Defibration of wood in the expedition huts of Antarctica: an unusual deterioration process occurring in the polar environment

Robert A. Blanchette and Benjamin W. Held
Department of Plant Pathology, University of Minnesota, St Paul, MN 55108-6030, USA
Roberta L. Farrell
Department of Biological Sciences, University of Waikato, Hamilton, New Zealand

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ABSTRACT. Significant deterioration to the historic expedition huts of the Ross Sea region of Antarctica has occurred during the past decades from exposure to the polar environment. One type of deterioration that has affected all of the huts is a chemical attack resulting in a defibration of wood. Wood surfaces have a rough, fuzzy appearance and consist of white to yellow-brown masses of detached fibers. The damage is commonly associated with areas where water with dissolved salts is absorbed by wood. As moisture evaporates from the wood surface, exceedingly high concentrations of salt accumulate. Chemical reactions within the wood cause a corrosive degradation on the middle lamella region of the woody cell wall (the area located between cells that cements them together) and may gradually degrade all cell-wall layers. As the deterioration progresses, cells continue to separate and the wood is converted into masses of detached and eroded wood fibers. In advanced stages of attack, the wood structure and integrity is severely compromised. This paper describes the defibration process, reports locations on Ross Island where the damage is severe, and discusses methods to control the problem. Successful preservation of these important historic structures and cultural objects depends on a more complete understanding of the unique deterioration processes underway and on implementation of effective strategies to conserve the huts.

Contents

Introduction

The Antarctic environment has protected many of the historic huts in the Ross Dependency from decay commonly encountered in temperate regions (Blanchette 2000). However, the extreme conditions of the polar environment do not completely exclude deterioration from taking place. During the past 9–10 decades, slow but significant deterioration has taken its toll on the wood of the huts. One form of deterioration that has been previously noted on various woods from Douglas Mawson's huts is a disruption of wood surfaces that leaves the wood with a furry appearance suggestive of mechanical abrasion (Hughes 2000). The damage has been referred to as defibring of wood. When the affected wood is wet, it appears as if the surface cells have been pulped. In this paper, the damage is referred to as a defibration of wood caused by a non-biological form of deterioration. This paper reports the results of analytical investigations to better understand the defibration process, assesses its occurrence and severity in the historic huts of the Ross Sea region, and discusses methods that can be used to stop the current deterioration as well as to reduce future damage.

Investigations of wood defibration occurring in temperate areas of the world

Very few studies of this phenomenon have been reported despite its general occurrence on wood in or near marine environments. This lack of information is probably due to the general belief that the damage is due to mechanical abrasion or weathering processes such as wind, freeze–thaw damage, and solar radiation. These types of natural weathering should not be confused with the unusual defibration process described in this paper. A brown, fuzzy condition of wood surfaces was reported on preservative-treated marine pilings, salt and fertilizer warehouses, and chemical plants (Johnson and others 1992; Wilcox and others 1991). It was found to occur just above the water line on preservative-treated pilings and wharves exposed to the ocean (Johnson and others 1992). The authors suggest the damage was caused by the growth of salt crystals within wood cells. It has also been observed on wood from warehouses where roadside salt is stored for de-icing roadways (Johnson and others 1992), and on the internal surfaces of boats and cooling towers (Bootle 1983). In Sydney, Australia, a study of roof damage completed along a 20-km region from the coast indicated that roofing timbers were occasionally found with surfaces having an orange-brown woolly appearance (Wilkins and Simpson 1988). No evidence of biological decay was found, and it was postulated that thermal degradation of the wood and salt accumulation was responsible for the

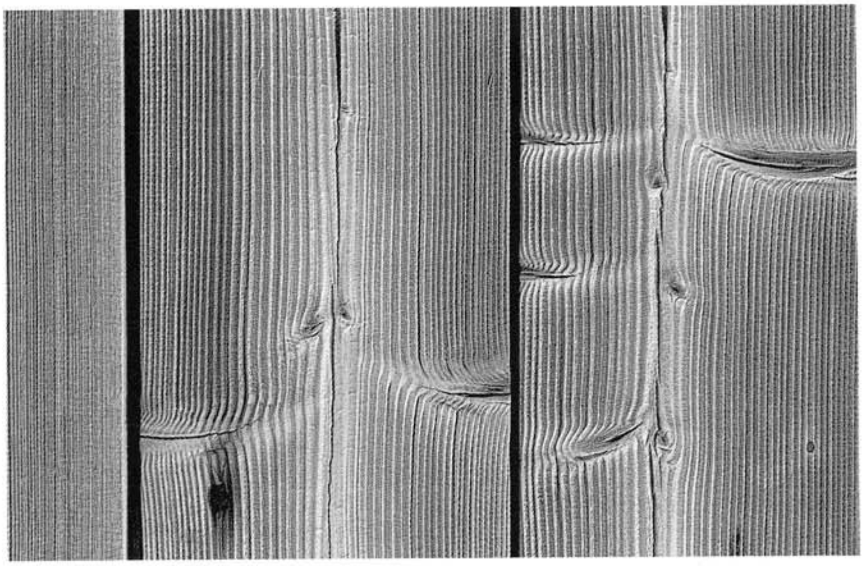


Fig. 1. Wind-eroded wood from the exterior of Shackleton's hut at Cape Royds.

