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CASE STUDY

Wood deterioration in Chacoan great houses of the southwestern United States

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ABSTRACT

'Great houses' built by the Ancestral Puebloans (Anasazi) (900–1200AD) still contain thousands of pieces of wood used as beams, secondary roof supports and lintels. The wood is an integral part of the surviving Chacoan architecture and has served as a valuable resource for determining the exact age of the structures and for obtaining information about raw material production, procurement and harvesting methods. An assessment of wood deterioration at the great houses in Aztec Ruins National Monument and Pueblo Bonito, Pueblo del Arroyo and Chetro Ketl located in Chaco Culture National Historic Park in New Mexico have revealed that both microbial and non-biological deterioration was taking place. The major type of decay found throughout the structures was caused by soft-rot fungi. Cavity formation in secondary walls of conifer woods and an erosion of cell walls in aspen woods was prevalent. A brown-rot type of wood degradation was also found, primarily associated with areas of subterranean termite damage. Another form of deterioration present in some of the woods was a chemical defibration of wood. This corrosive attack, caused by high concentrations of salts, destroyed the middle lamella between cells, resulting in a stringy mass of loosely attached fibres. Reburial of great house structures as an effective conservation strategy will require an environment that is not conducive to decay, since active wood-destroying fungi are present in the prehistoric woods. If moisture and other conditions suitable for decay exist, the wood will be destroyed and this important historical resource lost.

Deterioration of wood products occurs under a wide range of environmental conditions. Even in arid regions, decomposition processes caused by biological and non-biological agents progressively degrade the wood structure. Although biological degradative processes may occur more slowly when moisture, nutrients, oxygen and other essential compounds are limited, substantial deterioration can take place over time even under the most adverse and restrictive environmental conditions. In some of the most extreme environments, such as the dry, cold climate of Antarctica or the bottom of lakes and oceans where waterlogged woods from sunken ships are found, deterioration can be very slow. However, with time, substantial deterioration of wood from microbes or non-biological agents can occur even in these unusual environments [1–3]. When archaeological wood is found, it is rarely free from some form of deterioration. Over the past few decades a large number of investigations have focused on the processes and organisms responsible for deterioration in waterlogged woods [1, 4–6] but there have been very few studies undertaken on the aetiology of decay in dry terrestrial environments where archaeological wood is found [7–9].

Archaeological wood is an extremely important resource since it holds great potential for providing information about the past [10]. When the Chacoan 'great houses' were made, tens of thousands of trees were used for beams, secondary roof supports, and door and window lintels. Today, these great houses provide one of the largest examples of prehistoric wood left of any site in the American southwest [11]. In the West Ruin of the Aztec Ruins National Monument alone, over 6000 pieces of

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wood still exist [10]. Analysis of wood from Chacoan great houses has provided new information on precise dating of the structures, raw material production, resource availability and socio-economic strategies related to wood harvesting and construction [10, 11–14]. Deterioration of wood and mud brick masonry has occurred in these great houses since the structures were abandoned about 1000 years ago but has apparently accelerated following excavation and exposure of the masonry and wood to the environment during the past several decades.

The reburial of archaeological sites as an effective conservation strategy to protect masonry structures and wood is currently being used to ensure preservation of the Chacoan prehistoric structures long into the future (see paper by Ford *et al.*, this volume). For these programmes to be successful, the agents responsible for deterioration and the reburial environment must be studied carefully carefully so that conservation plans will effectively prevent future biological and non-biological deterioration from taking place. In New Mexico, where the Chaco Culture Historic Park and Aztec Ruins National Monument are located, the agents responsible for deterioration of the prehistoric wood have not been identified and deterioration processes occurring at these sites are not well understood. This paper describes the types of biological decay and non-biological forms of deterioration found in great houses at Chaco Culture National Historic Park and Aztec Ruins National Monument, examines the various processes of deterioration occurring in these woods and discusses requirements for successfully preserving the wood at these important archaeological sites.

MICROBIAL WOOD DECOMPOSITION IN TERRESTRIAL ENVIRONMENTS

Although there is currently little information on the specific types of deterioration occurring in wood of the Chacoan great houses, a great deal of general information on wood decay is available from studies of wood in modern settings, tree and forest ecosystem studies and from studies of waterlogged archaeological woods.

Fungi are the primary degraders of wood in terrestrial sites and decay can be classified based on the type of degradation that is present. Three groups – brown-rot, white-rot and soft-rot fungi – have been identified and a number of sub-categories occur in the brown- and white-rot group [15]. Since wood degradation occurs by the actions of extracellular enzymes and other metabolites produced by the fungus, the type and sequence of attack on wood cell wall components (i.e. cellulose, hemicellulose and lignin) can vary depending on the specific degradative actions of the fungus. Different types of decay result and the residual degraded wood is often differentiated by its appearance. Brown-rot fungi, which are the major causes of wood decay in buildings and wood in service, depolymerize cellulose early in the decay process, resulting in large losses of wood strength. As decay advances, cellulose and hemicellulose are degraded and lignin may be chemically altered. The resulting decay is brown because of the high lignin content of the residual wood.

