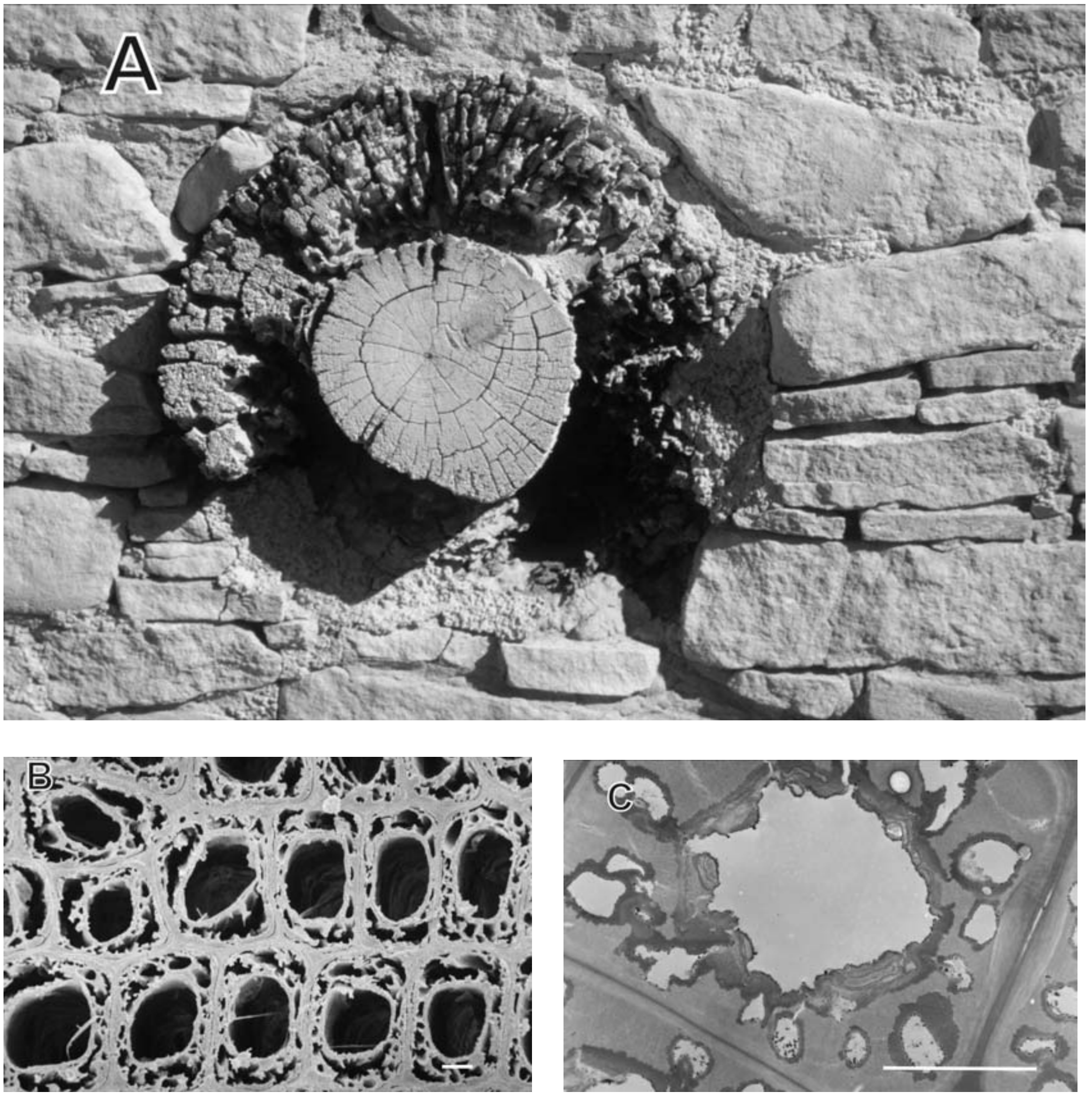
DECAY IN ARCHAEOLOGICAL AND HISTORIC WOODS