damage. It was also recognized that this phenomenon deserves increased study if a cure or prevention is to be undertaken effectively. Surprisingly, very few investigations have been completed on the chemical reactions that result in this form of deterioration.

One related investigation found a similar type of attack on wood from a potash fertilizer storehouse (Parameswaran 1981). The degradation of surface cells and their separation appear to be identical to the previously reported damage. Although the source and composition of the salts were different, the resulting deterioration was the same. Parameswaran (1981) compared the corrosive action to that of cold alkali, such as potassium and sodium hydroxides, or similar to the alkali pulping process for papermaking. The wood fibers were degraded by dissolution of the middle lamella and the affected wood was morphologically similar to the delignification process documented during the chemical pulping process for paper production. One difference, however, in these processes is that the reactions in the wood from the potash storehouse took many years to cause significant damage, whereas the pulping process (using high concentrations of alkali and heat) can be accomplished in a few hours.

In all of these previous studies of defibration damage to wood, it is evident that the problem is most serious in areas sheltered from rain. It is common on boat interiors, pilings under wharves, and roof rafters that are protected from direct rain. Since accumulations of high-salt concentrations appear necessary for defibration, wood receiving sufficient rain will leach out salt before concentrations are high enough to cause significant damage.

Defibration in the historic huts of the Ross Dependency

This type of wood degradation is different from natural weathering of wood by the environment or by physical and photochemical reactions. In Antarctica, wind erosion is a significant factor that causes damage to wood (Fig. 1). Wind with ice crystals and sand particles blasts the surface of the wood and causes it gradually to erode, a process known as corrasion. The Antarctic's strong windstorms and high-velocity katabatic winds have resulted in significant damage to historic expedition huts (Harrowfield 1981, 1996). Wind-borne particles do not erode wood uniformly. Areas between the rings (earlywood cells) are eroded before the thick-walled latewood cells. This results in the formation of erosion troughs and deeply furrowed wood surfaces that are commonly found on wood of the historic huts (Figs 2a, 3a, 4a). The effects from wind are different than those observed for defibration (Fig. 2) and should not be confused in discussions of non-biological deterioration activity.

Scott's hut at Cape Evans

An extensive area of defibration damage is found on the west side of the Cape Evans hut facing the Ross Sea (Figs 2a, 2b). The surface of the exterior wallboards is bleached white and severely defibrated (Figs 2c, 2d). When dry, the wood surface is covered with a mass of detached wood fibers. These dry fibers are often removed by the wind in unprotected areas of the hut. In addition, as snow and ice melt from the roof, water cascades down the sides of the hut walls and large masses of fibers are washed off (Fig. 2d). Repeated defibration and fiber removal from wind or meltwater results in significant thinning of the boards and in gradual destruction of the historic wood. In 1991, conservators replaced some of the exterior wallboards from the west side of the hut due to severe defibration damage (Fig. 2e). The authors' observations in 1999 and 2000 indicated that the replaced boards are already exhibiting significant defibration (Fig. 2d). Most of the original boards remaining on this side of the hut are severely affected and continue to experience successive defibration (Fig. 2c).

Elemental analyses using multi-elemental inductively coupled plasma atomic emission spectroscopy (Blanchette and others 1994; Munter and Grande 1981; US Environmental Protection Agency 1979, 1983) of defibrated wood fibers, snow and ice from the roof, and meltwaters that dripped onto the exterior wall boards show exceedingly high concentrations of salts are present (Tables 1, 2). The roof of the hut at Cape Evans not only accumulates snow but high concentrations of sodium and chloride as well as potassium, magnesium, and sulfur (Tables 2, 3). Deposition of these elements is apparently from wind-blown seawater and salts that accumulate on the surface of the black volcanic sands. Mount Erebus, releasing plumes of