In contrast, white-rot fungi can degrade all cell wall components, including lignin. The degraded wood usually appears bleached of colour during the early stages of attack and becomes white as decay progresses. Some white-rot fungi are very selective, degrading lignin from wood but not much cellulose [16]. These fungi appear to utilize hemicellulose in wood and large white zones of cellulose remain after advanced stages of decay. Some white-rot fungi have been reported to cause decay in wood products, such as utility poles, but most attack trees or degrade woody residues in forests.

A third type of fungal attack on wood is caused by soft-rot fungi. Unlike white- and brown-rot fungi that are considered to be classified in the Basidiomycota, soft-rot is caused by fungi in the Ascomycota and related asexual taxa. They were first reported as the cause of a softening of wood surfaces in very wet woods and the name soft-rot was used to describe this type of degradation. However, soft-rot decay can be visually very similar to that of brown-rot and can be easily confused based on macroscopic characters. A major difference between soft-rot and brown-rot fungi is the type of cell wall attack that occurs in wood. For general reviews of different types of microbial decay and their effect on historic wood, including general information on wood cell wall structure, see Blanchette [1] and Eriksson *et al.* [15]. Soft-rot fungi may cause two forms of degradation: type 1 and type 2 [17]. Soft-rot fungi that cause type 1 degradation attack and degrade wood by penetrating the woody cell wall and forming cavities within it. Chains of conical-shaped cavities follow the microfibrillar structure, producing a spiral of minute holes within the cell wall. In transverse sections of soft-rotted wood, numerous holes can be seen that progressively enlarge within the cell wall as decay continues. Soft-rot fungi that cause a type 2 attack erode the entire secondary wall but do not degrade the compound middle lamella region of the cell wall. In both types of attack the residual wood is brown and large losses of wood strength are associated with the decay. Although soft-rot was first described over fifty years ago, this type of decay and the fungi that cause it are not well understood [8, 18]. Soft-rot fungi are common wood destroyers found in waterlogged woods but they also occur in terrestrial environments and appear to be present in dry sites or environments that exclude aggressive white- and brown-rot fungi [7, 8]. Soft-rot has been found in wood from many different archaeological sites where extreme environmental conditions appear to have influenced microbial diversity and wood decomposition.

Bacteria may also colonize and degrade wood cell walls in environments that suppress fungal colonization such as waterlogged woods, buried woods in saturated or oxygen limiting environments and preservative-treated woods [17]. Several different groups of bacteria have been identified and classified based on their degradative actions. Bacterial cavitation, tunnelling and erosion of the woody cell wall have been previously characterized and decay patterns documented [1, 17, 19]. In addition to cell wall degrading bacteria, other bacteria degrade only the extractive component of wood, attack just the bordered pit membranes between adjacent cells or are secondary organisms that act as scavengers to metabolize wood components degraded by other microbes [15, 17]. Wood-destroying bacteria are commonly found in very wet environments and high moisture levels appear to be essential for colonization and decay of wood.

MICROBIAL DECAY OF WOOD IN GREAT HOUSES

An assessment of wood beams, secondary roof supports, and door and window lintels was carried out at Puebloan great houses built in the early 1100s AD at Aztec Ruins National Monument, and at Pueblo Bonito, Pueblo del Arroyo and Chetro Ketl located in Chaco Culture National Historic Park in New Mexico. The great houses in Chaco Canyon were built from 900 AD to 1200 AD. Large quantities of wood were used in the construction of each great house. In Pueblo Bonito alone, it has been estimated that 25,000 trees were used. Today, the great house ruins still contain thousands of pieces of wood (Fig. 1(a)–(d)). The major wood types used were ponderosa pine, Douglas fir, juniper and aspen. Exposed wood in the great houses is extremely weathered with large cracks and checks occurring (Fig. 1(a)–1(b)). Some woods have noticeable areas of advanced decay that appear brown with surface checks and where the integrity of the wood has been greatly altered (Fig. 1(d)). Wood that has been protected from the elements is often free from extensive defect and degradation (Fig. 1(c)).

Segments of wood, approximately 1mm×3mm, were obtained from sites throughout the great houses and examined to determine the type of decay present. Samples were prepared for scanning and transmission electron microscopy using methods described elsewhere [7, 8]. The major type of decay found in all woods that appeared weathered or decayed was a soft-rot degradation (Fig. 2(a)–(d)). Both type 1 and type 2 forms of soft-rot were present. Type 1 was found in coniferous woods and the decay consisted of typical soft-rot cavities that appeared as eroded holes in transverse sections of the wood cell walls (Fig. 2(a) and (c)). In many woods, advanced stages of decay were present and cell walls were riddled with numerous holes. In areas with advanced decay, many of the cavities within the cell wall coalesced, forming large voids in the secondary wall. The integrity of wood displaying advanced stages of soft-rot (Fig. 2(b)) was severely compromised. In aspen wood, type 2 soft-rot was common. The cell wall was eroded from the cell lumina toward the compound middle lamella. In many samples, the secondary wall was almost completely eroded but the middle lamella between cells remained (Fig. 2(d)). Soft-rot degradation in aspen and coniferous woods was most severe on the outer regions of the beams and lintels, although it often progressed into the interior parts of these woods. Large cracks and checks in the wood apparently provided an avenue for fungi to colonize the interiors of the beams and lintels and produced a micro-environment that was conducive to fungal growth. In this dry region of the southwestern United States, crevasses in the wood likely hold moisture for extended periods and also may serve to collect wind-blown soil particles that could provide additional nutrients for soft-rot fungi to utilize. Previous investigations have demonstrated that soft-rot fungi need nitrogen from soil or other external sources to cause significant decay [8, 20].