Wood from Anasazi Great Houses

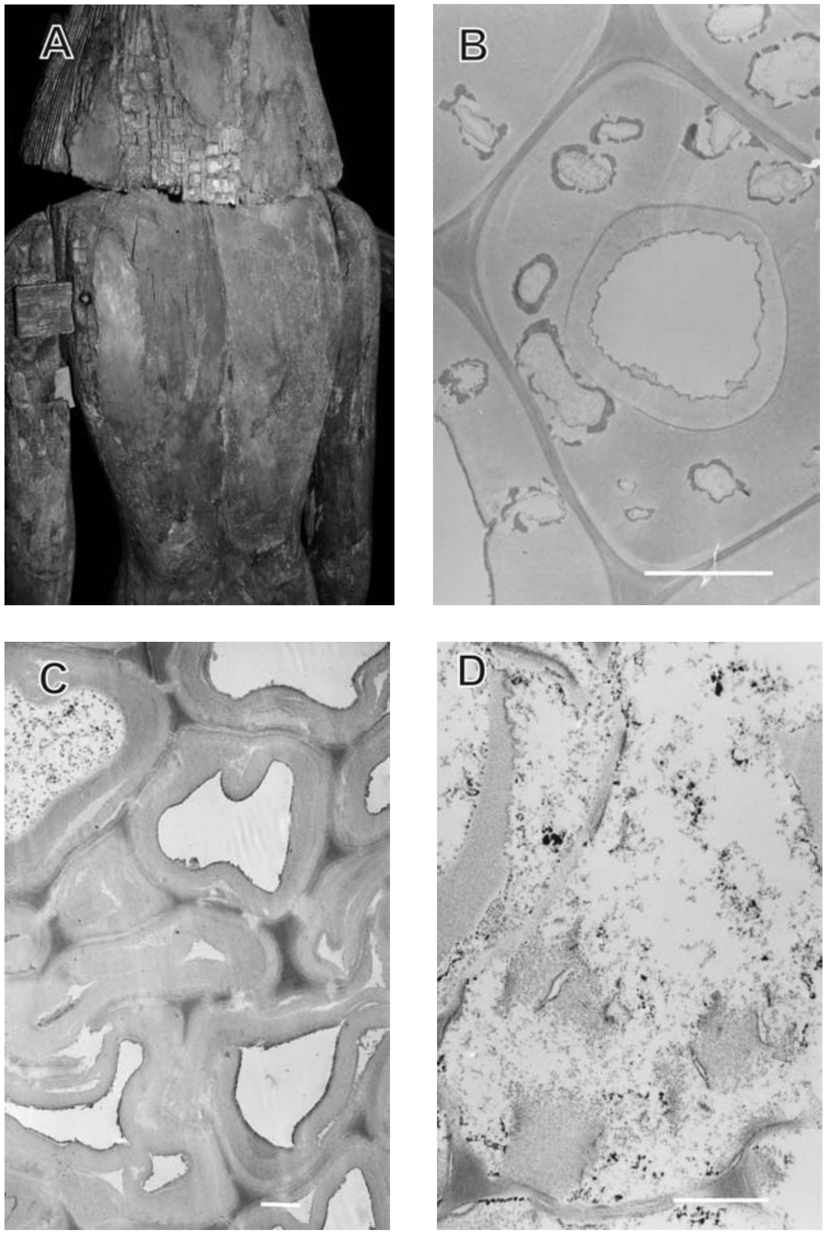
The Anasazi of northwestern New Mexico built great houses approximately 1000 years ago using enormous amounts of wood from a variety of tree species. In Chaco Canyon, it is estimated that tens of thousands of trees were used for roof beams, secondary support materials in roofs, and door and ventilator lintels to build Pueblo Bonito, Pueblo del Arroyo, Chetro Ketl, and other great houses that are now part of the Chaco Culture National Historic Park (Windes and McKenna, 2001). In Aztec Ruins National Monument, located approximately 80 km north of Chaco Canyon, the West Ruin currently has about 6000 pieces of exposed wood (Tennessen et al., 2002). Most excavations of the great houses were done in the late 19th and early 20th century. After these excavations, mud brick walls and a large amount of wood that remained in the structures were exposed to the environment. Although the San Juan Basin is an arid region of the southwestern U.S. receiving only about 20 cm of annual precipitation, exposed wood has deteriorated, and over the past 8 to 10 decades all woods have had some degree of degradation present. Soft-rot fungi caused the major type of decay found in wood from Aztec Ruins and Chaco Canyon great houses. The ends of beams in the great houses showing cracks and what is usually considered to have characteristics of general weathering were found to have typical Type I soft-rot attack [FIGS. 1A-C]. Wood that visually appeared brown with cracks and checks was also found with decay typical of soft-rot fungi. This occurred in samples of Douglas fir, pine, juniper, cottonwood, and aspen. In cottonwood or aspen a Type II attacked was observed. Some brown rot was evident in a few wood samples from these sites and appeared to be associated with dry land termite damage. Since the mud brick and wood have continued to deteriorate in many of the excavated great houses, the U.S. National Park Service is currently reburying large sections of the structures as a method of preservation. The effect of reburial on reactivation of extant fungi in the wood and on the potential for new decay fungi to colonize and attack the wood is not known and needs investigation.