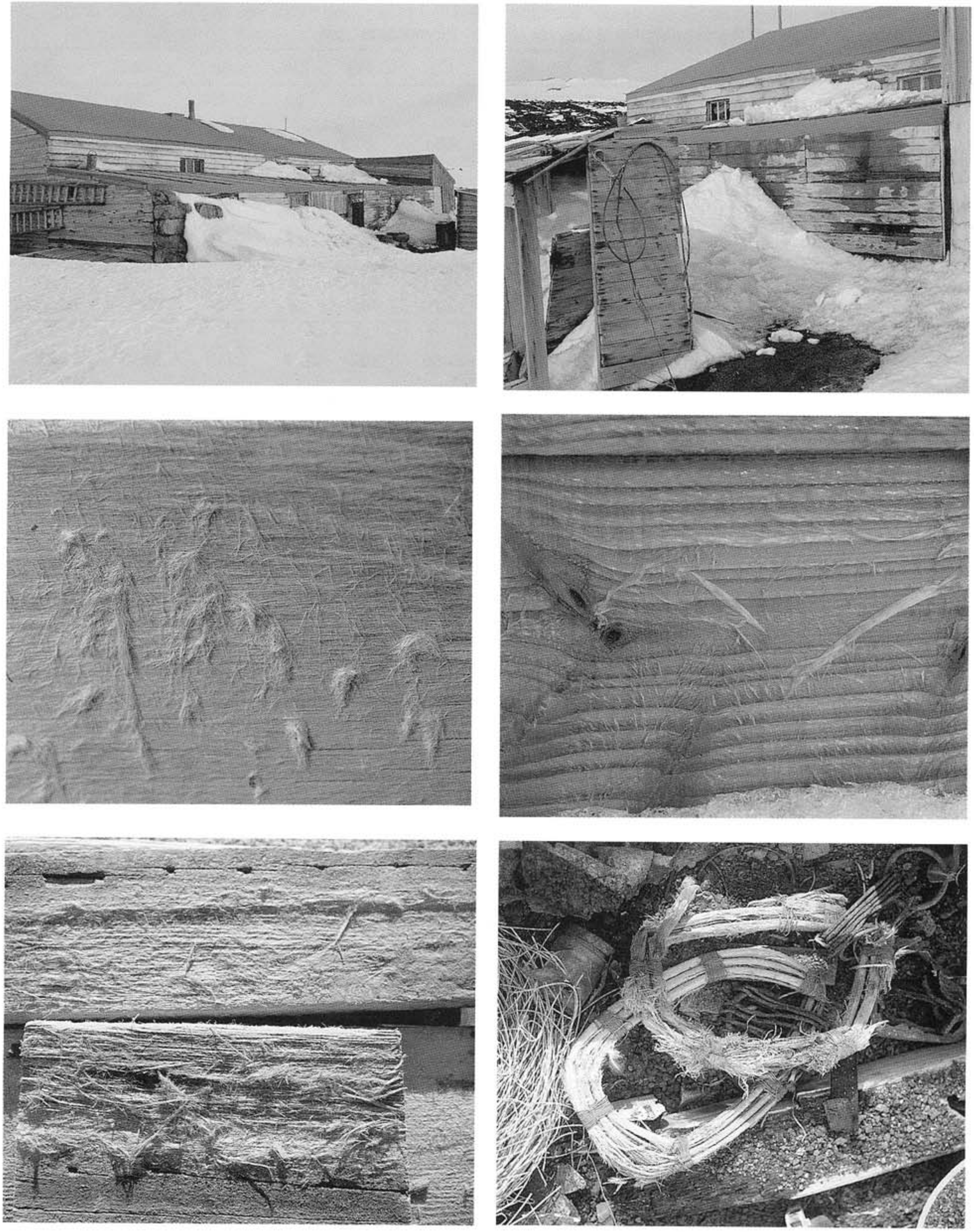


Fig. 2. Deterioration in Scott's hut at Cape Evans. 2a (top left). View of hut with snow seen on the roof and drifts of snow on the side of the hut. 2b (top right). Side of hut facing the Ross Sea. Snow melting from the roof drips down on the exterior boards and drifted snow melts onto external boards of the hut. 2c (middle left). Dry defibrated wallboard from the exterior of hut showing white masses of detached fibers. 2d (middle right). Wet defibrated wallboard from the exterior of hut. Water cascading off the roof has removed large masses of defibrated fibers from the wood surface. This board was replaced in 1991 and had already become severely damaged by December 2000. 2e (bottom left). Severely defibrated wood from the outside wall of hut, which was removed during conservation work in 1991. The affected boards were badly damaged and weakened by defibration. 2f (bottom right). Defibrated remnants of pony snowshoes made of rattan outside of hut.

Table 1. Elemental analyses of historic woods from the expedition huts of the Ross Sea region. Methods are from Blanchette and others (1994) and Munter and Grande (1981). Elements in ppm.