Although soft-rot was the most frequently encountered type of decay in the great houses, some woods displayed a typical brown-rot. This decay was often found in wood near or at ground level and the decayed wood was usually associated with subterranean termite damage. The brown-rotted wood was extremely fragile and weak. Sections of the wood showed a characteristic depolymerization of cellulose and large losses of wood carbohydrates occurred in advanced stages of decay. The lack of cellulose within the degraded cell walls caused them to easily bend and collapse (Fig. 3(a) and (b)). When dry, the wood could be crushed easily into a fine powder when slight pressure was applied. The decayed wood had a visual appearance that was similar to advanced stages of

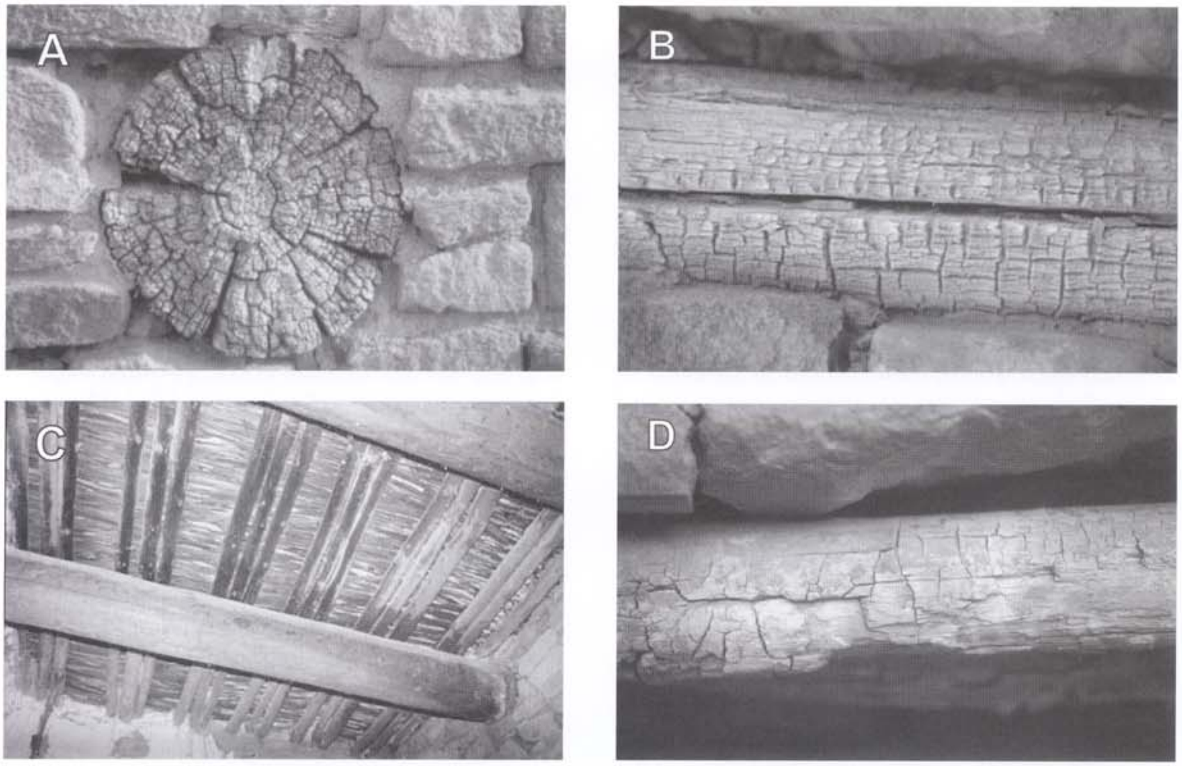


Figure 1. Woods from Chacoan great houses showing their current condition. (a). End of a pine beam showing severe deterioration with large cracks and crevasses in the wood. (b). Lintel showing surface weathering and deterioration. (c). The roof of a room in Aztec ruins that had been protected from the environment, showing relatively sound beams and secondary support structures. (d). Advanced stages of decay in a lintel. The structural integrity of the wood has been greatly compromised and parts of the lintel have been lost through fragmenting and detachment of the decayed wood.

soft-rot and it was not possible to differentiate brown-rot from soft-rot by macroscopic examination. However, it was easily separated microscopically by examining the degradation characteristics present in the woody cell walls. In most samples, the decay present was either a soft-rot or a brown-rot. Only in a few wood samples was there evidence of both types of decay present in the same sample and this likely resulted from a brown-rot colonizing wood that had incipient stages of soft-rot already present.

Samples of decayed wood were also used to isolate and obtain pure cultures of fungi present in the prehistoric wood. Cultures of active brown-rot and soft-rot fungi were isolated from many of the prehistoric woods examined.