Ancient Egyptian Wood

Archaeological woods from different ancient Egyptian tombs in the Nile Valley were examined to determine the major types of deterioration present. A previous publication has provided a detailed assessment of decay in many different archaeological woods from Egypt (Blanchette et al., 1994) and selected examples are used here to compare the various types of deterioration observed with those found in other terrestrial sites. All of the sites are from the arid Nile Valley region, although some moisture was undoubtedly present during the time the wood was in



[FIGURE 1] Soft rot in wood from Anasazi great houses. [A] Exposed beam from Chetro Ketl, a great house that is part of the Chaco Culture National Historic Park, New Mexico showing wood decay. [B] Scanning electron micrograph of a transverse section showing soft rot cavities within secondary walls of wood cells. [C] Transmission electron micrograph of a transverse section with soft-rot cavities inside the secondary wall. Bar = 5µm.



[FIGURE 2] Decay associated with wooden objects from ancient Egyptian Tombs. [A] Wooden Statue from the tomb of the scribe of Mitry, Saqqara 2340 B.C. (currently in the Metropolitan Museum of Art 26.2). (B TO D] Transmission electron micrographs of transverse sections showing characteristics of soft rot [B] and brown rot [C AND D]. [B] Soft rot Type I cavities within the secondary wall. [C] Cells degraded by brown rot fungi are swollen and appear porous. [D] A residual cell structure disintegrated into minute particles after brown rot attack. The brown rot fungus degraded the cellulose leaving severely altered cell walls that had very little strength. Bar = 5µm.

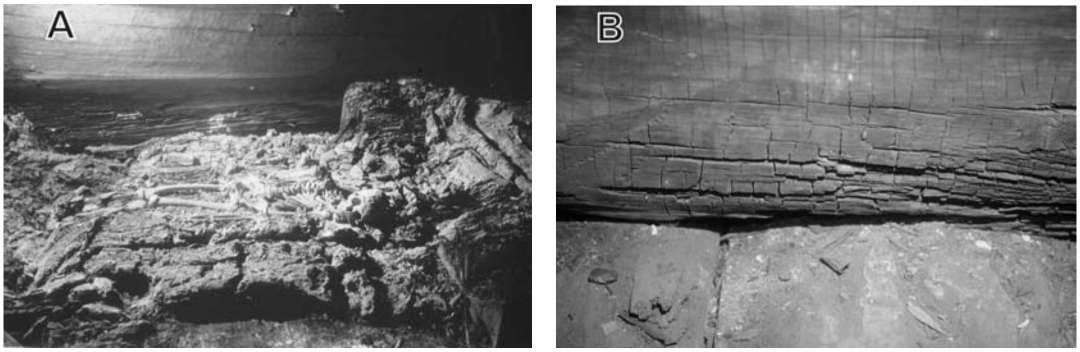
the various tombs. Evidence of insect damage on some of the objects provides further evidence that the tombs were not completely sealed off from outside influences. In wooden statues from Saqqara (2340 B.C.), two types of decay were found [FIGS. 2A-D]. A brown rot was present in the lower parts of some objects in areas that appeared to be in contact with the floor and lower walls of the tomb chamber. The decay caused extensive damage and resulted in severe weakening of wood strength. Transverse sections of the affected wood showed swollen and porous cell walls that were extremely weak. The entire cell wall often collapsed and disintegrated into minute particles. This decay represented a very advanced stage of brown rot with little cellulose remaining. The residual cell walls were made up of only a loose matrix of lignin that maintained little of the original wood's strength properties. The decay, however, was localized to certain parts of the object, with relatively sound wood, or wood with soft rot, present in other areas. In these wooden statues and other objects examined, brown-rotted wood was associated with sites of termite or other insect damage.

Soft rot (Type I) was also evident in many objects examined [FIG. 2A]. Visually, the decay resembled brown rot and appeared brown with checking occurring in the dry wood; however, microscopic examination indicated that a soft-rot fungus caused the decay. Various stages of soft rot were observed, with some cells exhibiting extensive cavity formation while others had only a few cavities within the secondary walls [FIG. 2B].

The environment of some tombs was conducive to brown rot attack by basidiomycetes, indicating that sufficient moisture was present and conditions were appropriate for this type of decay fungus to colonize and degrade the wood. The associated insect damage indicates that the tomb and burial site were not free from outside influences, and termites and other insects entering the tomb could have vectored the decay fungi. The ability of insects to enter the tomb suggests that avenues for additional moisture may also have been present. The presence of soft rot on upper regions of statues [FIG. 2A] or other wooden objects not in direct contact with the tomb floor suggests that micro-environmental conditions in these areas may not have been conducive to brown-rot degradation and fungi tolerant of reduced levels of moisture (soft-rot fungi) were most prevalent.