Location	Material	P	K	Ca	Mg	Mn	Al	Fe	Na
Cape Evans	Interior wood	7	411	859	507	60	15	58	2073
	Exterior defibrated wood fibers	279	1274	961	876	34	3339	1469	3896
	Exterior defibrated wood	132	4355	6379	8331	49	558	431	98,650
Cape Royds	Exterior defibrated wood	478	4005	5720	5092	66	5576	2356	35,870
	Porch defibrated ceiling	132	2828	7451	6091	71	647	649	52,970
	Defibrated crate	340	3523	8579	4682	52	3584	2510	28,221
Discovery hut	Defibrated exterior wood #1	1205	4495	5453	3994	127	8210	4454	147,000
	Defibrated exterior wood #2	547	7070	4250	10,728	78	3285	2602	246,321
	Defibrated veranda wood	408	3451	12,456	5601	72	4853	4129	28,902
	Sound modern wood	102	527	403	133	51	5	10	7

volcanic smoke, may also be a contributing source of sulfur and other elements found in elevated concentrations.

Samples of dry defibrated wood had sodium concentrations of 98,650 ppm in comparison to wood from the hut interior with 2073 ppm and to sound modern pine wood (from a pine grown and milled in the United States) that had 7 ppm (Table 1). Wet defibrated wood fibers had concentrations of 3896 ppm sodium, indicating that the meltwaters had apparently leached out salts. The concentrations of salts in snow sampled from the roof varied, depending on when the sample was taken. A sample of freshly fallen snow had relatively low ion concentrations of sodium, sulfur, and chloride (Tables 2, 3), whereas older snow and ice from the roof had more than 5000 ppm sodium and had elevated concentrations of chloride, potassium, magnesium, and sulfur.

The data from the snow samples collected suggest that as snow and ice slowly melt on the roof, salts from wind-blown deposits and those in the snow are dissolved in the meltwater. The water and salt solution gradually drips directly onto the exterior wallboards. The solution is gradually evaporated from the wood surface, causing the salts to precipitate and concentrations to increase. Through time, extremely high salt concentrations build up and corrosive reactions to the wood take place. Moisture appears essential for the process to occur. In 2000, an unusual amount of snow had fallen and a greater than normal amount of meltwater was observed coming off the roof in December. Moisture, with associated dissolved salts, was covering almost the entire west exterior wall of the hut (Fig. 2b).

High salt concentrations can also be seen around the lower exterior boards of the hut. Moisture and salts migrate up the wood from the ground where meltwater collects. The moisture evaporates on the wood above the ground and salts precipitate. This also affects most of the wooden artifacts that are in ground contact. Wooden crates, dog houses, and other wooden items can be found with defibration damage. All of these woods absorb moisture from the ground and accumulate salts. Wood is not the only material to suffer from the degradative actions of the salts. Rattan pony snowshoes located outside of the hut were also found severely defibrated, demonstrating that the corrosive nature of the attack is not restricted to wooden artifacts (Fig. 2f).

Shackleton's hut at Cape Royds

Some defibration is present on the exterior boards near the ground line at the hut at Cape Royds, especially on the north or stable side of the hut (Fig. 3). Wooden boxes containing stores located on the east and south sides of the hut are also affected. The birch plywood ('Venesta') boxes, selected by Shackleton to reduce the weight and size of the supply boxes during shipment, are damaged to a greater extent than other solid wood boxes. The plywood has become delaminated and surfaces are heavily defibrated (Fig. 3d). High salts and defibration are taking a heavy toll on these stores outside the hut.

An area of advanced defibration is located on the interior walls of the entry porch to the hut. The ceiling and parts of the walls have white to yellow-brown detached fibers that cover the wood surfaces (Fig. 3b). Moisture and salts are blown and trapped in the porch area, apparently functioning as planned by Shackleton to protect the living quarters from the Antarctic environment. As moisture evaporates, the salts accumulate and concentrations of salts exceeding 50,000 ppm were found in the defibrated wood (Table 1). Snow found in the hut also had high concentrations of salts, indicating that the wind-blown snow that enters carries considerable salt concentrations into the interior. Salts are also evident on wood inside the

