DETERIORATION PROCESSES AFFECTING HISTORIC SITES IN ANTARCTICA AND THE CONSERVATION IMPLICATIONS.

by

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ABSTRACT

Despite the widespread belief that deterioration is minimal or absent in Antarctica because of the 'dry cold', field research undertaken for this thesis at twelve Antarctic sites identified diverse deterioration problems, often related to moisture and salts. Accurate diagnosis of causes of deterioration is essential to ensure appropriate conservation treatments and rate measurements can help determine treatment priorities.

The **main methods used in the research** were field observations at 12 locations, various analyses of samples of materials and studies of temperature and relative humidity measurements and wind and other observational data from diverse sources. Temperature and humidity data measured by dataloggers inside of the AAE main hut at Cape Denison were used to assess potential changes in interior conditions following ice removal. Since exposure of sample materials to measure rates of deterioration by light and wind proved problematic, new methods based on repeated *in situ* observations of historic materials were developed, particularly to assess the damage to wood caused by wind. Modified ISO standard methods were used to measure salt deposition and corrosion rates and Raman microscopy and XRD were used to analyse salts. Visitor questionnaires and observations were employed to examine attitudes and awareness of conservation requirements relevant to site management. The outcomes of conservation treatments were assessed by field observations and reviews of site reports.

The **main conclusions of the research** were that diagnosis of some conservation problems has mis-attributed or over-stated the seriousness of some problems and under-estimated others.

Meltwater was found to be a greater risk than ice accumulation, except where the weight of ice is unsupported. Analysis of temperature and RH data at Cape Denison found hoarfrost formation on sensors indicate conditions are colder than in reality.

Removal of ice, a key conservation strategy at most huts, has not reduced high humidity as intended and treatments aimed at removing and continued exclusion of ice may not succeed unless mass transfer changes occurring in buildings are considered. These should determine whether internal cycles involving phase change (formation of hoarfrost and melting of ice from condensation occurring inside walls and ceilings) could continue to cause cyclic melting and re-freezing on structures and artefacts inside the building even if ice ingress is excluded. Melting of ice was often associated with
corrosion and biodeterioration.

Corrosion rates at inland locations were the lowest measured on earth, but coastal corrosion rates exceeded predictions from ISO standard 9223 and were comparable to temperate rural Australia. Measurements found conditions for corrosion occurred above -10°C when RH exceeded 50%. Thus the ISO standard, widely used to estimate corrosion risks, underestimates these risks.
Inside Ross Island huts, analyses found sulphates were more prevalent than chlorides, despite proximity to the sea. The author identified defibring at some locations at Cape Denison and more extensively at Ross Island and Cape Adare and linked this to salts rather than 'freeze-thaw' cycles. Referring to more detailed subsequent research by others at Ross Island, the difficulties in diagnosing salt risks were identified since winds remove damaged fibres which may synergise surface loss.

Observations and measurements and surface damage to timber at Cape Denison showed location of damage is consistent with the boundary layer formed by katabatic winds, thus losses at edges and corners of buildings are high, but were overstated elsewhere. Plucking of wood fibres in the lee of the wind may be as damaging as particle impacts. Photodeterioration observations showed damage events occur relatively rarely over much of the building surfaces.

Observations at historic sites found significant variability in visitor impacts. Visitors' attitudes generally supported retention of older buildings but were generally less supportive of retaining outdoor artefacts implying a need to improve interpretation. Analysis of selected site management plans identified information gaps in diagnosing deterioration and in evaluating treatments. Scientific resources of historic sites have been frequently overlooked and removal of dateable bio-artefacts and datum points in environmental clean ups could threaten opportunities to derive further historical and environmental information. The thesis proposes a framework for identifying and conserving these resources.

Significance of the findings

The research helps to provide a more holistic approach to understanding deterioration of Antarctic historic sites and provides a framework for assessing conservation strategies that could be applied in other locations with severe climates.

FORM B
CERTIFICATE OF AUTHORSHIP OF THESIS

Except where clearly acknowledged in footnotes, quotations and the bibliography, I certify that I am the sole author of the thesis submitted today entitled –

DETERIORATION PROCESSES AFFECTING HISTORIC SITES IN ANTARCTICA AND THE IMPLICATIONS FOR CONSERVATION.