Wood from Tumulus MM

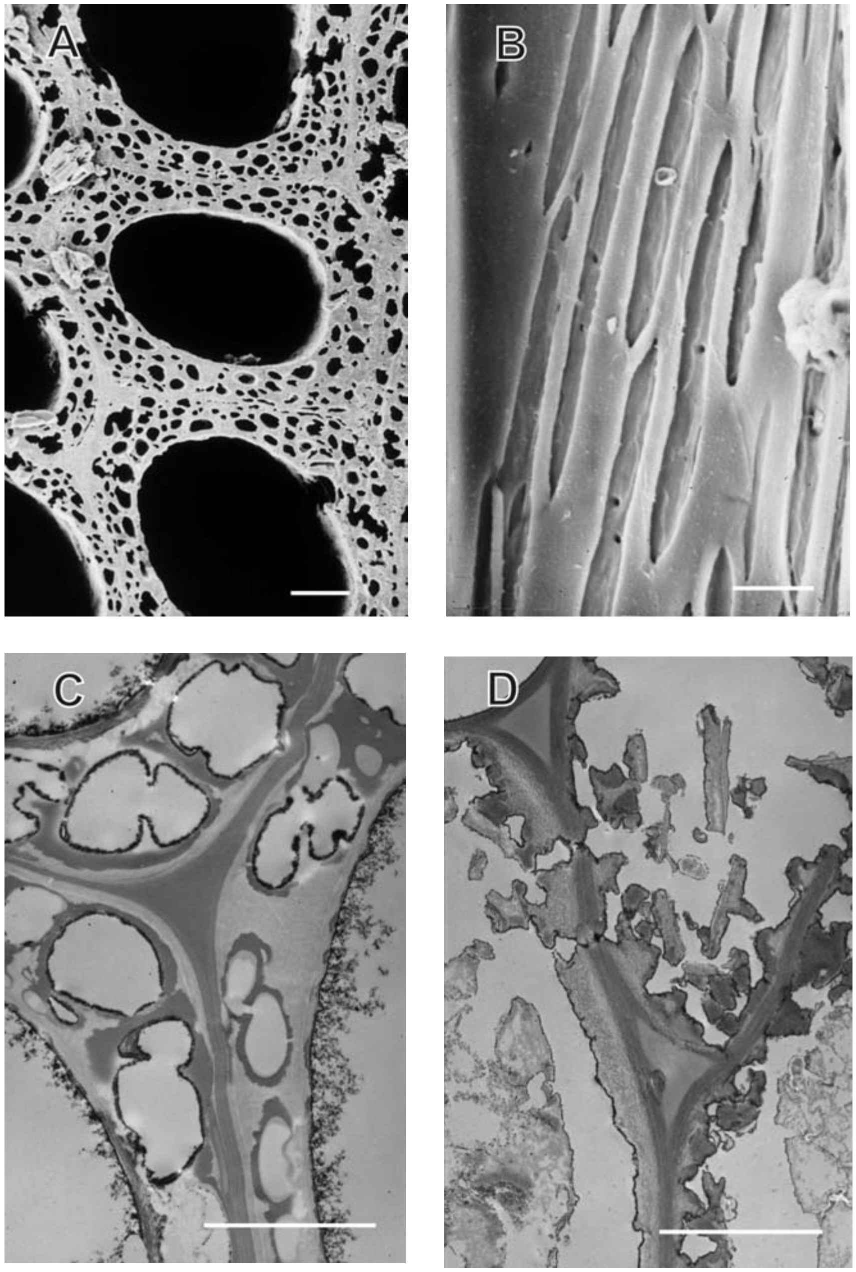
Tumulus MM (Midas Mound), built in the 8th century B.C., is thought to be the tomb of the Phrygian King Midas. An inner wooden funeral chamber was made from pine and cedar timbers and an outer tomb structure consisting of large-diameter juniper logs surrounded it (Young, 1981). After the king was placed in the tomb it was covered by limestone rubble, a dome of clay, and 53 m of limestone-rich earth. When excavated, the wooden tomb was found to contain magnificent