NON-BIOLOGICAL DETERIORATION OF WOOD IN GREAT HOUSES

An unusual type of degradation was found to be affecting some woods at Pueblo del Arroyo, Chetro Ketl and Aztec Ruins that caused a defibration of wood surfaces. Wood cells separated and detached from beam and lintel surfaces, resulting in a stringy mass of loosely attached fibres (Fig. 4(a) and (b)). In some areas, the degradation caused severe defibration and large areas of the exposed wood were affected. The defibrated wood was white to yellow-brown in colour and was found in pine, aspen and juniper. Scanning electron microscopy indicated that the middle lamella region between cells was destroyed and the loss of this cementing region between cells caused them to separate from one another (Fig. 4(c)–(e)). The secondary walls remained intact but some erosion of this layer was apparent in advanced stages of deterioration, indicating that degradation of the cellulose-rich secondary wall layers was also taking place. Defibration of the coniferous woods resulted in detached tracheids (Fig. 4(d)) and in aspen all cell types (vessels, fibres and parenchyma cells) were affected (Fig. 4(e)). No evidence of microbial activity was observed. Multi-elemental inductively coupled plasma atomic emission spectroscopy [7] of wood samples from defibrated areas indicated that

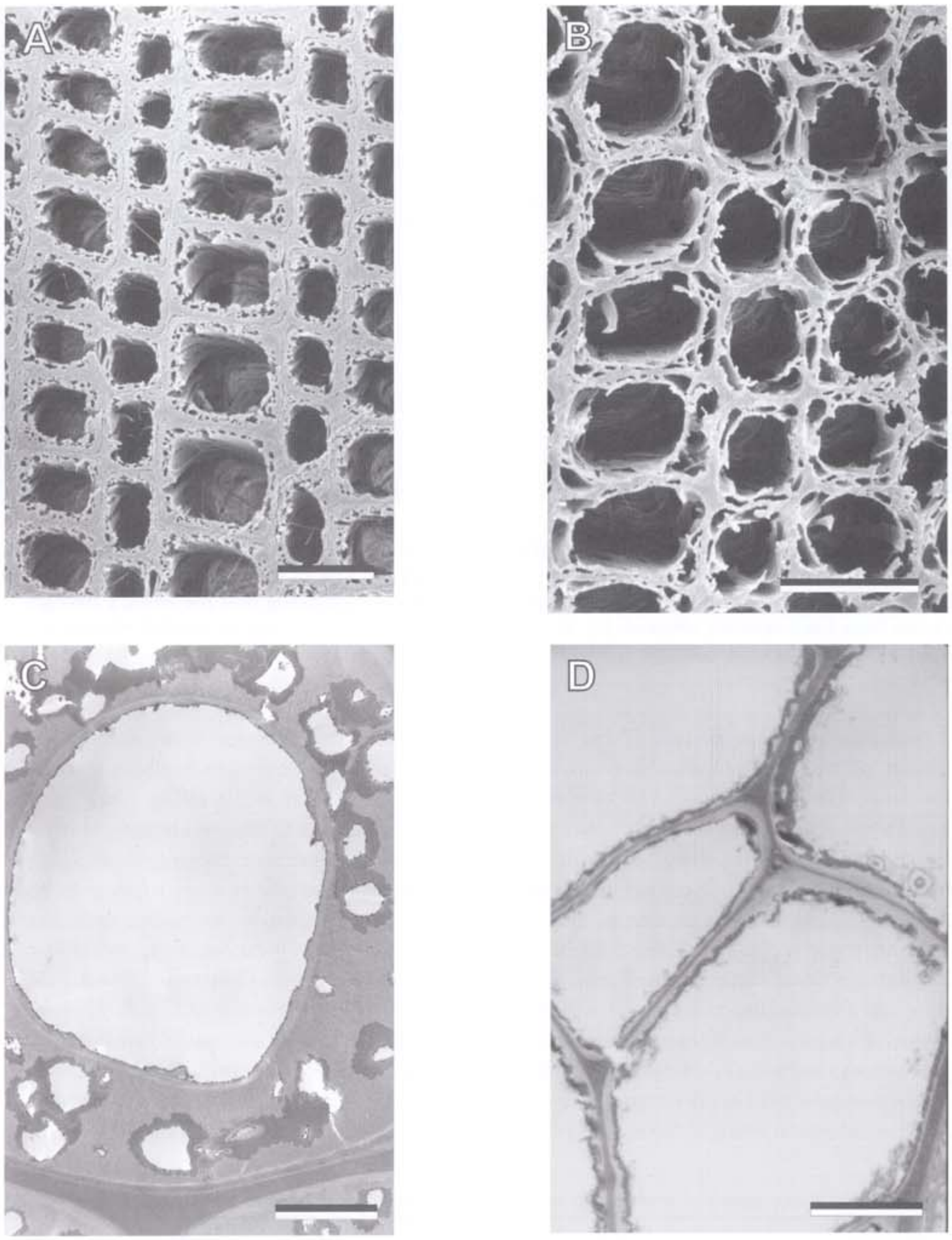


Figure 2. Scanning (a and b) and transmission electron (c and d) micrographs of transverse sections from prehistoric wood with soft-rot. (a). Early to intermediate stages of type I soft-rot from a pine beam with small- to moderate-sized cavities within the cell walls. (b). Advanced type I soft-rot from a pine beam showing large cavities that have coalesced, producing large voids in the cell walls. (c). Cavities within the cell wall of wood from a pine beam with type I soft-rot. The soft-rot cavities appear as holes surrounded by electron dense staining in the secondary wall of the wood cell. (d). Advanced stage of type 2 soft-rot in aspen wood showing an almost complete erosion of the secondary wall. The middle lamella between cells is left undegraded. (a) and (b), bar = 25 μm; (c) and (d), bar = 5 μm.