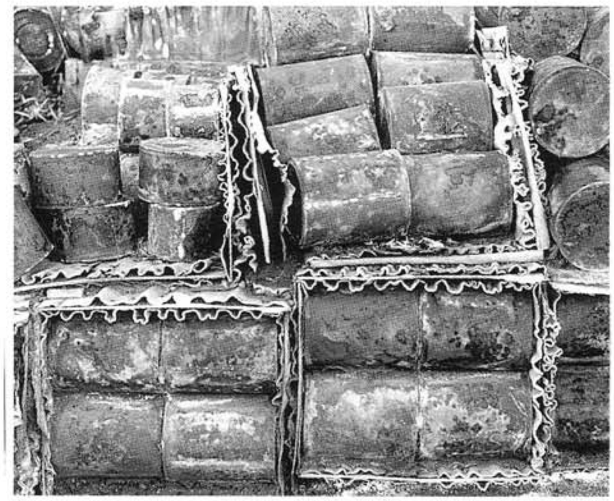


Fig. 3. Deterioration in Shackleton's hut at Cape Royds. 3a (top left). View of drifted snow covering the side of the hut. 3b (top right). Defibrated board from a wall inside the porch of the hut, showing loosened surface fibers on the wood. 3c (bottom left). Salt accumulation on exterior boards of hut near ground. 3d (bottom right). Delaminated and defibrated wood boxes outside of the hut. These plywood or 'Venesta' crates made out of birch wood have defibrated surfaces.

main room of the hut, but advanced, visible defibration has not been observed. Snow is often able to directly enter the hut through small cracks and crevices in the structure. In addition, snow, sand, and salts enter the building with visitors. A boot brush at the hut functions well to help limit the amount of snow and debris carried into the hut on boots but is only as effective as the visitors' diligence to clean their footwear. With every visiting group there is some moisture, salt, and grit added to the hut interior. Once salts are absorbed into the wood they are not readily removed.

Scott's *Discovery* hut

The greatest concentration of salts found from all hut samples was from exterior wood beneath the veranda of *Discovery* hut near the ground (Fig. 4). Two different samples analyzed contained 147,000 and 246,000 ppm of sodium (Table 1). Magnesium, potassium, aluminum, and other elements were also found in high amounts as compared to concentrations typical for sound pine wood. The architecture of *Discovery* hut allows snow and ice to accumulate next to the hut under the veranda (Fig. 4b). Moisture and salts migrate into the wood and defibration results. The detached fibers, often with dirt and precipitated salt crystals, are not as easily seen as those on the hut at Cape Evans (Fig. 4c). The lack of excessive moisture dripping directly down the walls of *Discovery* hut apparently results in little disruption of the loosened surface fibers.

Wood around the windows on the veranda roof is also affected. Heat from the sunlight passing through the windows provides a microclimate that evaporates moisture from the wood, causing salts to accumulate and defibration processes to take place. As in the other huts, defibration is most apparent in areas protected from direct winds. Erosion of wood by wind is severe on some external woods of the hut. In areas where blasting winds carry snow, grit, and ice, the weakened fibers are readily removed. Salt accumulation can be found within the hut on wall and ceiling timbers, but the authors have observed no

Table 2. Elemental analyses of snow and meltwater samples from the historic huts of the Ross Sea region. Methods used are from US Environmental Protection Agency (1983). Elements in ppm. (a) = Methods for elemental analyses on water samples allowed sulfur concentration to be obtained. Sulfur was not possible to analyze using the elemental analyses for the wood samples used in this study and is not presented in Table 1.

Location	Sample	P	K	Ca	Mg	Mn	Al	Fe	Na	S(a)
Cape Evans	Roof melt water	0.1	272	281	1064	0.1	0.4	0.2	5736	221
	Old snow from roof	2	28	25	40	0.2	0.2	0.2	395	21
	New snow from roof	0	1	1	2	0	0.2	0.2	23	4
Cape Royds	Snow inside hut	0.1	38	38	78	0.3	0.1	0.2	778	60
	Melt water on ground	22	64	35	82	0.1	0.2	0.1	579	47
Discovery hut	Snow inside hut	0.3	9	6	6	0.1	0.2	0.3	51	13

advanced defibration on these woods (Fig. 4d). Moisture from snow entering the hut during storms and on the boots of tourists appears to be a continual source of water and salts into the interior, which may not only influence future wood defibration but serves to add humidity and salts that affect metal objects and other artifacts.