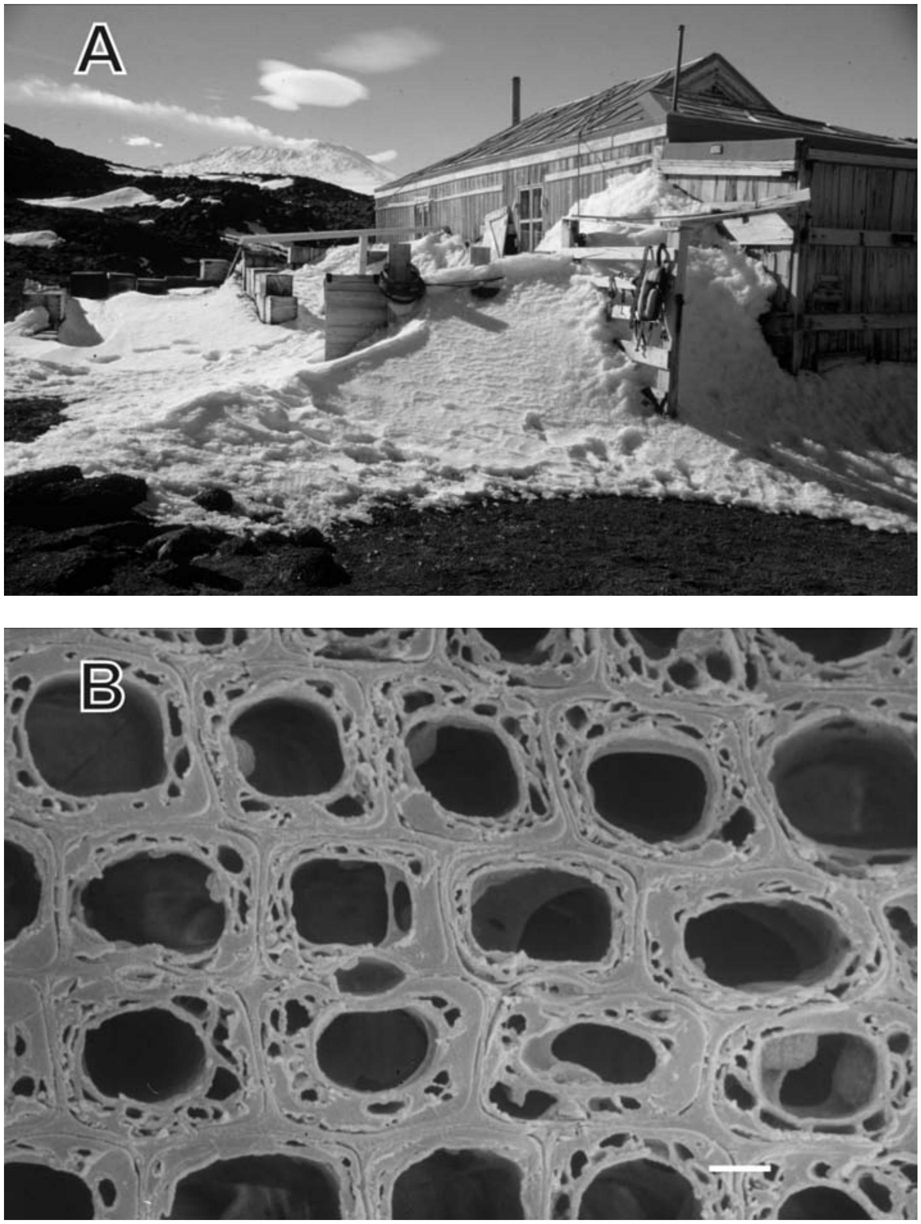
[FIGURE 3] Wood decay in the Tumulus MM Tomb, Gordion, Turkey. [A] The King's remains can be seen on the severely degraded cedar coffin within the wooden tomb chamber. [B] The lower wall and floor shows decay by soft rot fungi. The decayed wood appeared brown with numerous cracks and checks.

furniture, a coffin with human remains, and many other cultural properties (Simpson and Payton, 1986).

Investigations of decay in the wooden tomb structure, furniture, and coffin indicated that only a soft-rot type of attack was present throughout the tomb [FIGS. 3A-B]. The decay was extremely advanced and micromorphological examination showed Type I soft rot within cell walls of all woods examined [FIGS. 4A-D]. In transverse sections, the secondary wall contained an extraordinary number of cavities [FIG. 4A]. Often cavities were observed to coalesce, forming larger voids in the cell walls. The numerous holes present in the secondary walls resulted in very weak cells that were found to easily fragment [FIGS. 4B AND D]. In longitudinal sections, the soft-rot cavities were often clearly evident [FIG. 4B]. The furniture made primarily from boxwood and walnut also had cell walls with Type I soft-rot attack. The degradation, however, had progressed to such an advanced stage that most of the secondary wall was often completely removed, and decay resembled that of Type II soft rot. The environmental conditions within the tomb over the past 2700 years were dry, but leachate from alkaline water seeped into the tomb chamber through the limestone overburden. This moisture could have come from clay placed over the tomb when the tumulus was built or from other natural sources. Apparently, the conditions within the tomb were not conducive to white- and brown-rot fungi, but soft-rot fungi, able to tolerate the low moisture and alkaline conditions, caused considerable degradation (Blanchette and Simpson, 1992). Recently it was shown by stable nitrogen isotope analyses that the soft-rot fungus probably started to degrade the tomb at the coffin area and mobilized the king's highly ^{15}N-enriched nutrients to continually colonize and decay wood throughout