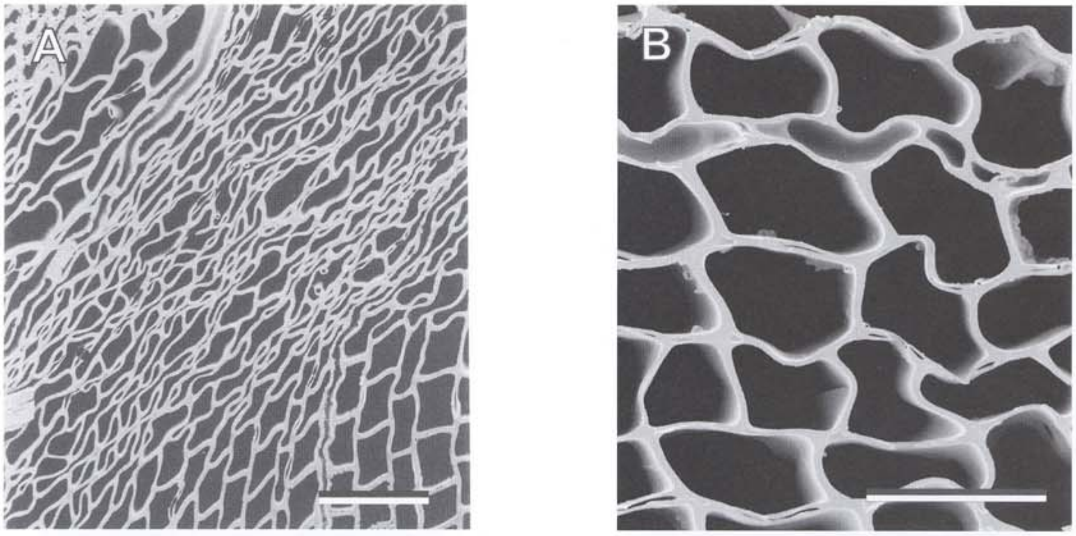


Figure 3. Scanning electron micrographs of transverse sections from brown-rotted wood in a pine beam. (a). Wood cells affected by brown-rot have lost their integrity because of extensive depolymerization and degradation of cellulose. Distorted and collapsed cells can be seen indicating that the wood's strength properties have been severely affected. (b). Brown-rot does not cause cavities or eroded regions in cell walls but a diffuse attack on cellulose has taken place leaving the cells extremely weak and fragile. Bar = 50 µm.

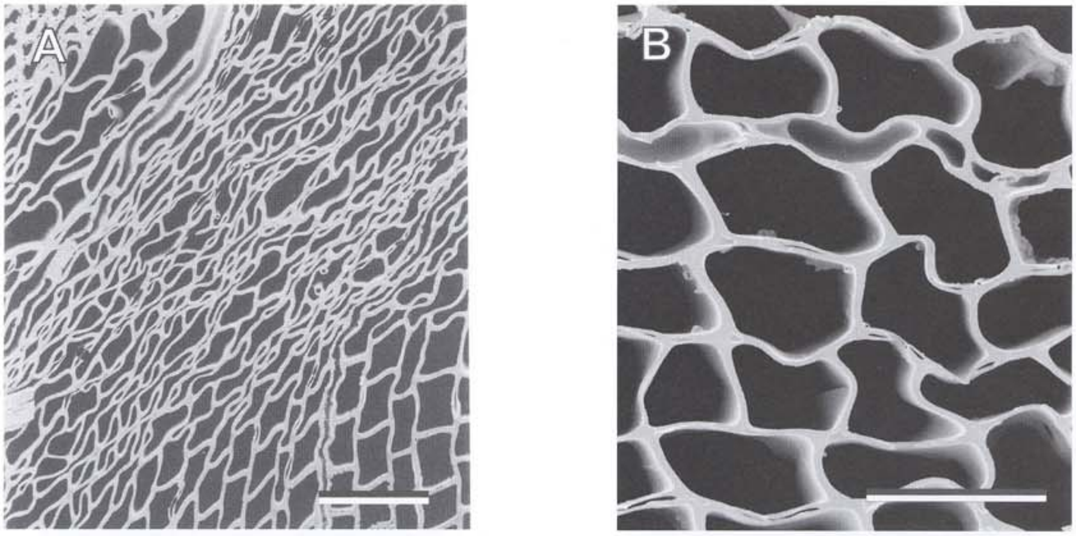
high salt concentrations were present (Table 1). The concentration of sodium in areas with advanced defibration ranged from 40,000 to 185,000 ppm. Although wood is usually considered to be resistant to the corrosive activity of salts, chemical degradation of wood by high concentrations of salts has been reported in some environments [2, 7, 21]. In these situations, dissolved salts migrate into wood and, as moisture evaporates, the salts accumulate on wood surfaces. Over time, the repeated exposure of wet and dry cycles results in the build up of extremely high salt concentrations. Salts often are considered to cause mechanical alterations to substrates but previous investigations of salt deterioration in wood have shown that a chemical attack of the wood occurs [2]. This chemical corrosion causes the lignified middle lamella to be destroyed and cells to separate. A similar scenario appears to be taking place in woods from defibrated areas of the great houses. Moisture from rain and snow migrates into the wood from adjacent masonry or seepage that occurs along the edge of the structure. Dissolved salts, often seen precipitated on exposed mud brick walls in the great houses, apparently move into the wood where moisture evaporates from its surfaces. Areas experiencing the most significant damage were protected from direct rain fall that would have leached the accumulated salts out of the wood. The destructive, degradative effects of salts on metals and other materials are well documented but very little is known about the processes

Table 1. Elemental analyses (ppm) of prehistoric wood from Chacoan great houses and sound modern wood.