I further certify that to the best of my knowledge the thesis contains no material previously published or written by another person except where due reference is made in the text of the thesis.

The material in the thesis has not been the basis of an award of any other degree or diploma except where due reference is made in the text of the thesis.

The thesis complies with University requirements for a thesis as set out in *Gold Book Part 7: Examination of Higher Degree by Research Theses Policy, Schedule Two (S2).* Refer to http://www.canberra.edu.au/research-students/goldbook

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GLOSSARY[1]

AAE	Australasian Antarctic Expedition, led by Douglas Mawson, 1911-14
ablation (of ice)	"Combined processes (such as sublimation, fusion or melting, evaporation) which remove snow or ice from … a snow-field". (US National Snow and Ice Data Center, NSIDC).
accumulation zone	An area in which the amount of snow and ice that is deposited exceeds that lost by deflation, evaporation , melting, or other means.
ANARE	Australian National Antarctic Research Expeditions
ANAN	Antarctic Non-Government Activity News, an Australian Antarctic Division publication
ASHRAE	American Society of Heating, Refrigeration and Airconditioning Engineers
AS/NZS	Australian and New Zealand Standard
ASOC	Antarctic and Southern Ocean Coalition
ATCM	Antarctic Treaty Consultative Meeting
ATS	Antarctic Treaty Secretariat
AWS	Automatic Weather Station
BANZARE	British Australian and New Zealand Research Expedition, 1927-30
BOM	[Australian] Bureau of Meteorology
Butynol, Butylclad	Trade names of butyl rubber sheeting roof membranes used at Ross Dependency huts.
CEP	Committee for Environmental Protection (of Antarctica), an Antarctic Treaty committee.
CFD	Computational Fluid Dynamics
CMP	Conservation Management Plan
corrasion (fig 7.1)	The US Navy Hydrographic Office publication No 609, 1952) definition: "wearing away of the surface of ice or other material through the friction of solid material transported by water or air". Discussed in Chapter 7.
conservation	"all the processes of looking after a place so as to retain its cultural significance" (Burra Charter of Australia ICOMOS), thus inclusive of preservation, restoration, etc.
CSIRO	Commonwealth Scientific and Industrial Research Organisation, the Australian Government's main research agency
defibring (fig 2.2)	Effect on the surface of wood of chemical action by salts, not 'freeze-thaw' processes. The same process is called 'defibration' by Blanchette et al (2002), see references. Discussed in section 2.5.3 and differentiated from 'defibring' used by Kaila (1988).
DEW Line	'Distant Early Warning' Line, a system of military bases in the Arctic during the Cold War of 1947-1991
DEWHA	[Australian Government] Department of Environment, Water, Heritage and the Arts
EMC	Equilibrium Moisture content. See also MC. Moisture is released from the cell walls until it stabilises at an equilibrium moisture content (EMC) dependent on RH and ambient temperature. Thus EMC is the point at which wood is stable and in equilibrium with the humidity of its surroundings and is no longer gaining nor losing moisture.
EPF	Expeditions Polaires Francaises
EW	Early wood
fabric	"All the physical material of the place including components, fixtures, contents, and objects". (Burra Charter of Australia ICOMOS)
firn	Rounded, well-bonded snow that is older than one year; firn has a density greater than 550 kilograms per cubic-meter (35 pounds per cubic-foot); called névé during the first year.
föhn	Wind warmed and dried by descent, in general on the lee side of a mountain.
freeze-thaw	This term was used by various authors to define a range of effects, discussed in Chapter 4,

[1] Detailed references to both scientific and vernacular Antarctic terminology are available in 'The Antarctic Dictionary- a complete guide to Antarctic English', by Bernadette Hince, CSIRO Publishing, Collingwood, Victoria Australia 2000 and the National Snow and Ice Data Center (US) website at http://nsidc.org/arcticmet/glossary/permafrost.html