[FIGURE 4] Decay by soft rot in wood from the coffin and tomb structure found within Tumulus MM. Scanning [A AND B] and transmission electron micrographs of transverse [A, C AND D] and radial sections [B]. [A] Advanced stages of soft rot in wood from the coffin showed extraordinarily numerous cavities within the secondary wall. [B] Cell wall degradation by Type I soft rot showing the elongated cavities with pointed ends. [C AND D] Wood from the tomb floor with cavities in the secondary wall. Little of the cell wall remained unaffected between the cavities and the extremely weak decayed cells easily fragmented. Bar = 5μm.



[FIGURE 5] Decay in Cape Royds hut, Ross Island, Antarctica. [A] Historic hut at Cape Royds built by Ernest Shackleton in 1908 during the Nimrod Expedition. [B] Soft rot in wood from the Cape Royds hut with cavities within the cell walls. Bar = 5µm.

the tomb (Filley et al., 2001). The redistribution of the king's nitrogen, high in ^{15}N due to his diet that had been rich in meat, could be identified in samples taken from the entire tomb. In areas of the tomb sampled that were not decayed, ^{15}N values were extremely low. The soft-rot fungus effectively recycled the nutrients of the king and transported them from the wooden coffin [FIG. 3A] into the floor and wall timbers of the tomb [FIG. 3B] over long periods of time. The extensive amount of decay found in the massive cedar coffin, cedar timbers of the tomb floor, and juniper logs (all woods with natural resistance to decay) suggests that the fungus was active for hundreds of years within the tomb, and one major decay episode, possibly caused by one soft-rot fungus, was responsible for the deterioration (Filley et al., 2001).

Arctic and Antarctic Historic Woods

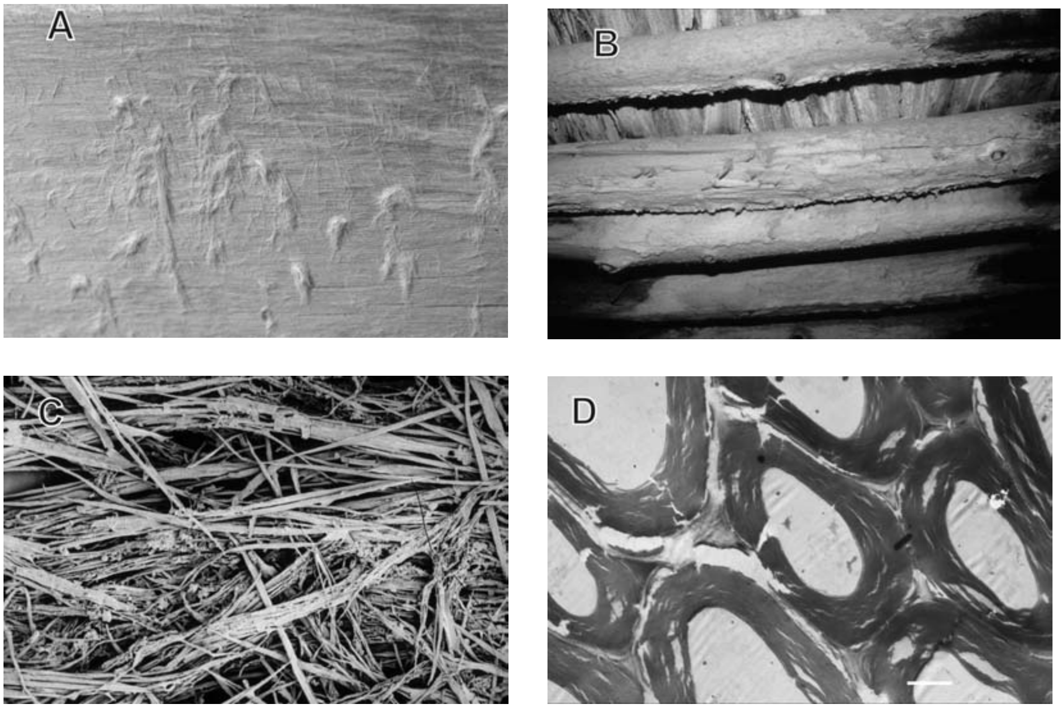
Three huts, Discovery Hut (built by Robert F. Scott and his crew in 1901), Cape Royds Hut (erected by Ernest Shackleton's Nimrod expedition in 1908; [FIG. 5A]), and the Cape Evans Hut (built by Scott's Terra Nova expedition in 1911), were used for sheltering men and equipment for several years during scientific investigations and attempts to reach the South Pole. The Cape Evans hut was also used by the Ross Sea Party in 1914-17, which was part of Shackleton's Imperial Trans-Antarctic expedition. These sites were abandoned once the expeditions were over, leaving the buildings and thousands of artifacts behind. Today these historic sites from Antarctica's Heroic Era provide a remarkable view into the past. Furniture, food stores, scientific apparatus, and other items are left in the huts as a reminder of what everyday life was like for the early explorers.