Defibration processes of wood in Antarctica

The corrosive activity of salts on metal is well known but wood is often considered immune from these effects. Given sufficient time — for example, five years of exposure on some wharf pilings in the southern United States (Johnson and others 1992) — salts can severely affect the strength and physical condition of wood. These chemicals are dissolved in water and rapidly migrate into the porous structure of wood. After the wood has absorbed the solutes, evaporation carries the salts to the wood surface, where they precipitate and accumulate in high concentrations. The morphological and chemical degradation observed in the structural wood of the Antarctic huts is similar to the attack reported in the potash storehouse by Parameswaran (1981) (Fig. 5). Chemical reactions that cause defibration of wood appear to involve a sequential degradation of hemicellulose and lignin. This attack causes a separation of wood cells at the middle lamella regions (Figs 5a, 5b). The secondary wall is least affected, and the detached cells consist primarily of the thick-wall secondary layers (Figs 5c, 5d). Even these secondary wall layers may be adversely affected through long periods of time, and cells from very advanced stages of defibration are eroded and fragmented. The polar environment, although very cold, is conducive to this type of degradation. During the Antarctic summer, snow and ground-ice melt, providing moisture that dissolves salts. In the Ross Sea region, salt migration occurs in soils, and thin crusts of salts are frequently found on the soil surface (Campbell and Claridge 1987). These salts, as well as salt from the sea, are widely dispersed by wind. Salt-enriched water in contact with the wood is absorbed and evaporated when temperatures are above freezing. Salts continue to accumulate and, without rainfall, exceedingly large concentrations develop. The chlorides, nitrates, and sulfates of sodium, potassium, and magnesium are corrosive on all materials, including metal, soil minerals, and wood. The rate of metal corrosion in Antarctica has recently been shown to be exceedingly high (Otieno-Alego and others 2000). In studies of steel coupons exposed to the elements in continental Antarctica, the rate of corrosion was comparable to coastal regions of Australia and nearly three times the levels observed in the sub-Antarctic islands. This investigation also showed that chloride and sulfur levels in rust from metals at the continental Antarctic sites far exceeded those of temperate areas (Otieno-Alego and others 2000).

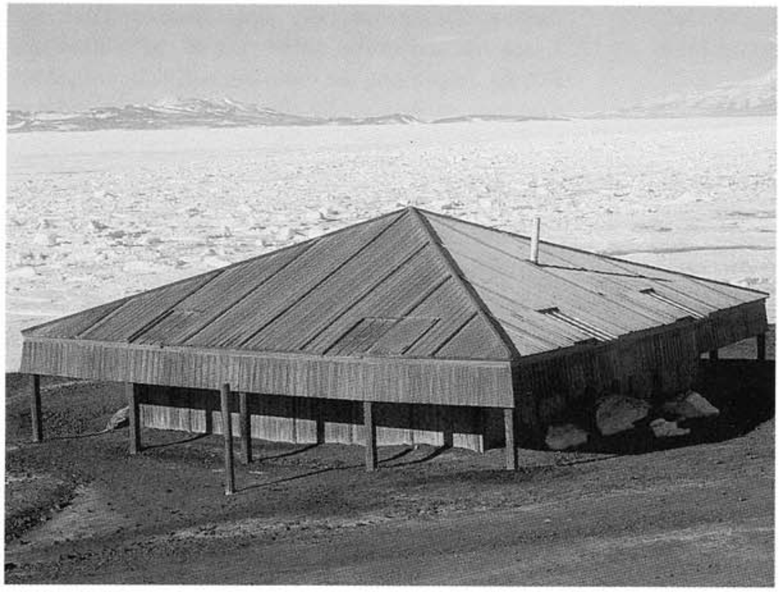
Table 3. Chloride concentrations (mg l^{-1}) in snow and meltwater samples from the historic huts of the Ross Sea region. Methods used are from US Environmental Protection Agency (1979).

Location	Sample	Choride (mg l^{-1})
Cape Evans	Roof meltwater	12,283
	Old snow from roof	626
	New snow from roof	34
Cape Royds	Snow inside hut	1298
	Meltwater on ground	1074
Discovery hut	Snow inside hut	77

Preservation of the historic huts

To prevent wood defibration in the historic huts of the Ross Sea region, it is necessary to stop moisture and salt migration into the wood. Each specific location requires individual consideration. The following list of possible actions is presented for use by conservators, architects, and scientists to consider for successful preservation of the wood.