Wood sample	Ca	Mg	Na	K	Al
Chetro Ketl, pine beam (95-14)[a]	21,535	2446	6017	1101	281
Chetro Ketl, pine beam (95-22)[a]	7631	788	13,707	471	1029
Pueblo del Arroyo, room 44, aspen	9386	2252	185,996	267	1865
Pueblo del Arroyo, room 44, juniper	69,673	4686	46,523	2343	3953
Pueblo del Arroyo, room 44, pine	3127	4476	53,433	7090	689
Pueblo del Arroyo, room 62, pine	28,830	1737	9641	1160	2199
Modern wood[b]	8575	1061	67	581	465

[a]Numbers in parentheses are sample numbers; two different beams were sampled in Chetro Ketl.

[b]A sample of modern wood was obtained from a dead tree near the great houses in Chaco Canyon for comparison.



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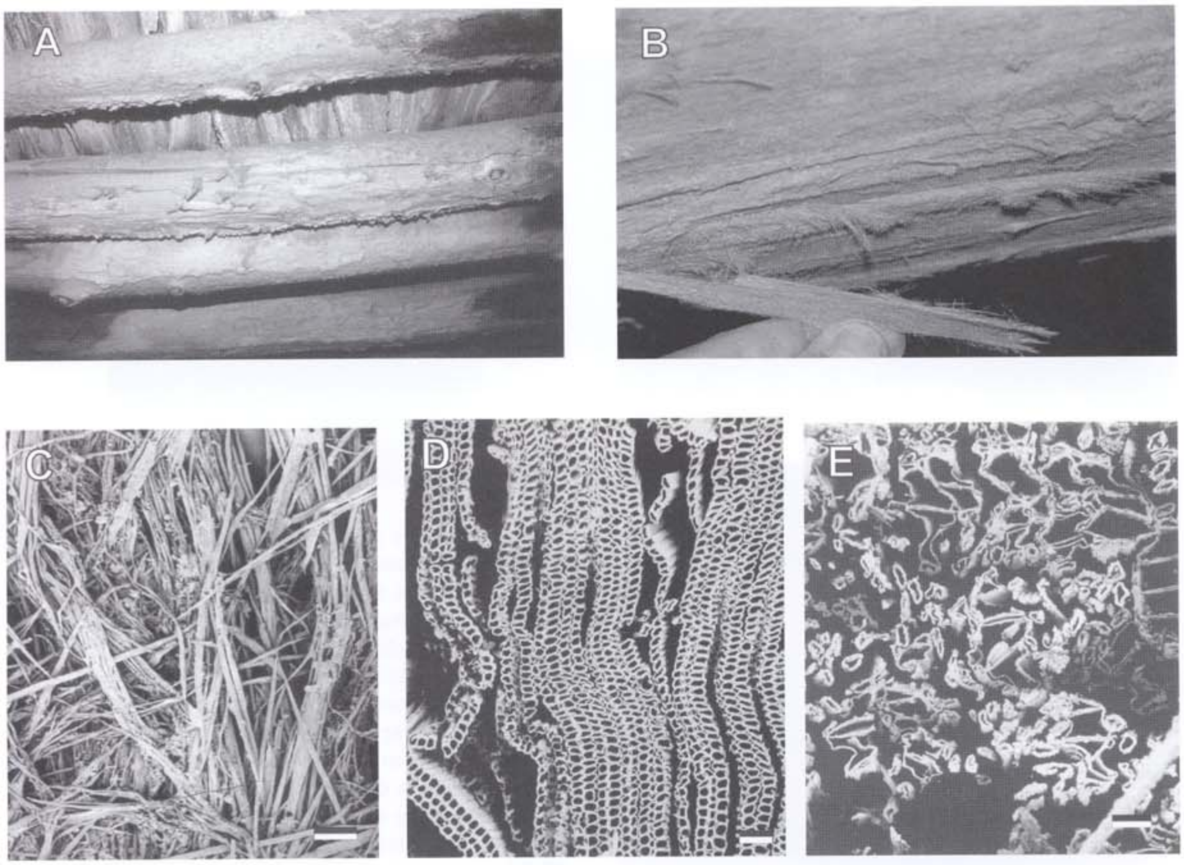

Figure 4. Salt deterioration in wood from Chacoan great houses (a and b) and scanning electron micrographs of the chemical deterioration (c–e). (a) and (b). Beams and secondary roof supports showing defibrated wood surfaces. The surface fibres of the wood are detached and separated by the corrosive chemical attack of high concentrations of salt. (c). Radial section of the wood showing defibration of the cells. (d). Transverse section of pine showing the detachment of cells caused by dissolution of the middle lamella between cells. (e). Transverse section of aspen showing all cells are defibrated due to the degradation of the middle lamella. (c)–(e), bar = 50 μm.

taking place in wood. The results from this study demonstrate that water migration through soils and masonry into wood can result, over time, in extensive damage from salts.