damage	but which are inconsistent or in some cases inaccurate (for example, defibring has often been mis-attributed to freeze-thaw damage). Freezing and thawing processes can both cause damage, but for different reasons. Freezing damage affecting rocks is caused by physical processes at the freezing front, whereas thawing damage is essentially water damage.
GOSEAC	Group of Specialists on Environmental Affairs and Conservation, a group within the Scientific Committee on Antarctic Research
HERCON criteria	Heritage Conservation criteria adopted by the [Australian] National Environment Protection and Heritage Council (EPHC) in 2008 to provide a consistent set of national criteria to identify and manage heritage across Australia.
hoarfrost (fig 4.14)	A deposit of interlocking ice crystals (hoar crystals) formed by direct sublimation on objects, usually those of small diameter freely exposed to the air, which surface is sufficiently cooled, mostly by nocturnal radiation, to cause the direct sublimation of the water vapor contained in the ambient air (NSIDC).
IAATO	International Association of Antarctic Tour Operators, a NGO.
ICOMOS	International Council on Monuments and Sites, a non-government body linked to UNESCO.
IGY	International Geophysical Year -an international program of scientific research conducted during 1956-57.
IPHC	International Polar Heritage Committee, a committee of ICOMOS
ISO	International Standards Organisation
katabatic	"Any wind blowing down an incline; the opposite to anabatic wind. If the wind is warm, it is called a foehn; if cold, it may be a fall wind (bora), or a gravity wind (mountain wind)". (NSIDC). In Antarctica these are high velocity winds flowing from the polar plateau.
LW	Late wood
Madrid Protocol	The Protocol on Environmental Protection to the Antarctic Treaty, agreed at Madrid on 4 October 1991.
maintenance	The "continuous protective care of the fabric and setting of a place, …. distinguished from repair. Repair involves restoration or reconstruction". (Burra Charter of Australia ICOMOS)
MC	Moisture content is the weight of water contained in a piece of timber, as a percentage of the weight of oven-dry wood. Newly cut wood has a high MC.
MHF	Mawson's Huts Foundation, a non-government organisation undertaking conservation at the AAE site at Cape Denison.
nd	No date
NEPA	[US] National Environmental Protection Act
névé	One year old snow which is in the process of bonding together and compacting. It has a density greater than 550 kilograms per cubic-meter; see also 'firn'.
NGO	Non Governmental Organisation
NSS	Non-sea salt, see Chapter 5
NZAHT	New Zealand Antarctic Heritage Trust, a non-government organisation undertaking conservation at historic sites in the Ross Dependency.
permafrost	"Layer of soil or rock, at some depth beneath the surface, in which the temperature has been continuously below 0 °C for at least some years. It exists where summer heating fails to reach the base of the layer of frozen ground". (US National Snow and Ice Data Center, NSIDC)
ppb, ppm	Parts per million, parts per billion
preservation[2]	"Maintaining the fabric of a place in its existing state and retarding deterioration". (Burra Charter of Australia ICOMOS)
PVD	Peak-valley distance, the height difference between latewood and earlywood affected by corrasion
reconstruction	"Returning a place to a known earlier state and is distinguished from restoration by the introduction of new material into the fabric". (Burra Charter of Australia ICOMOS)
restoration	"Returning the existing fabric of a place to a known earlier state by removing accretions or by reassembling existing components without the introduction of new material". (Burra Charter of Australia ICOMOS)

[2] The precise definitions in the Burra Charter are used interchangeably by many people in common usage.

RH	Relative humidity, the percentage of water in the air compared to that at saturation
SCAR	Scientific Council on Antarctic Research
SEM	Scanning Electron Microscopy
SMA	Specially Managed Area, also called ASMA (Antarctic SMA)
SPA	Specially Protected Area, also called ASPA (Antarctic SPA)
Sp, spp	Sp= species (singular); spp= species (plural)
SPRI	Scott Polar Research Institute, University of Cambridge
SS	Sea salt (as discussed in Chapter 5), distinct from non sea salt (NSS)
SSSI	Site of Special Scientific Interest. This designation was replaced by ASPA and ASMA.
sublimation	Phase change directly from the solid to the gaseous state without becoming liquid.
TAAF	Territoires Australes et Antarctiques Francaises
tin pest	Deterioration of tin caused by allotropic change, see Chapter 6.
Time of Wetness, TOW	The period (usually in hours per year) during which a metallic surface is covered by adsorptive and/or liquid films of electrolyte that are capable of causing atmospheric corrosion. (ISO 9223: 3.2)
TNB	Terra Nova Bay, Italian station in the Ross Sea area.
UKAHT	United Kingdom Antarctic Heritage Trust, non-government organisation undertaking conservation at UK Antarctic sites.