1. Reduce snow accumulation on or near the huts. Barriers to deflect the snow from drifting onto the huts or



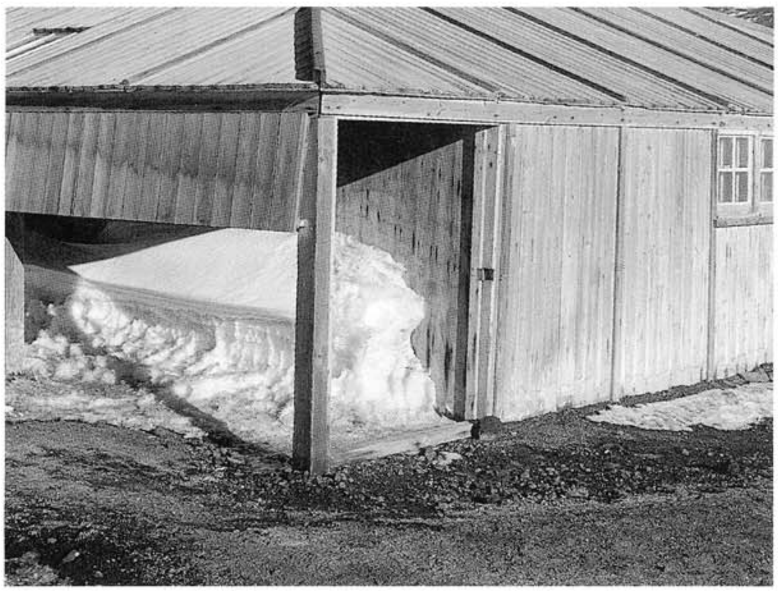


Fig. 4. Deterioration in Scott's *Discovery* hut at Hut Point. 4a (top left). View of hut and veranda. 4b (middle left). Snow accumulation under veranda and salt accumulation on lower exterior boards on side of hut without veranda facing the Ross Sea. 4c (bottom left). Salt accumulation and defibration of exterior boards near the ground on hut. 4d (top right). Salt accumulation on ceiling inside hut.

physically removing snowdrifts each spring will help reduce the amount of moisture that contacts the external hut wood.

2. Improve drainage of snow and ground-ice melt around the huts. This is especially important around the Cape Evans hut and in the stable area of the hut at Cape Royds. Improving the drainage will help reduce the moisture wicked up by the external hut wood and