However, during the past few decades, serious wood deterioration has become evident in the huts and artifacts, causing concern about the long-term preservation of these historic sites (Harrowfield, 1995). It is a great misconception that the polar cold and dry climate can protect organic material from decomposition (Blanchette et al., 2002; Hughes, 2000). In actuality, significant deterioration takes place over time in the Ross Sea Region. Examination of wood in contact with the ground at these historic sites indicated that wood decay was occurring. Microscopic examination showed that a soft-rot attack was present [FIG. 5B]. Isolations made on culture media from the wood revealed that *Phialophora*-like species were associated with the degradation. The only type of biological decay found was a soft rot causing Type I attack. At the locations of the huts, the environment is above 0°C for only a few weeks in the austral summer, and high concentrations of salts are present in soils and in the historic woods. The extreme polar environment influences the microorganisms that are able to persist in this ecosystem. The *Phialophora*-like organisms are able to tolerate the adverse conditions and cause a slow degradation of the historic wood over time.

In the Canadian High Arctic, the early explorers of the North Polar Region also built huts during their explorations. In 1881, an American expedition led by Adolphus Greely built a large building called Fort Conger about 500 miles from the North Pole on Ellesmere Island (Dick, 2001). This was part of the International Polar Year efforts to study the Arctic regions. Fort Conger was the American headquarters for exploration of the interior of Ellesmere Island and the coast of northern Greenland, and for the collection of scientific information throughout the region. The Greely expedition did not get relief shipments as expected, and 19 of the 25 men in the expedition died of starvation and exposure. Robert Peary also used this site as a base camp for his campaigns to reach the North Pole. In 1900, he refitted Fort Conger from a large building into a smaller group of wooden huts for use during his attempts to reach the pole (Dick, 2001). Today, the huts remain with a tremendous amount of historic wood and other artifacts still present at the site. Wood decay is also prevalent and samples obtained from the wood of Fort Conger and the huts built by Peary indicated that soft-rot fungi were the only type of wood-degrading fungi present. All woods examined had a Type I soft-rot attack. Environmental conditions in the Arctic are also extreme, with a very short summer season and high salt concentrations occurring in soils and wood along the coastal regions. These conditions limit the types of organisms that can attack the wood with only specific soft-rot fungi, able to tolerate the adverse conditions, as the dominant decay-causing organism present.

Nonbiological Deterioration

In addition to the biological degradation found at these different archaeological and historic sites, nonbiological degradation was also found. The occurrence of this chemical deterioration of wood is much more common than previously realized. The decay is characterized by a fuzzy, defibrated appearance on wood surfaces suggestive of mechanical abrasion (Blanchette et al., 2002) [FIGS. 6A AND B]. Surface wood cells are detached and may be removed by wind or snowmelt, exposing the underlying cells that are then subjected to the same defibration process. Over long periods of time, the wood is gradually eroded away. In Antarctica, defibration is associated with wood containing high salt concentrations [FIG. 6A]. The wood absorbs moisture and salts from snowmelt and the salts precipitate at the evaporative surface. As evaporation occurs, exceedingly high concentrations of salts accumulate in the wood. In Polar Regions where rainfall does not occur, salts are not leached from the wood. The salts corrode the wood, causing a chemical deterioration of the middle lamella region of wood cells. The selective attack on the middle lamella causes a separation of wood cells, and individual cells detach from the wood surface [FIG. 6C]. When wet, the affected area appears as if the wood surface has been pulped.