PREFACE

The author first travelled to Antarctica in 1985 to record the condition of artefacts and contribute to a conservation management plan for 'Mawson's Huts', the abandoned base of the Australasian Antarctic Expedition (1911-14) at Cape Denison.

This initial visit revealed many conservation problems, such as unexpectedly extensive corrosion, although other problems, such as 'timbers worn paper-thin', appeared overstated. The favoured treatment strategy for the building was to remove the 'damaging' ice accumulation inside it and install vapour barriers to prevent further ingress and lower RH. Subsequent visits to other Antarctic historic sites revealed similar strategies had not lowered high RH, and additional problems had occurred.

Reasons for choosing this topic

These observations suggested that further materials conservation research was required to clarify causes and rates of deterioration to develop more effective conservation strategies.

Field observations prompted questioning of widespread assumptions, including:

- whether removing ice could reduce high RH;
- whether improved strategies to control temperature are needed to reduce meltwater-related problems; and
- whether corrosion can occur in below freezing and at RH below 80%.

Given the severe and unfamiliar conditions in Antarctica and the high costs of logistics, it was considered important to make best use scientific information already available in the literature and to use standardised methods to measure rates of deterioration. This enables comparison with data from other comparable locations (especially the Arctic) and facilitates evaluation of the efficacy of conservation treatments. Understanding the interaction of deterioration processes was also considered important.

The conservation of historic buildings requires a multidisciplinary approach involving consideration of historical significance, materials science, engineering, architecture and environmental management. This thesis therefore attempts to communicate the importance of integrating all these perspectives to improve management of Antarctic historic sites.

Limits of the scope of the thesis

Geographic and logistics constraints

The difficulty of obtaining travel and logistics support severely limited opportunities to examine Antarctic sites. There was also little funding to conduct analysis of materials or to obtain appropriate equipment. Travel costs to Antarctica are particularly high, and in the case of sea voyages, requires many weeks of travel for a few days ashore. Nevertheless the author visited 12 Antarctic historic sites dating from 1895 to 1961, including five of the six most significant 'Heroic Age' sites. This is unusual since few conservators have the opportunity to visit more than one or two locations in such a remote continent. Four voyages were undertaken over a 12 year period, but it was not possible to visit Antarctic Peninsula sites, which have a warmer climate and more visitors, although information about these sites was included where possible.

Coverage of historical significance of sites
Space limitations precluded detailed discussion of the significance of the sites and artefacts, except when directly relevant to the understanding of deterioration processes or the development of treatment methods.

Limited consideration of structural issues
Structural problems of Antarctic historic buildings require professional assessment by an engineer, which is beyond the author’s skills as a materials conservator. However, where materials deterioration has structural implications these are discussed without detailed engineering calculations.

Limitations on treatment of sites and artefacts
The thesis focusses on causes and rates of deterioration and the implications for treatments, but treatments could not be carried out due to the scale of work and authorisation requirements.

Structure of the thesis

This thesis used the standard scientific approach (theory, hypothesis, methodology, results, statistical analysis, discussion and conclusions) to study the key deterioration processes affecting the Antarctic historic sites.

Chapter 1 analyses historical significance criteria for the sites and their climatic and political context.
Chapter 2 examines the scientific and heritage literature, and identifies overall gaps in knowledge.
Chapter 3 identifies an overall methodological approach for the thesis and provides the observations template used at each site and the risk assessment tool.
Chapters 4 to 9 each study a particular deterioration issue (temperature, humidity and ice; salts; corrosion; wind damage; photodeterioration and biodeterioration) using scientific methodologies to identify the deterioration process, measure deterioration rates and to consider treatment implications.
Chapter 10 uses a questionnaire to survey visitors about their visit and their views on preservation of the historic sites. Field observations were used to assess physical impacts of visitation and consider management requirements.
Chapter 11 examines the interactions of deterioration processes to and considers the implications for the effectiveness of conservation management plans.

Benefits of the research

The research provides new and more ‘holistic’ information on the deterioration of materials and buildings in extreme climates. By improving diagnosis of the cause of deterioration, rather than treating symptoms, treatments can be more effective. Improved quantification of affecting deterioration processes (eg minimum conditions for deterioration to occur) can have wider benefits applicable to managing environmental risks from deterioration of buildings and artefacts and in designing new infrastructure in Antarctica.