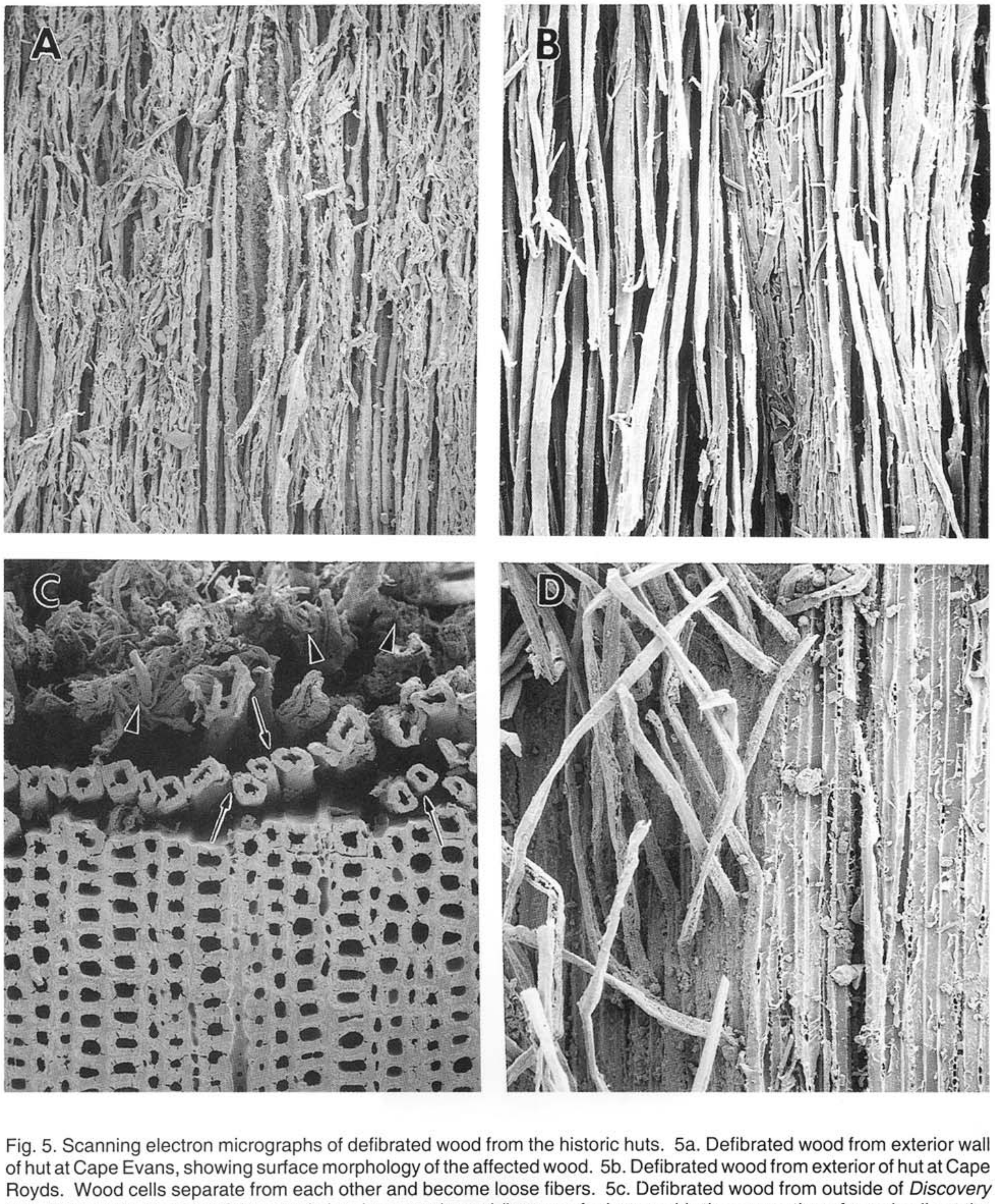


Fig. 5. Scanning electron micrographs of defibrated wood from the historic huts. 5a. Defibrated wood from exterior wall of hut at Cape Evans, showing surface morphology of the affected wood. 5b. Defibrated wood from exterior of hut at Cape Royds. Wood cells separate from each other and become loose fibers. 5c. Defibrated wood from outside of *Discovery* hut. Transverse section of the wood showing sound wood (bottom of micrograph), the separation of wood cells at the middle lamella (arrows), and continued fragmentation and erosion of the fibers on the exposed surface of the wood (arrowheads). 5d. Defibrated wood from the exterior of the Cape Evans hut. Water and wind erosion has removed some of the older defibrated cells from the surface of the wood, leaving only a few detached cells. As the defibration process continues, other wood cells below the detached fibers will be degraded.

wooden artifacts.

3. Improve drainage of snowmelt from hut roofs. Of special concern is the melting of snow at the hut at Cape Evans, where water drips directly on the west exterior wallboards. An extension of the roof or other method to divert water from directly falling on the sides of the building is needed.
4. Reduce moisture from entering the interior of the huts. None of the historic huts are airtight, and some snow does enter during severe storms. The amount of snow can often be significant and should be removed in early spring before melting occurs. Tourists also should be made aware that moisture should be excluded from the hut and boots must be clean before entering. The current use of boot brushes outside the huts appears to be successful in removing rocks, dirt, and excessive moisture. It would be more effective, however, to have tourists, scientists, or any visitors leave boots outside and adopt a system of putting on clean slippers or protective overshoes when entering the huts.
5. Environmental monitoring of the huts. It is not known precisely to what degree visitors and tourist groups entering the huts change the relative humidity, and detailed environmental monitoring of all three huts is currently underway. Conclusive findings of humidity changes inside the huts can only be made after a prolonged monitoring period.
6. Remove accumulated salts from exterior and interior woods in a non-abrasive manner. In some cases, this may be warranted inside the huts to reduce the amount of salts that may be dispersed and available to affect other artifacts (metals, textiles, etc). Physically removing the salts from the wood surfaces, however, does not remove salt concentrations within the wood, and degradative actions can continue if moisture is present. Areas with visible salts should be regarded as potential sites for defibration to occur in the future.
7. Additional research to better understand the defibration process. If more basic information were known about the chemical reactions involved with the defibration process of wood, better methods of control could be developed. Although the process appears somewhat similar to the defibration process in temperate areas, unique conditions found in the Ross Sea region (high UV light intensity, high amounts of sulfur, freeze–thawing of wood, or other factors) could have a synergistic effect on defibration reaction rates.

Conclusions

Defibration processes of wood cause significant damage in the historic expedition huts of Antarctica. In the past, this type of degradation has been viewed more as a curiosity than as the important problem it actually is. The exact reactions involved in this unusual form of chemical damage to wood are not known, but moisture-carrying salts are always associated with the damage. Many types of salts, not just sodium chloride, cause wood defibration. Affected wood from the historic huts has a white to brown fuzzy appearance. The degradation affects the middle lamella region of the cell walls, and once this cementing material between cells is altered, the wood fibers separate. Defibration is a progressive form of deterioration. The attack starts on wood surfaces and will progressively degrade all of the wood if the conditions are favorable for a sufficiently long time. In Antarctica, the defibration process is relatively slow, but, over many years, very severe damage can occur (Figs 2c–2f).

Chemical deterioration causing defibration of wood is only one of many different types of degradation occurring in the historic expedition huts of Antarctica. Investigations by the authors are continuing to elucidate other types of non-biological and biological forms of deterioration so that a more comprehensive understanding of these processes can be obtained. Results from these studies provide needed information for conservators to plan effective long-term conservation strategies to preserve these extraordinary historic sites for the future.

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