[FIGURE 6] Non-biological degradation of wood. [A] Exterior wallboard from Robert F. Scott's Cape Evans hut in Antarctica showing severe defibration of wood from high salt concentrations. Wood cells are degraded and detached from the wood. [B] Difibration in roof beams from Pueblo del Arroyo, an Anasazi great house in Chaco Culture National Historic Park, New Mexico. [C] Scanning electron micrograph of chemically deteriorated wood from Cape Evans hut in Antarctica showing wood cells separating at the middle lamella and detaching from adjacent cells. [D] Transmission electron micrograph of a transverse section from the mask of a coffin lid from an ancient Egyptian tomb at Abydos 1570-1293 B.C. (currently in the Museum of Fine Arts, Boston 01.7431) showing salt deterioration that has affected the wood cells. Cells are delaminated by degradation of the middle lamella and secondary walls also show deterioration with cracks and fissures present within the remaining secondary wall layers. Detached wood fibers in C are approximately 50 to 80μm wide. Bar in D = 5μm

Although the mechanism of chemical degradation taking place is not well understood, the decay appears similar to the attack on wood found in temperate regions on preservative-treated marine pilings, in wood from warehouses that store deicing salts and fertilizer, and on the internal surfaces of boats and cooling towers (Johnson et al., 1992; Wilkins and Simpson, 1988). In these situations the damage is thought to be caused by the growth of salt crystals within wood cells. The results presented here indicate that cell separation is due to a chemical attack on the middle lamella causing cells to break away from adjacent cells. This type of deterioration has also been found in woods from Anasazi great houses at Chaco Culture National Historic Monument and Aztec Ruins National Monument [FIG. 6B], as well as in some woods from ancient Egyptian tombs. In wood of the great houses, roof beams protected from direct rain absorbed runoff water containing dissolved salts. Evaporation resulted in salt accumulation on the beam surfaces. Over time these surfaces were deteriorated by chemical action of the salts, causing the entire surface of the affected beams to become defibrated [FIG. 6B]. Often, the roof beams were in a protected location and a large layer of detached wood fibers remained on the wood surfaces.

Similar surface defibration was found on Egyptian woods. These woods, located in tombs where moisture apparently carried alkaline substances into the wood, had localized areas of defibrated cells. Transmission electron micrographs of the deteriorated woods showed that the middle lamella was destroyed and cells detached from one another [FIG. 6D]. In addition, the secondary wall also appeared to separate. Parallel series of separations occurred within the secondary wall layers, indicating that all parts of the woody cell wall, including the cellulose-rich secondary wall layers, were affected by the chemical attack [FIG. 6D]. Differences in appearance of the surface deterioration occurring in the Egyptian woods were most likely due to the much longer time of burial, to the more direct contact with alkaline substances, or to the different types of salts as compared to those found in the Antarctic historic huts or the Anasazi great house woods.

CONCLUSIONS

Environmental conditions that exist in areas where archaeological wood is protected from rapid decay exclude most wood-destroying fungi. However, microorganisms that can tolerate these extreme conditions grow and may degrade the wood. In the wooden objects examined in these studies, soft-rot fungi were the major wood-destroying organisms found. They appear to dominate in woods subjected to a variety of conditions, including the limited moisture of buried tombs, high salt concentrations, and the extreme conditions of the cold polar environment. In temperate and tropical ecosystems, white- and brown-rot fungi are the major decay fungi that cause rapid degradation of wood, and soft-rot fungi are not frequently encountered. However, soft-rot fungi do occur and can be found in naturally decay resistant woods, preservative treated woods, and waterlogged woods. In addition to these selected situations where soft rot is found, these fungi also appear common in archaeological woods from dry, alkaline, or cold terrestrial sites. The presence of some brown rot in the ancient Egyptian woods and the Anasazi great houses suggests that when conditions are favorable brown-rot fungi may cause substantial decay in buried objects or wood exposed to the environment. The association of brown rot with termite and other insect damage indicates that specific conditions may influence the introduction of brown-rot fungi into the tombs. Sufficient moisture and nutrients also have to be available at these locations, and salts or other substances that inhibit growth of basidiomycetes must be limited.

Although soft-rot fungi are the major cause of decay in archaeological wood from terrestrial sites, little is known about the biology and ecology of these fungi. Since many sites, such as Tumulus MM, support the growth of only soft-rot fungi, and exceedingly advanced stages of decay can be found, these sites provide an excellent opportunity to study this unusual form of wood decay.

The defibration of wood due to salt deterioration processes was found frequently in the woods examined at these different terrestrial sites. Now that the characteristics of this form of chemical damage are known, and methods to distinguish it from other types of deterioration have been demonstrated, there will undoubtedly be more reports on its occurrence. Additional investigations of the mechanism of chemical attack on wood are needed and further characterization of the varying types of damage should be carried out.

Archaeologists, conservators, and other scientists working with excavated archaeological woods have the opportunity to gain significant information about past cultures by studying wood. The use of wood to understand site chronology, past environments, deterioration processes, and microbial biodiversity in extreme environments strongly suggests that archaeological wood should not be neglected. Information on the chemical and morphological condition of the woods is also of prime importance so that appropriate objects conservation methods can be selected, and if in situ preservation is required, this type of information will help in the selection of procedures that will ensure successful preservation of the materials.

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