Many of the great house wood samples used for multi-elemental analyses from areas that did not have extensive defibration did show an elevated level of salts (Table 1), and this higher salt content likely influences the type of fungi colonizing the wood and the resulting decay. Alkaline conditions have been known to promote soft-rot attack and inhibit growth by other wood-destroying fungi [8]. In wood where chemical corrosion was extensive, no evidence of fungal degradation was present. Although the exceedingly high concentrations of salts apparently inhibited fungal attack, the chemical corrosion of the wood by the salts was very damaging. The migration of salts into the walls of the mud brick structures has been recognized as a problem for the masonry but the investigations reported here also indicate that salts can have detrimental effects on wood.

BACKFILLING GREAT HOUSE RUINS AND WOOD PRESERVATION

Historic photographs taken of Chetro Ketl during excavation in 1920 show that deterioration was present in long periods of time [7]. This deterioration resulted in an attack that affected only a few millimetres depth into the wood. If sufficient water is present at Chacoan great houses to bring dissolved salts into wood, it is likely that enough moisture is present to facilitate the chemical corrosion processes that occur in wood when salts are present.

The reburial of Chacoan great houses and other important archaeological sites to protect them from deterioration and loss is a strategy that deserves serious consideration. These conservation efforts should be successful if the burial conditions created are effective in inhibiting biological and non-biological processes. Investigations to obtain more information on the biology and ecology of wood-destroying organisms that affect archaeological wood in dry terrestrial sites should be continued and the degradative processes taking place in these prehistoric woods need to be better understood. Increased knowledge of these organisms and decay mechanisms will aid efforts to control their devastating effects and to preserve these national treasures. As the great houses are reburied, it will be essential to monitor the wood and the burial environment to ensure that conditions are not conducive for decay to take place. If conditions become favourable for decay, immediate remedial action would be needed or loss of the wood will be inevitable.

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REFERENCES

1 Blanchette, R.A. A review of microbial deterioration found in archaeological wood from different environments. *International Biodeterioration and Biodegradation* **46** (2000) 189–204.

2 Blanchette, R.A., Held, B.W. and Farrell, R.L. Defibration of wood in the expedition huts of Antarctica: an unusual deterioration process in the polar environment. *Polar Record* **38** (2002) 313–322.

3 Jordan, B.A. Site characteristics impacting the survival of historic waterlogged wood: a review. *International Biodeterioration and Biodegradation* **47** (2001) 47–54.

4 Bjordal, C.G., Nilsson, T. and Daniel, G. Microbial decay of waterlogged archaeological wood found in Sweden applicable to archaeology and conservation. *International Biodeterioration and Biodegradation* **43** (1999) 63–73.

5 Blanchette, R.A. and Hoffmann, P. Degradation processes in waterlogged archeological wood. In: *Proceedings of the 5th ICOM Group on Wet Organic Archaeological Materials Conference, Portland, Maine*. International Council of Museums, Committee for Conservation Working Group on Wet Organic Archaeological Materials, Bremerhaven, Germany (1994) 111–142.

6 Powell, K.L., Pedley, S., Daniel, G. and Corfield, M. Ultrastructural observations of microbial succession and decay of wood buried at a Bronze Age archaeological site. *International Biodeterioration and Degradation* **47** (2001) 165–173.

7 Blanchette, R.A., Haight, J.E., Koestler, R.J., Hatchfield, P.B. and Arnold, D. An assessment of deterioration in archaeological wood from ancient Egypt. *Journal of the American Institute of Conservation* **33** (1994) 55–70.

8 Filley, T.R., Blanchette, R.A., Simpson, E. and Fogel, M.L. Nitrogen cycling by wood decomposing soft-rot fungi in the 'King Midas tomb', Goridon, Turkey. *Proceedings of the National Academy of Sciences* **98** (2001) 13,346–13,350.

9 Nilsson, T. and Daniel, G. Structure and the aging process of dry archaeological wood. In: Rowell, R.M. and Barbour, R.J. (eds) *Archaeological Wood: Properties, Chemistry and Preservation*. Advances in Chemistry Series 225, American Chemical Society, Washington DC (1990) 67–86.

10 Tennessen, D., Blanchette, R.A. and Windes, T.C. Differentiating aspen and cottonwood in prehistoric wood from Chacoan great house ruins. *Journal of Archaeological Science* **29** (2002) 521–527.

11 Lekson, S.H., Windes, T.C., Stein, J.R. and James, W.J. The Chaco Canyon community. *Scientific American* **259** (1988) 100–109.

12 Douglass, A.E. *Dating Pueblo Bonito and Other Ruins in the Southwest.* Contributed Technical Papers, Pueblo Bonito Series No. 1.

National Geographic Society, Washington DC (1935).
13 Windes, T.C. and Ford, D. The Chaco wood project: the chronometric reappraisal of Pueblo Bonito. *American Antiquity* **61** (1994) 295–310.
14 Windes T.C. and McKenna, P.J. Going against the grain: wood production in Chacoan Society. *American Antiquity* **66** (2001) 119–140.
15 Eriksson, K.L., Blanchette, R.A. and Ander, P. *Microbial and Enzymatic Degradation of Wood and Wood Components*. Springer-Verlag, Heidelberg (1990).
16 Blanchette, R.A. Delignification by wood decay fungi. *Annual Review of Phytopathology* **29** (1991) 381–398.
17 Daniel, G. and Nilsson, T. Developments in the study of soft rot and bacterial decay. In: Bruce, A. and Palfreyman, J.W. (eds) *Forest Products Biotechnology*. Taylor & Francis, London (1998).
18 Worrall, J.J., Anagnost, S.E. and Zabel, R.A. Comparison of wood decay among diverse lignicolous fungi. *Mycologia* **89** (1997) 199–219.
19 Blanchette, R.A., Nilsson, T., Daniel, G. and Abad, A. Biological degradation of wood. In: Rowell, R.M. and Barbour, R.J. (eds) *Archaeological Wood: Properties, Chemistry and Prevention*. Advances in Chemistry Series 225. American Chemical Society, Washington DC (1990) 141–174.
20 Worrall, J. and Wang, C.J.K. Importance of mobilization of nutrients in soft rot of wood. *Canadian Journal of Microbiology* **37** (1991) 864–868.
21 Parameswaran, N. Micromorphology of spruce timber after long-term service in a potash store house. *Holz als Roh und Werstoff* **39** (1981) 149–156.
22 Zabel, R.A. and Morrell, J.J. *Wood Microbiology: Decay and Its Prevention*. Academic Press, New York (1992).

Détérioration du bois dans les grandes maisons de Chaco dans le Sud-Ouest des Etats Unis

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Résumé

Les grandes maisons construites par les Pueblo Ancestraux (Anasazi) (900 à 1200 ap. J.C.) contiennent encore des milliers d'objets en bois utilisés comme poutres, supports de toits secondaires et linteaux. Le bois forme une partie intégrale de l'architecture qui se conserve encore à Chaco et il a servi comme une ressource d'une grande valeur pour déterminer l'âge exact des structures ainsi que pour obtenir des informations sur la production de matières premières, et les méthodes d'obtention et de récollection. L'évaluation de la détérioration du bois dans les grandes maisons du Aztec Ruins National Monument (Monument National de Aztec Ruin) et de Pueblo Bonito, Pueblo del Arroyo et Chetro Ketl situés dans le *Chaco Culture National Historic Park* (Parc Historique National de la Culture Chaco) au Nouveau Mexique a révélé la présence de détériorations aussi bien d'origine biologique que non-biologique. Le principal type d'altération retrouvé dans toutes les structures est dû aux champignons de pourriture douce. Les principales altérations impliquent la formation de cavités dans les parois secondaires des bois de conifères et dans l'érosion des parois cellulaires dans le bois de tremble. Une pourriture de type marron a également été retrouvée, principalement associée avec les zones d'altération souterraine occasionnées par les termites. Une autre forme de détérioration présente dans certains bois est un défibrage chimique du bois. Cette attaque corrosive, due à des concentrations élevées en sels, a détruit les lamelles médianes entre les cellules, créant ainsi une masse filamenteuse de fibres débilement unies. Le ré-enterrement des structures des grandes maisons en tant que stratégie effective de conservation, requerra d'un environnement qui ne permette aucune altération, puisque à l'intérieur des bois préhistoriques il existe des champignons actifs capables de détruire. S'il existe une présence d'humidité ou d'autres conditions favorables pour l'altération, le bois sera détruit et cette importante ressource historique sera perdue.

Deterioro de madera en las casas grandes de Chaco en el Suroeste de los Estados Unidos

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Resumen

Las casas grandes construidas por los Pueblo Ancestrales (Anasazi) (900 a 1200 d.C.) aún contienen miles de objetos de madera utilizados como vigas, soportes de techos secundarios y dinteles. La madera forma una parte integral de la arquitectura que aún se conserva en Chaco y ha servido como un recurso valioso para determinar la edad exacta de las estructuras así como para obtener información acerca de la producción de materias primas, y los métodos de obtención y de recolección. La evaluación del deterioro de la madera en las casas grandes de Aztec Ruins National Monument (Monumento Nacional de Aztec Ruin) y de Pueblo Bonito, Pueblo del Arroyo y Chetro Ketl localizadas en el *Chaco Culture National Historic Park* (Parque Histórico Nacional de Cultura Chaco) en Nuevo México reveló la presencia de deterioros tanto biológicos como no biológicos. El principal tipo de alteración encontrado en todas las estructuras está ocasionado por hongos de pudrición suave. Los daños predominantes son la formación de cavidades en las paredes secundarias de las maderas coníferas y la erosión de las paredes celulares en la madera de álamos. También se encontró una pudrición de tipo café, principalmente asociada con las áreas de daños subterráneos ocasionados por termitas. Otra forma de deterioro presente en algunas de las maderas fue una desfibración química de la madera. Este ataque corrosivo, ocasionado por altas concentraciones de sales, destruyó las láminas medias entre las células, generando una masa filamentosa de fibras débilmente unidas. El re-enterramiento de las estructuras de las casas grandes como estrategia efectiva de conservación requerirá de un ambiente que no permita ningún deterioro, ya que dentro de las maderas prehistóricas existen hongos activos capaces de destruir. Si existe una presencia de humedad u otras condiciones favorables para la alteración, la madera se destruirá, y se perderá este importante recurso histórico.